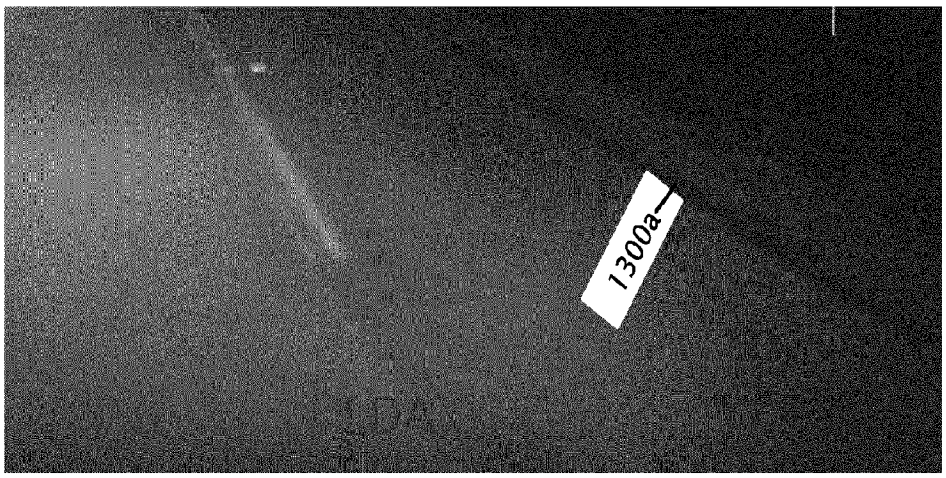


Fig. 13a

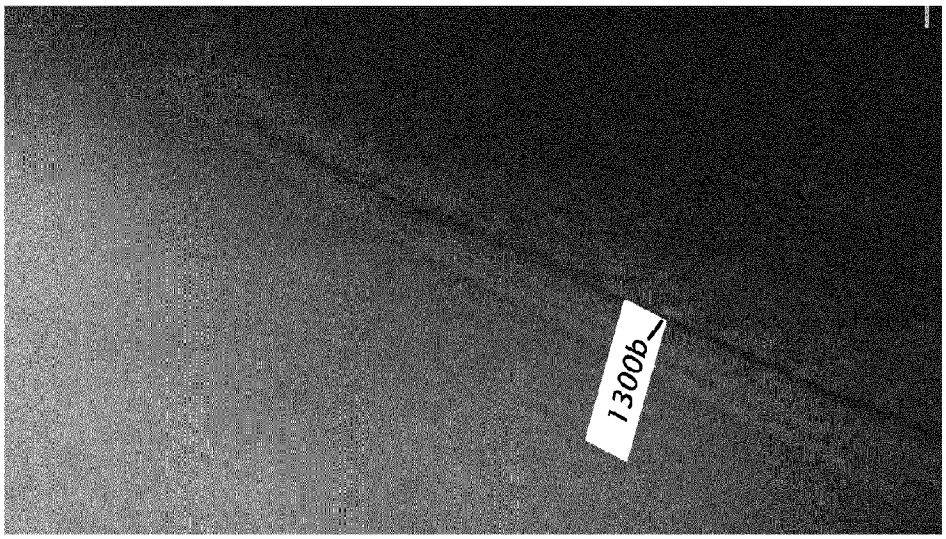


Fig. 13b

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European Patent Office
Office européen des brevets

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(12) EUROPEAN PATENT APPLICATION

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(30) Priority: **12.12.2011 US 201161569306 P**
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(74) Representative: **Jehan, Robert**
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London, WC1V 7QH (GB)

(54) Detection of obstacles at night by analysis of shadows

(57) A driver assistance systems mountable in a host vehicle while the host vehicle is moving forward with headlights on for detection of obstacles based on shadows. The driver assistance system includes a camera (12) operatively connectible to a processor (30). A first image frame and a second image frame are captured of a road. A first dark image patch and a second dark image patch include intensity values less than a threshold value. The first and the second dark image patches are tracked from the first image frame to the second image frame as corresponding images of the same portion of the road. Respective thicknesses in vertical image coordinates are measured of the first and second dark image patches responsive to the tracking.

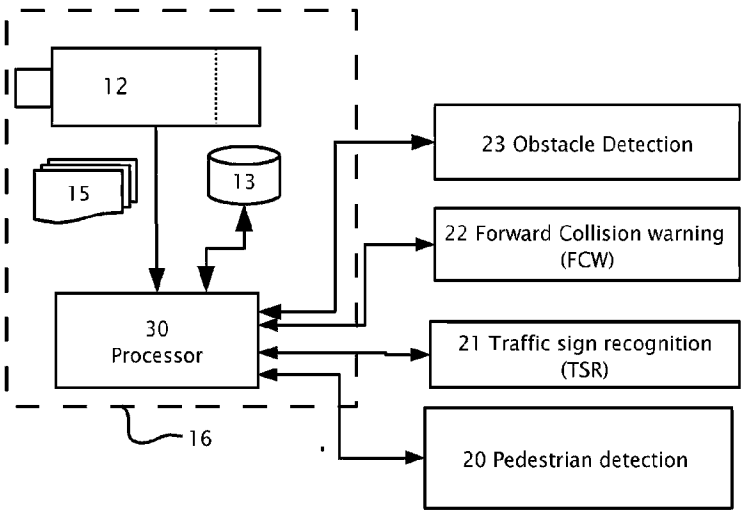


Fig. 2

EP 2 605 185 A3

Europäisches Patentamt
European Patent Office
Office européen des brevets

EUROPEAN SEARCH REPORT

Application Number
EP 12 27 5201

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G06K

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
The Hague	30 May 2014	Kollreider, Klaus

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X : particularly relevant if taken alone
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EPO FORM 1503 03.82 (P04C01)

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For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

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EFS ID:	48308116
Application Number:	18222774
International Application Number:	
Confirmation Number:	9586
Title of Invention:	CONTROLLING DRIVING MODES OF SELF-DRIVING VEHICLES
First Named Inventor/Applicant Name:	Michael S. Gordon
Customer Number:	164
Filer:	Ian David MacKinnon
Filer Authorized By:	
Attorney Docket Number:	S0974-P08818US08
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Filing Date:	
Time Stamp:	17:10:17
Application Type:	Utility under 35 USC 111(a)

Payment information:

Submitted with Payment	no

File Listing:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
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PTO/SB/08a (02-18)
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INFORMATION DISCLOSURE STATEMENT BY APPLICANT

(Not for submission under 37 CFR 1.99)

Application Number	
Filing Date	
First Named Inventor	Michael S. Gordon
Art Unit	
Examiner Name	
Attorney Docket Number	S0974-P08818US08

U.S.PATENTS Remove

Examiner Initial*	Cite No	Patent Number	Kind Code[1]	Issue Date	Name of Patentee or Applicant of cited Document	Pages,Columns,Lines where Relevant Passages or Relevant Figures Appear
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	Application Number	
	Filing Date	
	First Named Inventor	Michael S. Gordon
	Art Unit	
	Examiner Name	
	Attorney Docket Number	S0974-P08818US08

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	Application Number	
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	First Named Inventor	Michael S. Gordon
	Art Unit	
	Examiner Name	
	Attorney Docket Number	S0974-P08818US08

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	First Named Inventor	Michael S. Gordon
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	Examiner Name	
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	Art Unit	
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	Attorney Docket Number	S0974-P08818US08

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Examiner Initials*	Cite No	Include name of the author (in CAPITAL LETTERS), title of the article (when appropriate), title of the item (book, magazine, journal, serial, symposium, catalog, etc), date, pages(s), volume-issue number(s), publisher, city and/or country where published.	T[5]
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CERTIFICATION STATEMENT

Please see 37 CFR 1.97 and 1.98 to make the appropriate selection(s):

That each item of information contained in the information disclosure statement was first cited in any communication from a foreign patent office in a counterpart foreign application not more than three months prior to the filing of the information disclosure statement. See 37 CFR 1.97(e)(1).

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☐ That no item of information contained in the information disclosure statement was cited in a communication from a foreign patent office in a counterpart foreign application, and, to the knowledge of the person signing the certification after making reasonable inquiry, no item of information contained in the information disclosure statement was known to any individual designated in 37 CFR 1.56(c) more than three months prior to the filing of the information disclosure statement. See 37 CFR 1.97(e)(2).

See attached certification statement.

The fee set forth in 37 CFR 1.17 (p) has been submitted herewith.

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SIGNATURE

A signature of the applicant or representative is required in accordance with CFR 1.33, 10.18. Please see CFR 1.4(d) for the form of the signature.

Signature	/Ian D. MacKinnon/	Date (YYYY-MM-DD)	2023-07-17
Name/Print	Ian D. MacKinnon	Registration Number	34,660

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Application Number	
Filing Date	July 17, 2023
First Named Inventor	Michael S. Gordon
Title	CONTROLLING DRIVING MODES OF SELF-DRIVING VEHICLES
Art Unit	
Examiner Name	
Attorney Docket Number	S0974-P08825US04

SIGNATURE of Applicant or Patent Practitioner

Signature	/Ian D. MacKinnon/	Date (Optional)	July 17, 2023
Name	Ian D. MacKinnon	Registration Number	34,660
Title (if Applicant is a juristic entity)			
Applicant Name (if Applicant is a juristic entity)			

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The undersigned (whose title is supplied below) is authorized to act on behalf of the applicant (e.g., where the applicant is a juristic entity).

Signature	York Eggleston IV	Date (Optional)	2/28/2020
Name	York Eggleston IV		
Title	Managing Principal		

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CONTROLLING DRIVING MODES OF SELF-DRIVING VEHICLES

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application is a continuation of U.S. Application No. 17/374,656 filed July 13, 2021, which in turn claims the benefit of continuation of U.S. Application No. 16/997,202, filed August 19, 2020, Patent No. 11,091,171 on August 17, 2021, which is a continuation of 16/899,407 filed June 11, 2020, which is a continuation of U.S. Application No. 15/955,874, Filed April 18, 2018, Patent No. 10,717,446, on July 21, 2020, which is a continuation of U.S. Application No. 15/341,225 filed November 2, 2016, Patent No. 10,029,701 on July 24, 2018, which is a continuation of U.S. Application No. 14/865,393 filed on September 25, 2015 Patent No. 9,566,986 on February 14, 2017, are hereby incorporated by reference in their entirety.

BACKGROUND

[0002] The present disclosure relates to the field of vehicles, and specifically to the field of self-driving vehicles. Still more specifically, the present disclosure relates to the field of controlling whether self-driving vehicles operate in autonomous mode or manual mode.

[0003] Self-driving vehicles (SDVs) are vehicles that are able to autonomously drive themselves through private and/or public spaces. Using a system of sensors that detect the location and/or surroundings of the SDV, logic within or associated with the SDV controls the speed, propulsion, braking, and steering of the SDV based on the sensor-detected location and surroundings of the SDV.

SUMMARY

[0004] A computer-implemented method, system, and/or computer program product controls a driving mode of a self-driving vehicle (SDV). One or more processors determine a control processor competence level of a self-driving vehicle (SDV) control processor. The control processor competence level describes a competence level of the SDV control processor in controlling the SDV while the SDV experiences the current operational anomaly. One or more processors receive a driver profile of the human driver of the SDV. The driver profile describes a

human driver competence level of the human driver in controlling the SDV while the SDV experiences the current operational anomaly. One or more processors compare the control processor competence level to the human driver competence level. One or more processors then selectively assign control of the SDV to the SDV control processor or to the human driver while the SDV experiences the current operational anomaly based on which of the control processor competence level and the human driver competence level is relatively higher to one another.

BRIEF DESCRIPTION OF THE DRAWINGS

[0005] FIG. 1 depicts an exemplary system and network in which the present disclosure may be implemented;

[0006] FIG. 2 illustrates an exemplary self-driving vehicle (SDV) traveling on a roadway in accordance with one or more embodiments of the present invention;

[0007] FIG. 3 depicts additional detail of control hardware within an SDV;

[0008] FIG. 4 depicts communication linkages among SDVs, roadway sensor(s), a roadway monitoring system, and/or a coordinating server;

[0009] FIG. 5 is a high-level flow chart of one or more steps performed by one or more processors to control a driving mode of an SDV in accordance with one or more embodiments of the present invention;

[0010] FIG. 6 depicts a cloud computing node according to an embodiment of the present disclosure;

[0011] FIG. 7 depicts a cloud computing environment according to an embodiment of the present disclosure; and

[0012] FIG. 8 depicts abstraction model layers according to an embodiment of the present disclosure.

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DETAILED DESCRIPTION

[0013] The present invention may be a system, a method, and/or a computer program product. The computer program product may include a computer readable storage medium (or media) having computer readable program instructions thereon for causing a processor to carry out aspects of the present invention.

[0014] The computer readable storage medium can be a tangible device that can retain and store instructions for use by an instruction execution device. The computer readable storage medium may be, for example, but is not limited to, an electronic storage device, a magnetic storage device, an optical storage device, an electromagnetic storage device, a semiconductor storage device, or any suitable combination of the foregoing. A non-exhaustive list of more specific examples of the computer readable storage medium includes the following: a portable computer diskette, a hard disk, a random access memory (RAM), a read-only memory (ROM), an erasable programmable read-only memory (EPROM or Flash memory), a static random access memory (SRAM), a portable compact disc read-only memory (CD-ROM), a digital versatile disk (DVD), a memory stick, a floppy disk, a mechanically encoded device such as punch-cards or raised structures in a groove having instructions recorded thereon, and any suitable combination of the foregoing. A computer readable storage medium, as used herein, is not to be construed as being transitory signals per se, such as radio waves or other freely propagating electromagnetic waves, electromagnetic waves propagating through a waveguide or other transmission media (e.g., light pulses passing through a fiber-optic cable), or electrical signals transmitted through a wire.

[0015] Computer readable program instructions described herein can be downloaded to respective computing/processing devices from a computer readable storage medium or to an external computer or external storage device via a network, for example, the Internet, a local area network, a wide area network and/or a wireless network. The network may comprise copper transmission cables, optical transmission fibers, wireless transmission, routers, firewalls, switches, gateway computers and/or edge servers. A network adapter card or network interface in each computing/processing device receives computer readable program instructions from the network and forwards the computer readable program instructions for storage in a computer readable storage medium within the respective computing/processing device.

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[0016] Computer readable program instructions for carrying out operations of the present invention may be assembler instructions, instruction-set-architecture (ISA) instructions, machine instructions, machine dependent instructions, microcode, firmware instructions, state-setting data, or either source code or object code written in any combination of one or more programming languages, including an object oriented programming language such as Java, Smalltalk, C++ or the like, and conventional procedural programming languages, such as the "C" programming language or similar programming languages. The computer readable program instructions may execute entirely on the user's computer, partly on the user's computer, as a stand-alone software package, partly on the user's computer and partly on a remote computer or entirely on the remote computer or server. In the latter scenario, the remote computer may be connected to the user's computer through any type of network, including a local area network (LAN) or a wide area network (WAN), or the connection may be made to an external computer (for example, through the Internet using an Internet Service Provider). In some embodiments, electronic circuitry including, for example, programmable logic circuitry, field-programmable gate arrays (FPGA), or programmable logic arrays (PLA) may execute the computer readable program instructions by utilizing state information of the computer readable program instructions to personalize the electronic circuitry, in order to perform aspects of the present invention.

[0017] Aspects of the present invention are described herein with reference to flowchart illustrations and/or block diagrams of methods, apparatus (systems), and computer program products according to embodiments of the invention. It will be understood that each block of the flowchart illustrations and/or block diagrams, and combinations of blocks in the flowchart illustrations and/or block diagrams, can be implemented by computer readable program instructions.

[0018] These computer readable program instructions may be provided to a processor of a general purpose computer, special purpose computer, or other programmable data processing apparatus to produce a machine, such that the instructions, which execute via the processor of the computer or other programmable data processing apparatus, create means for implementing the functions/acts specified in the flowchart and/or block diagram block or blocks. These computer readable program instructions may also be stored in a computer readable storage medium that can direct a computer, a programmable data processing apparatus, and/or other devices to function in a particular manner, such that the computer readable storage medium having instructions stored

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therein comprises an article of manufacture including instructions which implement aspects of the function/act specified in the flowchart and/or block diagram block or blocks.

[0019] The computer readable program instructions may also be loaded onto a computer, other programmable data processing apparatus, or other device to cause a series of operational steps to be performed on the computer, other programmable apparatus or other device to produce a computer implemented process, such that the instructions which execute on the computer, other programmable apparatus, or other device implement the functions/acts specified in the flowchart and/or block diagram block or blocks.

[0020] The flowchart and block diagrams in the Figures illustrate the architecture, functionality, and operation of possible implementations of systems, methods, and computer program products according to various embodiments of the present invention. In this regard, each block in the flowchart or block diagrams may represent a module, segment, or portion of instructions, which comprises one or more executable instructions for implementing the specified logical function(s). In some alternative implementations, the functions noted in the block may occur out of the order noted in the figures. For example, two blocks shown in succession may, in fact, be executed substantially concurrently, or the blocks may sometimes be executed in the reverse order, depending upon the functionality involved. It will also be noted that each block of the block diagrams and/or flowchart illustration, and combinations of blocks in the block diagrams and/or flowchart illustration, can be implemented by special purpose hardware-based systems that perform the specified functions or acts or carry out combinations of special purpose hardware and computer instructions.

[0021] With reference now to the figures, and in particular to FIG. 1, there is depicted a block diagram of an exemplary system and network that may be utilized by and/or in the implementation of the present invention. Some or all of the exemplary architecture, including both depicted hardware and software, shown for and within computer 101 may be utilized by software deploying server 149 shown in FIG. 1, and/or coordinating server 201 and/or roadway monitoring system 208 shown in FIG. 2, and/or a self-driving vehicle (SDV) on-board computer 301 shown in FIG. 3, and/or a coordinating server 401 depicted in FIG. 4.

[0022] Exemplary computer 101 includes a processor 103 that is coupled to a system bus 105. Processor 103 may utilize one or more processors, each of which has one or more processor cores. A video adapter 107, which drives/supports a display 109, is also coupled to system bus

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105. System bus 105 is coupled via a bus bridge 111 to an input/output (I/O) bus 113. An I/O interface 115 is coupled to I/O bus 113. I/O interface 115 affords communication with various I/O devices, including a keyboard 117, a mouse 119, a media tray 121 (which may include storage devices such as CD-ROM drives, multi-media interfaces, etc.), a transceiver 123 (capable of transmitting and/or receiving electronic communication signals), and external USB port(s) 125. While the format of the ports connected to I/O interface 115 may be any known to those skilled in the art of computer architecture, in one embodiment some or all of these ports are universal serial bus (USB) ports.

[0023] As depicted, computer 101 is able to communicate with a software deploying server 149 and/or other devices/systems (e.g., establishing communication among SDV 202, SDV 210, and/or roadway monitoring system 208 depicted in the figures below) using a network interface 129. Network interface 129 is a hardware network interface, such as a network interface card (NIC), etc. Network 127 may be an external network such as the Internet, or an internal network such as an Ethernet or a virtual private network (VPN). In one or more embodiments, network 127 is a wireless network, such as a Wi-Fi network, a cellular network, etc.

[0024] A hard drive interface 131 is also coupled to system bus 105. Hard drive interface 131 interfaces with a hard drive 133. In one embodiment, hard drive 133 populates a system memory 135, which is also coupled to system bus 105. System memory is defined as a lowest level of volatile memory in computer 101. This volatile memory includes additional higher levels of volatile memory (not shown), including, but not limited to, cache memory, registers and buffers. Data that populates system memory 135 includes computer 101's operating system (OS) 137 and application programs 143.

[0025] OS 137 includes a shell 139, for providing transparent user access to resources such as application programs 143. Generally, shell 139 is a program that provides an interpreter and an interface between the user and the operating system. More specifically, shell 139 executes commands that are entered into a command line user interface or from a file. Thus, shell 139, also called a command processor, is generally the highest level of the operating system software hierarchy and serves as a command interpreter. The shell provides a system prompt, interprets commands entered by keyboard, mouse, or other user input media, and sends the interpreted command(s) to the appropriate lower levels of the operating system (e.g., a kernel 141) for

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processing. While shell 139 is a text-based, line-oriented user interface, the present invention will equally well support other user interface modes, such as graphical, voice, gestural, etc.

[0026] As depicted, OS 137 also includes kernel 141, which includes lower levels of functionality for OS 137, including providing essential services required by other parts of OS 137 and application programs 143, including memory management, process and task management, disk management, and mouse and keyboard management.

[0027] Application programs 143 include a renderer, shown in exemplary manner as a browser 145. Browser 145 includes program modules and instructions enabling a world wide web (WWW) client (i.e., computer 101) to send and receive network messages to the Internet using hypertext transfer protocol (HTTP) messaging, thus enabling communication with software deploying server 149 and other systems.

[0028] Application programs 143 in computer 101's system memory (as well as software deploying server 149's system memory) also include Logic for Managing Self-Driving Vehicles (LMSDV) 147. LMSDV 147 includes code for implementing the processes described below, including those described in FIGS. 2-5. In one embodiment, computer 101 is able to download LMSDV 147 from software deploying server 149, including in an on-demand basis, wherein the code in LMSDV 147 is not downloaded until needed for execution. In one embodiment of the present invention, software deploying server 149 performs all of the functions associated with the present invention (including execution of LMSDV 147), thus freeing computer 101 from having to use its own internal computing resources to execute LMSDV 147.

[0029] Also within computer 101 is a positioning system 151, which determines a real-time current location of computer 101 (particularly when part of an emergency vehicle and/or a self-driving vehicle as described herein). Positioning system 151 may be a combination of accelerometers, speedometers, etc., or it may be a global positioning system (GPS) that utilizes space-based satellites to provide triangulated signals used to determine two-dimensional or three-dimensional locations.

[0030] Also associated with computer 101 are sensors 153, which detect an environment of the computer 101. More specifically, sensors 153 are able to detect vehicles, road obstructions, pavement, etc. For example, if computer 101 is on board a self-driving vehicle (SDV), then sensors 153 may be cameras, radar transceivers, etc. that allow the SDV to detect the environment (e.g., other vehicles, road obstructions, pavement, etc.) of that SDV, thus enabling it to be autonomously

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self-driven. Similarly, sensors 153 may be cameras, thermometers, moisture detectors, etc. that detect ambient weather conditions.

[0031] In another embodiment, sensors 153 are sensors that detect an operational state of an SDV, including anomalous states such as, but not limited to, a presence of snow tires mounted on the SDV during a first road condition of the roadway, an absence of snow tires mounted on the SDV during a second road condition of the roadway, tire pressure in a tire mounted on the SDV being below a predetermined level, tire tread on a tire mounted on the SDV being less than a predefined limit, a windshield wiper edge of a windshield wiper mounted on the SDV being less than a predefined width, a level of windshield washer fluid in a windshield washer fluid reservoir mounted on the SDV being less than a predefined volume, an inoperable headlamp mounted on the SDV, condensation frosting of windows on the SDV exceeding a predetermined limit, a failure of an antilock breaking system in the SDV, a failure of an all wheel traction system in the SDV, and a faulty braking system in the SDV.

[0032] The hardware elements depicted in computer 101 are not intended to be exhaustive, but rather are representative to highlight essential components required by the present invention. For instance, computer 101 may include alternate memory storage devices such as magnetic cassettes, digital versatile disks (DVDs), Bernoulli cartridges, and the like. These and other variations are intended to be within the spirit and scope of the present invention.

[0033] The present invention describes a self-driving vehicle (SDV) traveling on a roadway. First, at any point in time the SDV may be in autonomous mode or manual mode, as described and discussed in detail herein. Second, the "roadway" upon which the SDV is traveling is defined as any surface capable of supporting the weight of the SDV, including but not limited to public streets, public highways, toll roads, parking lots, private road, open fields, etc. The streets/roads/lots may be paved or unpaved.

[0034] With reference now to FIG. 2, an exemplary self-driving vehicle (SDV) 202 traveling along a roadway 204 in accordance with one or more embodiments of the present invention is presented. Additional details of one or more embodiments of the SDV 202 (which may have a same architecture as SDV 210 and/or SDV 212, which are discussed below) are presented in FIG. 3.

[0035] As shown in FIG. 3, SDV 202 has an SDV on-board computer 301 that controls operations of the SDV 202. According to directives from a driving mode module 307, the SDV

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202 can be selectively operated in manual mode or autonomous mode. In a preferred embodiment, driving mode module 307 is a dedicated hardware device that selectively directs the SDV on-board computer 301 to operate the SDV 202 in autonomous mode or manual mode.

[0036] While in manual mode, SDV 202 operates as a traditional motor vehicle, in which a human driver controls the engine throttle, engine on/off switch, steering mechanism, braking system, horn, signals, etc. found on a motor vehicle. These vehicle mechanisms may be operated in a "drive-by-wire" manner, in which inputs to an SDV control processor 303 by the driver result in output signals that control the SDV vehicular physical control mechanisms 305 (e.g., the engine throttle, steering mechanisms, braking systems, turn signals, etc.).

[0037] While in autonomous mode, SDV 202 operates without the input of a human driver, such that the engine, steering mechanism, braking system, horn, signals, etc. are controlled by the SDV control processor 303, but now under the control of the SDV on-board computer 301. That is, by processing inputs taken from navigation and control sensors 309 and the driving mode module 307 indicating that the SDV 202 is to be controlled autonomously, then driver inputs are no longer needed.

[0038] As just mentioned, the SDV on-board computer 301 uses outputs from navigation and control sensors 309 to control the SDV 202. Navigation and control sensors 309 include hardware sensors that 1) determine the location of the SDV 202; 2) sense other cars and/or obstacles and/or physical structures around SDV 202; 3) measure the speed and direction of the SDV 202; and 4) provide any other inputs needed to safely control the movement of the SDV 202.

[0039] With respect to the feature of 1) determining the location of the SDV 202, this can be achieved through the use of a positioning system such as positioning system 151 shown in FIG. 1. Positioning system 151 may use a global positioning system (GPS), which uses space-based satellites that provide positioning signals that are triangulated by a GPS receiver to determine a 3-D geophysical position of the SDV 202. Positioning system 151 may also use, either alone or in conjunction with a GPS system, physical movement sensors such as accelerometers (which measure rates of changes to a vehicle in any direction), speedometers (which measure the instantaneous speed of a vehicle), airflow meters (which measure the flow of air around a vehicle), etc. Such physical movement sensors may incorporate the use of semiconductor strain gauges, electromechanical gauges that take readings from drivetrain rotations, barometric sensors, etc.

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[0040] With respect to the feature of 2) sensing other cars and/or obstacles and/or physical structures around SDV 202, the positioning system 151 may use radar or other electromagnetic energy that is emitted from an electromagnetic radiation transmitter (e.g., transceiver 323 shown in FIG. 3), bounced off a physical structure (e.g., another car), and then received by an electromagnetic radiation receiver (e.g., transceiver 323). By measuring the time it takes to receive back the emitted electromagnetic radiation, and/or evaluating a Doppler shift (i.e., a change in frequency to the electromagnetic radiation that is caused by the relative movement of the SDV 202 to objects being interrogated by the electromagnetic radiation) in the received electromagnetic radiation from when it was transmitted, the presence and location of other physical objects can be ascertained by the SDV on-board computer 301.

[0041] With respect to the feature of 3) measuring the speed and direction of the SDV 202, this can be accomplished by taking readings from an on-board speedometer (not depicted) on the SDV 202 and/or detecting movements to the steering mechanism (also not depicted) on the SDV 202 and/or the positioning system 151 discussed above.

[0042] With respect to the feature of 4) providing any other inputs needed to safely control the movement of the SDV 202, such inputs include, but are not limited to, control signals to activate a horn, turning indicators, flashing emergency lights, etc. on the SDV 202.

[0043] Returning to FIG. 2, current conditions of the roadway 204, including weather conditions, traffic conditions, the quantity of vehicles traveling along roadway 204, the speed of vehicle traveling along roadway 204, construction events, accident events, etc., can be determined and transmitted by the roadway monitoring system 208. That is, roadway monitoring system 208 is able to determine current roadway conditions of roadway 204 based on internal sensors 153 shown in FIG. 1, and/or from information received from SDV 202 and/or SDV 210 and/or SDV 212, and/or from information received by an information service (e.g., a weather station), and or from information received by roadway sensor(s) 206 (e.g., thermometers, moisture detectors, vehicle detectors, etc. that are laid on top or and/or embedded within roadway 204).

[0044] In accordance with one or more embodiments of the present invention, SDV 202 is selectively placed into autonomous mode or manual mode (described above) based on a detection of a vehicle fault in SDV 202. Exemplary vehicle faults include, but are not limited to the presence or absence of snow tires when required or not required, inadequate tire pressure, inadequate tire tread, inadequate windshield wiper edge, inadequate windshield washer fluid, headlamp failure,

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extreme amounts of water on windows or under tires, window frosting, snow on the windows/windshield, ice on the windows/windshield, improper wheel alignment, excessive brake wear (i.e., brake pads being worn down such that less than a predefined amount of brake material is left), antilock brake failure, all wheel traction failure, and/or inadequate braking. A threshold for seriousness of the fault may be applied to vehicle measures in order to determine if the switch (from manual mode to autonomous mode or vice versa) is required. Vehicle faults may also be results of bugs (software, firmware, hardware bugs), or single-event upsets, that get reproduced in certain conditions.

[0045] Thus in one or more embodiments of the present invention, a vehicle monitoring system (e.g., SDV on-board computer 301 shown in FIG. 3) detects a vehicle fault in the SDV. Based on the detected fault exceeding a threshold for danger, the SDV either switches from autonomous mode to manual mode or from manual mode to autonomous mode.

[0046] In one embodiment of the present invention, the vehicle monitoring system alters a route being taken by the SDV to a location where the fault may be remedied (e.g., a service station).

[0047] In one embodiment of the present invention, the vehicle monitoring system alters the route being taken by the SDV based on the severity of the fault (e.g., pulling over and stopping immediately, traveling to the nearest service station, traveling to the nearest dealership, returning to the owner's home, etc.).

[0048] In one embodiment of the present invention, the vehicle monitoring system has a fault-remediation table, where each row refers to a fault condition, a first column refers to a condition that gets manifested by that fault, and a second column that refers to the mode in which the vehicle should be driven when that condition is manifested. For example, a row may refer to a fault in the traction control system on the vehicle, the first column in that row may indicate that this fault is manifested by the vehicle hydroplaning, and the second column in that row may indicate that the vehicle needs to be taken out of autonomous mode and placed into manual mode, thus allowing the driver to manually control the speed and steering to stop the hydroplaning, which the automatic traction control system is unable to do. In one embodiment, this table is updated from a central server or offline systems based on other SDVs responding to the same fault. Thus, the SDV is able to apply the information from the table and changes driving mode as and when needed.

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[0049] In one embodiment of the present invention, a driver profile provides an indication of the driver's physical or other abilities. This information is then used to further determine whether the SDV should be in autonomous or manual mode.

[0050] In one embodiment of the present invention, a further analysis of whether to place the SDV in autonomous or manual mode is performed if more than one person is in the vehicle (thus creating a possible distraction for the driver).

[0051] In one embodiment of the present invention, a further analysis of whether to place the SDV in autonomous or manual mode is performed if a person and a pet are in the same vehicle (another possible distraction for the driver).

[0052] In one or more embodiments of the present invention a weighted voting system is used to weight the various variables used in making the decision that is triggered by faults. Such inputs may include: a history of faults by one or more cars such as SDV 210 and SDV 212 shown in FIG. 2 (and the likely affects of such faults), votes by nearby cars, etc. Such weighted voting approaches may be characterized primarily by three aspects--the inputs, the weights, and the quota. The inputs are (I1, I2, . . . , IN), where N denotes the total number of inputs. An input's weight (w) is the number of "votes" associated with the input. The quota (q) is the minimum number of votes required to "pass a motion", which in this case refers primarily to a decision made to place the SDV in manual mode or autonomous mode.

[0053] In one or more embodiments of the present invention, active learning is employed so that the system as a whole learns from the experiences of many SDVs and drivers, in different geographies and among cohorts. Geographies may include cities, rural areas, and the like. Cohorts may include people with certain characteristics, disabilities, etc.

[0054] Thus, the present invention allows switching between human operated (manual mode) and self-driving modes (autonomous modes) that takes into account the vehicle's operational condition and expected tolerances of the vehicle to the different modes. Since unexpected changes to vehicle condition can cause an immediate response by utilizing the present invention, safety of the vehicle is optimized. Furthermore, self-diagnosis of faults can result in an immediate change in vehicle location to optimally resolve the fault (for example, to drive to the nearest flat tire repair shop).

[0055] Besides the condition of the SDV 202, the condition of roadway 204 and/or SDV 210 and/or SDV 212 is also used to determine whether to place SDV 202 in manual mode or

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autonomous mode. For example, if roadway is very narrow or runs along the side of a cliff, then SDV 202 likely would be safer if in autonomous mode. Similarly, if SDV 210 is experiencing a flat tire (as detected by an SDV on-board computer 301 within SDV 210), this fault condition is relayed to the SDV on-board computer 301 within SDV 202, either directly or via the coordinating server 201. Using this information will prompt the SDV on-board computer 301 within SDV 202 to place SDV 202 into autonomous mode, which is better at handling unexpected movement of vehicles (e.g., the sudden slowing down and/or lateral movement of SDV 210).

[0056] As depicted in FIG. 4, coordinating server 401 (analogous to coordinating server 201 shown in FIG. 2) and/or SDV 202 and/or SDV 210 and/or SDV 212 and/or roadway monitoring system 208 and/or roadway sensor(s) 206 (all introduced in FIG. 2) are able to communicate with one another wirelessly, using a wireless transceiver (e.g., transceiver 123 shown in FIG. 1) that is found in each of the coordinating server 401 and/or SDV 202 and/or SDV 210 and/or SDV 212 and/or roadway monitoring system 208 and/or roadway sensor(s) 206. This wireless communication optimizes the decision to place SDV 202 in autonomous or manual mode by taking information from SDV 202 and/or SDV 210 and/or SDV 212 and/or roadway monitoring system 208 and/or roadway sensor(s) 206 in order to determine which mode (autonomous or manual) to place SDV 202 in.

[0057] With reference now to FIG. 5, a high-level flow chart of one or more steps performed by one or more processors to control a driving mode of an SDV in accordance with one or more embodiments of the present invention is presented.

[0058] After initiator block 502, one or more processors (e.g., processor 103 shown in FIG. 1) receive sensor readings from a sensor (e.g., one or more of the sensors 153 shown in FIG. 1), as described in block 504. These sensor readings describe a current operational anomaly of an SDV (e.g., SDV 202 shown in FIG. 2). This current operational anomaly may be a software bug in a control system for the SDV; worn down brake pads; worn down or tearing windshield wipers; a malfunctioning drivetrain; etc.

[0059] The SDV is capable of being operated in autonomous mode by an on-board SDV control processor (e.g., SDV control processor 303 shown in FIG. 3) that is under the direct control of an SDV on-board computer (e.g., SDV on-board computer 301) or another computer system (e.g., coordinating server 401 shown in FIG. 4). A driving mode module selectively controls

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whether the SDV is operated in the autonomous mode (by the on-board SDV control processor) or in manual mode (in which the SDV is controlled by a human driver of the SDV).

[0060] As shown in block 506, one or more processors determine a control processor competence level of the on-board SDV control processor. The control processor competence level describes a competence level of the on-board SDV control processor in controlling the SDV while the SDV experiences the current operational anomaly. Various approaches may be used to determine this control processor competence level.

[0061] In one embodiment of the present invention, the control processor competence level of the on-board SDV control processor is history-based. That is, a record is reviewed on how effective the on-board SDV control processor has been in controlling the current SDV 202 or similar types of SDVs (i.e., SDVs that have the same design and/or performance characteristics as SDV 202) in situations in which the SDV are experiencing the same type of operational anomaly (e.g., tires with poor tread depth). This effectiveness may be based on past 1) accident frequency, 2) travel speed, 3) stopping and starting, 4) gas mileage, etc. That is, the control processor competence level of the on-board SDV control processor describes how well the on-board SDV control processor has been controlling SDV 202 or similar SDVs in terms of safety, cost, consistency, etc. when the current operational anomaly occurs within the SDV(s).

[0062] In one embodiment of the present invention, the control processor competence level of the on-board SDV control processor is based on an analysis of capability of the on-board SDV control processor. That is, a review of what control features can be handled by the on-board SDV control processor is used to define the control processor competence level of the on-board SDV control processor. For example, assume that such a review confirms that the on-board SDV control processor is able to control the speed of the SDV 202 (i.e., "cruise control"), but nothing else. As such, the control processor competence level of this on-board SDV control processor is relatively low when compared to an on-board SDV control processor that is able to automatically maintain safety distances (buffers of space) between other vehicles. Similarly, the control processor competence level of the on-board SDV control processor that can also maintain safety space cushions around the SDV has a control processor competence level that is lower than an on-board SDV control processor that is able to not only control the speed and safety cushion around the SDV, but can also control the steering of the SDV.

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[0063] As described in block 508 of FIG. 5, one or more processors receive a driver profile of the human driver of the SDV. This driver profile describes a human driver competence level of the human driver in controlling the SDV while the SDV experiences the current operational anomaly. That is, a driver may be very good at safely controlling the SDV when the air conditioning system on the SDV is working improperly, but may be very poor at safely controlling the SDV when the antilock braking system is not working and it is raining on the roadway.

[0064] In one embodiment of the present invention, the human driver competence level of the human driver is history-based. That is, a record is reviewed on how effectively this driver has controlled the current SDV 202 or similar types of SDVs that are experiencing the same operational anomaly as currently being experienced by SDV 202. This effectiveness may be based on past 1) accident frequency, 2) travel speed, 3) stopping and starting, 4) gas mileage, etc. That is, the human driver competence level of the human driver describes how well the current driver has controlled this or similar SDVs in terms of safety, cost, consistency, etc. in the past under the anomalous conditions being experienced by the vehicle.

[0065] In one embodiment of the present invention, the human driver competence level of the human driver is based on an analysis of capability of this human driver based on his traits/profile. That is, a review of this human driver's traits can lead to a conclusion regarding the strengths and weaknesses of this driver. For example, if this human driver has a record of poor night vision (as evidenced by a restriction on his/her license preventing him from driving at night), then the competence level of this driver to control a vehicle when a headlight is burned out is low.

[0066] As described in block 510 in FIG. 5, one or more processors then compare the control processor competence level to the human driver competence level. In order to compare these two levels, different approaches can be taken.

[0067] In one embodiment of the present invention, each control factor (e.g., driving the SDV at night) is compared using the on-board SDV control processor versus the human driver. Each control factor that is relevant to the current operational anomaly of the SDV (e.g., driving at night in rainy conditions) is evaluated for both the on-board SDV control processor and the human driver. The control factors are then summed, in order to determine whether the on-board SDV control processor of the human driver is better at handling the SDV while the SDV is experiencing the current operational anomaly.

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[0068] In one embodiment of the present invention, the control factors being compared and evaluated (for the on-board SDV control processor versus the human driver) are weighted according to their predetermined significance to the overall control of the SDV. For example, a review of all traffic accidents may show that failure to properly control spatial cushions between vehicles caused more accidents than failing to signal. Therefore, the control factor of failing to maintain spatial buffers around the vehicle is weighted more heavily than the control factor of controlling turn signals.

[0069] In one embodiment of the present invention, the control processor competence level and/or the human driver competence level are purely outcome based. That is, a history of safety, fuel efficiency, traffic flow (consistent or speeding up/slowing down), etc. of SDVs that are experiencing the operational anomaly are compared when being driven by the type of on-board SDV control processor in use by SDV 202 to a human driver having a similar profile as the current driver of the SDV 202. Whichever type of operator (i.e., the on-board SDV control processor of the human driver) has been able to drive the SDV, under operational anomalous conditions similar to the current operational condition being experienced by the SDV, in a safer and more efficient manner is deemed to have a higher competence level.

[0070] A shown in query block 512, a query is made as to which competence level is higher: the control processor competence level (CPCL) or the human driver competence level (HDCL). If the on-board SDV control processor is deemed to be better than the human driver in controlling the SDV while the SDV experiences the current operational anomaly (i.e., the on-board SDV control processor has a relatively higher competence level than that of the human driver), then control of the SDV is assigned to the on-board SDV (block 514). That is, the SDV is placed in autonomous mode.

[0071] However, if the human driver is deemed to be better than the on-board SDV control processor in controlling the SDV while the SDV experiences the current operational anomaly (i.e., the human driver has a relatively higher competence level than that of the on-board SDV control processor), then control of the SDV is assigned to the human (i.e., the SDV is placed in manual mode), as described in block 516.

[0072] In one embodiment of the present invention, an alert is issued before (or instead of) the driving mode module 307 and/or the SDV on-board computer 301 and/or the coordinating server 201 assigns the SDV to be operated in autonomous or manual mode. That is, in one

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embodiment, the driving mode module 307 and/or the SDV on-board computer 301 and/or the coordinating server 201 issues an alert (e.g., a message or icon displayed on a display within the cabin of the SDV 202) advising the driver of the SDV 202 to manually engage the autonomous mode or to disengage the autonomous mode and take over manual control of the SDV 202. This alert may simply precede the driving mode module 307 and/or the SDV on-board computer 301 and/or the coordinating server 201 automatically changes from autonomous mode to manual mode (or vice versa), or it may be the only action taken by the driving mode module 307 and/or the SDV on-board computer 301 and/or the coordinating server 201, thus leaving the transition from autonomous mode to manual mode or vice versa up to the driver.

[0073] The flow-chart in FIG. 5 ends at terminator block 518.

[0074] In one embodiment of the present invention, the comparison of the control processor competence level to the human driver competence level is general (i.e., whichever competence level is higher, regardless of what roadway is being traveled on). However, in another embodiment of the present invention, the comparison of the control processor competence level to the human driver competence level is roadway specific. That is, the competence levels are based on how well the SDV control processor and/or the human driver control the SDV on the specific roadway (roadway 204) that the SDV is traveling on, and/or the current environmental conditions (traffic, weather, darkness, etc.) of that specific roadway.

[0075] As described herein, in one or more embodiments of the present invention wherein the current operational anomaly is from a group consisting of a presence of snow tires mounted on the SDV during a first road condition of the roadway (e.g., the SDV has snow tires but it is in the middle of summer, when snow tires provide less traction than when in snow in the winter), an absence of snow tires mounted on the SDV during a second road condition of the roadway (e.g., non-snow tires on the SDV in the middle of a blizzard), tire pressure in a tire mounted on the SDV being below or above a predetermined level (i.e., one or more tires are underinflated or overinflated), tire tread on a tire mounted on the SDV being less than a predefined limit (i.e., there is an insufficient amount of tread left on one or more tires), a level of windshield washer fluid in a windshield washer fluid reservoir mounted on the SDV being less than a predefined volume, an inoperable headlamp mounted on the SDV (i.e., a headlight is burned out), condensation frosting of windows on the SDV exceeding a predetermined limit, a failure of an antilock breaking system in the SDV, a failure of an all wheel traction system in the SDV, a low automatic transmission

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fluid level, a low windshield washer fluid level, a low fluid level in the radiator, and a faulty braking system in the SDV. These conditions may be detected by sensors (e.g., fluid sensors in the windshield washer fluid reservoir), cameras (e.g., an on-board camera aimed at the tires to detect the amount of tread and inflation in the tires), mechanical sensors (e.g., sensors that detect problems in the drivetrain or braking system), etc.

[0076] In one embodiment of the present invention, a sensor (e.g., one of sensors 153 shown in FIG. 1) used to describe current conditions of the roadway is mounted on the SDV. Sensor readings produced by the sensor describe environmental conditions of the SDV in real time. In this embodiment, one or more processors receive an environmental report from an environmental reporting service. The environmental report describes a general condition for the roadway. For example, a weather service ("environmental reporting service") may report via a data link (e.g., network 127 in FIG. 1) to processors on the SDV that there is icing occurring on the roadway 206 shown in FIG. 2.

[0077] One or more processors then compare environmental information from the environmental report to the sensor readings that describe the environmental conditions of the SDV in real time. In response to the environmental report disagreeing with the sensor readings, one or more processors disregard the sensor readings from the sensor and use the environmental report to describe the current condition of the roadway. That is, the processors will trust the weather report of ice on the roadway over what the sensors detect, since the sensors are only able to detect ice conditions (if at all) on the surface below the SDV at any point in time.

[0078] In one embodiment of the present invention, one or more processors retrieve driver profile information about the human driver of the SDV. The human driver of the SDV (e.g., SDV 202 shown in FIG. 2) is assigned to a cohort of drivers traveling on the roadway in multiple SDVs (e.g., SDV 210 and SDV 212 shown in FIG. 2). The current human driver of the SDV shares more than a predetermined quantity of traits with members of the cohort of drivers. The processor(s) retrieve traffic pattern data for the multiple SDVs occupied by the cohort of drivers traveling on the roadway, and then examine the traffic pattern data to determine a first traffic flow of the multiple SDVs occupied by members of the cohort of drivers. The SDVs in the first traffic flow are operating in the autonomous mode on the roadway.

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[0079] The processor(s) also examine the traffic pattern data to determine a second traffic flow of the multiple SDVs occupied by members of the cohort of drivers. The multiple SDVs in the second traffic flow are operating in the manual mode on the roadway.

[0080] In response to determining that the first traffic flow has a lower accident rate than the second traffic flow, the processor(s) prohibit the SDV from operating in the manual mode.

[0081] For example, assume that a particular driver/occupant of an SDV has a characteristic (e.g., a history of traffic accidents while driving a vehicle in manual mode) found in other members of a cohort of drivers. Assume further that historical data shows that these cohort members have a history of accidents that is greater than that of on-board SDV control processors. Thus, if a particular driver matches up with the features found in members of this cohort, an assumption is made that this particular driver too is not as skilled as the on-board SDV control processor. As such, the control of the SDV is required to stay in autonomous mode, and is prohibited from switching to manual mode.

[0082] In one embodiment of the present invention, sensor readings are weighted and summed in order to determine whether or not an SDV should be required to operate in autonomous mode. Thus, one or more processors receive sensor readings from multiple sensors, where each of the multiple sensors detects a different type of anomalous operational condition of the vehicle. The processor(s) weight each of the sensor readings for different anomalous operational conditions of the vehicle, and then sum the weighted sensor readings for the anomalous operational conditions of the vehicle. The processor(s) determine whether the summed weighted sensor readings exceed a predefined level. In response to determining that the summed weighted sensor readings do exceed a predefined level, the on-board SDV control processor prohibits the SDV from operating in the manual mode. For example, assume that a first sensor detects faulty windshield wipers and the second sensor detects a faulty cabin air conditioning system. Assume further that historical data shows that many more accidents are caused by poor visibility (e.g., caused by faulty windshield wipers) than a warm cabin of the SDV. As such, the sensor readings from sensors that the faulty windshield wipers are weighted more heavily than sensor readings about cabin temperature. These weighted sensor readings are then added up. If the summed sensor reading weighted values exceed some predetermined value (which has been predetermined based on historic or engineering analyses as being a breakpoint over which the chance of accidents greatly increase), then control

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of the SDV must go into autonomous mode. However, if the summed sensor reading weighted values fall below this predetermined value, then control is pushed to (or left in) the manual mode.

[0083] In one or more embodiments of the present invention, the SDV 202 "learns" about how significant operational anomalies are. That is, by taking information from other SDVs and their driving history as well as the driving history of SDV 202 itself, SDV 202 is able to autonomous "learn" what operational anomalies are significant to the safe operation of SDV 202 (e.g., faulty brakes, faulty throttle controls, tires with little or no tread, etc.) and those which are comparatively insignificant (e.g., a cabin air conditioning system that is low on refrigerant, etc.).

[0084] In an embodiment of the present invention, if neither the autonomous mode nor the manual mode controls the SDV in a safe manner, then the SDV is autonomously pulled over to the side of the road and stopped. Thus, in this embodiment one or more processors set a minimum competence level threshold for the control processor competence level and the human driver competence level described above. The processor(s) then determines that neither the control processor competence level nor the human driver competence level meets or exceeds the minimum competence level threshold. In response to determining that neither the control processor competence level nor the human driver competence level exceeds the minimum competence level threshold, the driving mode module (e.g., driving mode module 307 in FIG. 3) directs the on-board SDV control processor to take control of the SDV and to bring the SDV to a stop.

[0085] In one embodiment, the decision by the driving mode module 307 in FIG. 3 to place the SDV in autonomous mode or manual mode is further dictated by how well a particular driver or a particular SDV control processor handles a specific geometry of the roadway 204 shown in FIG. 2 while a certain anomalous operational condition is being experienced by SDV 202. For example, assume that a particular driver manually maneuvers the SDV 202 around a cloverleaf exchange, in which the roadway loops around onto itself. If a driver does poorly in negotiating this cloverleaf exchange (e.g., hits the side of the cloverleaf barrier, is erratic in accelerating and/or braking through the cloverleaf, travels well above or well below the posted speed limit for the cloverleaf, etc.), as detected by various sensors 153 on the SDV 202, then the system will not let that driver negotiate through future and similarly configured (e.g., shaped) cloverleaves on the roadway, particularly if the SDV 202 is experiencing a problem (operational anomaly) with the antilock braking system (ABS). Rather, the system (e.g., driving mode module 307) will

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automatically engage the autonomous mode when the similarly configured cloverleaf comes up while the SDV 202 is experiencing this anomalous operational condition.

[0086] As described herein, in one embodiment of the present invention, the control processor competence level is based on a safety history for similar control processors in other SDVs. Thus, one or more processors retrieve control processor profile information about the SDV control processor that is on board the SDV. The processors(s) assign the SDV control processor that is on board the SDV to a cohort of SDV control processors in multiple other SDVs that are traveling on the roadway and experiencing a particular anomalous operational condition. This SDV control processor that is on board the SDV shares more than a predetermined quantity of traits with members of the cohort of SDV control processors. The processor(s) retrieve traffic pattern data for the multiple other SDVs that are traveling on the roadway, and then examine that traffic pattern data to determine a record of accidents for the multiple other SDVs traveling on the roadway while being controlled by the cohort of SDV control processors. The processor(s) then determine the control processor competence level (for the SDV control processor in SDV 202) based on the record of accidents for the multiple SDVs (e.g., SDV 210 and SDV 212) traveling on the roadway (e.g., roadway 204) while being controlled by the cohort of SDV control processors and the SDV 202 is experiencing the particular anomalous operational condition.

[0087] In one embodiment of the present invention, if environmental sensors on the roadway indicate that road conditions are too hazardous to allow the driver to manually control the vehicle while the vehicle is experiencing the anomalous operational condition, then manual mode is prohibited. That is, in one embodiment of the present invention, one or more processors receive sensor readings from multiple sensors (e.g., roadway sensor(s) 206 shown in FIG. 2). Each of the multiple sensors detects a different type of current condition of the roadway. The processor(s) weight each of the sensor readings for different current conditions of the roadway (e.g., one for temperature, one for darkness, one for precipitation, etc.), and then sum the weighted sensor readings for the different current conditions of the roadway. If summed weighted sensor readings exceed a predefined level, then the SDV control processor on the SDV prohibits the SDV from operating in the manual mode while the vehicle is experiencing the anomalous operational condition.

[0088] In one embodiment of the present invention, if the SDV control processor and the human driver are both incompetent to handle the operational anomaly (e.g., the SDV is on fire),

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then the SDV is automatically placed into autonomous mode and pulled over to the side of the road. That is, one or more processors set a minimum competence level threshold for the control processor competence level and the human driver competence level. If neither the control processor competence level nor the human driver competence level meets the minimum competence level threshold, then the driving mode module (e.g., driving mode module 307 in FIG. 3) directs the SDV control processor to take control of the SDV and to bring the SDV to an immediate stop.

[0089] In one embodiment of the present invention, if the roadway is too narrow, or is along a cliff, or otherwise is unduly hazardous, then this fact is considered when placing the SDV in autonomous or manual mode. Usually this will result in the SDV being placed into autonomous mode, but in some situations (e.g., where GPS or other positioning signals are spotty) it may be preferable/safer to let the driver manually control the vehicle. Thus, in one embodiment of the present invention the SDV on-board computer 301 and/or controlling server 201 receive, from one or more roadway sensors (e.g., roadway sensor(s) 206 in FIG. 2), a width of the roadway (e.g., roadway 204). Based on this information, one or more processors (e.g., within driving mode module 307 shown in FIG. 3) further selectively assign control of the SDV to the SDV control processor or to the human driver while the SDV experiences the current operational anomaly (and based on the width of the roadway).

[0090] In one embodiment of the present invention and as described above, the system will drive the SDV in autonomous mode to the nearest facility that can resolve the current operational anomaly. That is, control of the SDV is transferred to the SDV control processor, and then one or more processors (e.g., within SDV on-board computer 301) receive a location of a resource provider that has been predetermined to be capable of ameliorating the current operational anomaly in the SDV. The SDV control processor then maneuvers the SDV to the location of the resource provider.

[0091] In one or more embodiments, the present invention is implemented in a cloud environment. It is understood in advance that although this disclosure includes a detailed description on cloud computing, implementation of the teachings recited herein are not limited to a cloud computing environment. Rather, embodiments of the present invention are capable of being implemented in conjunction with any other type of computing environment now known or later developed.

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[0092] Cloud computing is a model of service delivery for enabling convenient, on-demand network access to a shared pool of configurable computing resources (e.g. networks, network bandwidth, servers, processing, memory, storage, applications, virtual machines, and services) that can be rapidly provisioned and released with minimal management effort or interaction with a provider of the service. This cloud model may include at least five characteristics, at least three service models, and at least four deployment models.

[0093] Characteristics are as follows:

[0094] On-demand self-service: a cloud consumer can unilaterally provision computing capabilities, such as server time and network storage, as needed automatically without requiring human interaction with the service's provider.

[0095] Broad network access: capabilities are available over a network and accessed through standard mechanisms that promote use by heterogeneous thin or thick client platforms (e.g., mobile phones, laptops, and PDAs).

[0096] Resource pooling: the provider's computing resources are pooled to serve multiple consumers using a multi-tenant model, with different physical and virtual resources dynamically assigned and reassigned according to demand. There is a sense of location independence in that the consumer generally has no control or knowledge over the exact location of the provided resources but may be able to specify location at a higher level of abstraction (e.g., country, state, or datacenter).

[0097] Rapid elasticity: capabilities can be rapidly and elastically provisioned, in some cases automatically, to quickly scale out and rapidly released to quickly scale in. To the consumer, the capabilities available for provisioning often appear to be unlimited and can be purchased in any quantity at any time.

[0098] Measured service: cloud systems automatically control and optimize resource use by leveraging a metering capability at some level of abstraction appropriate to the type of service (e.g., storage, processing, bandwidth, and active user accounts). Resource usage can be monitored, controlled, and reported providing transparency for both the provider and consumer of the utilized service.

[0099] Service Models are as follows:

[00100] Software as a Service (SaaS): the capability provided to the consumer is to use the provider's applications running on a cloud infrastructure. The applications are accessible from

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various client devices through a thin client interface such as a web browser (e.g., web-based e-mail). The consumer does not manage or control the underlying cloud infrastructure including network, servers, operating systems, storage, or even individual application capabilities, with the possible exception of limited user-specific application configuration settings.

[00101] Platform as a Service (PaaS): the capability provided to the consumer is to deploy onto the cloud infrastructure consumer-created or acquired applications created using programming languages and tools supported by the provider. The consumer does not manage or control the underlying cloud infrastructure including networks, servers, operating systems, or storage, but has control over the deployed applications and possibly application hosting environment configurations.

[00102] Infrastructure as a Service (IaaS): the capability provided to the consumer is to provision processing, storage, networks, and other fundamental computing resources where the consumer is able to deploy and run arbitrary software, which can include operating systems and applications. The consumer does not manage or control the underlying cloud infrastructure but has control over operating systems, storage, deployed applications, and possibly limited control of select networking components (e.g., host firewalls).

[00103] Deployment Models are as follows:

[00104] Private cloud: the cloud infrastructure is operated solely for an organization. It may be managed by the organization or a third party and may exist on-premises or off-premises.

[00105] Community cloud: the cloud infrastructure is shared by several organizations and supports a specific community that has shared concerns (e.g., mission, security requirements, policy, and compliance considerations). It may be managed by the organizations or a third party and may exist on-premises or off-premises.

[00106] Public cloud: the cloud infrastructure is made available to the general public or a large industry group and is owned by an organization selling cloud services.

[00107] Hybrid cloud: the cloud infrastructure is a composition of two or more clouds (private, community, or public) that remain unique entities but are bound together by standardized or proprietary technology that enables data and application portability (e.g., cloud bursting for load-balancing between clouds).

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[00108] A cloud computing environment is service oriented with a focus on statelessness, low coupling, modularity, and semantic interoperability. At the heart of cloud computing is an infrastructure comprising a network of interconnected nodes.

[00109] Referring now to FIG. 6, a schematic of an example of a cloud computing node is shown. Cloud computing node 10 is only one example of a suitable cloud computing node and is not intended to suggest any limitation as to the scope of use or functionality of embodiments of the invention described herein. Regardless, cloud computing node 10 is capable of being implemented and/or performing any of the functionality set forth hereinabove.

[00110] In cloud computing node 10 there is a computer system/server 12, which is operational with numerous other general purpose or special purpose computing system environments or configurations. Examples of well-known computing systems, environments, and/or configurations that may be suitable for use with computer system/server 12 include, but are not limited to, personal computer systems, server computer systems, thin clients, thick clients, hand-held or laptop devices, multiprocessor systems, microprocessor-based systems, set top boxes, programmable consumer electronics, network PCs, minicomputer systems, mainframe computer systems, and distributed cloud computing environments that include any of the above systems or devices, and the like.

[00111] Computer system/server 12 may be described in the general context of computer system-executable instructions, such as program modules, being executed by a computer system. Generally, program modules may include routines, programs, objects, components, logic, data structures, and so on that perform particular tasks or implement particular abstract data types. Computer system/server 12 may be practiced in distributed cloud computing environments where tasks are performed by remote processing devices that are linked through a communications network. In a distributed cloud computing environment, program modules may be located in both local and remote computer system storage media including memory storage devices.

[00112] As shown in FIG. 6, computer system/server 12 in cloud computing node 10 is shown in the form of a general-purpose computing device. The components of computer system/server 12 may include, but are not limited to, one or more processors or processing units 16, a system memory 28, and a bus 18 that couples various system components including system memory 28 to processor 16.

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[00113] Bus 18 represents one or more of any of several types of bus structures, including a memory bus or memory controller, a peripheral bus, an accelerated graphics port, and a processor or local bus using any of a variety of bus architectures. By way of example, and not limitation, such architectures include Industry Standard Architecture (ISA) bus, Micro Channel Architecture (MCA) bus, Enhanced ISA (EISA) bus, Video Electronics Standards Association (VESA) local bus, and Peripheral Component Interconnects (PCI) bus.

[00114] Computer system/server 12 typically includes a variety of computer system readable media. Such media may be any available media that is accessible by computer system/server 12, and it includes both volatile and non-volatile media, removable and non-removable media.

[00115] System memory 28 can include computer system readable media in the form of volatile memory, such as random access memory (RAM) 30 and/or cache memory 32. Computer system/server 12 may further include other removable/non-removable, volatile/non-volatile computer system storage media. By way of example only, storage system 34 can be provided for reading from and writing to a non-removable, non-volatile magnetic media (not shown and typically called a "hard drive"). Although not shown, a magnetic disk drive for reading from and writing to a removable, non-volatile magnetic disk (e.g., a "floppy disk"), and an optical disk drive for reading from or writing to a removable, non-volatile optical disk such as a CD-ROM, DVD-ROM or other optical media can be provided. In such instances, each can be connected to bus 18 by one or more data media interfaces. As will be further depicted and described below, memory 28 may include at least one program product having a set (e.g., at least one) of program modules that are configured to carry out the functions of embodiments of the invention.

[00116] Program/utility 40, having a set (at least one) of program modules 42, may be stored in memory 28 by way of example, and not limitation, as well as an operating system, one or more application programs, other program modules, and program data. Each of the operating system, one or more application programs, other program modules, and program data or some combination thereof, may include an implementation of a networking environment. Program modules 42 generally carry out the functions and/or methodologies of embodiments of the invention as described herein.

[00117] Computer system/server 12 may also communicate with one or more external devices 14 such as a keyboard, a pointing device, a display 24, etc.; one or more devices that enable

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a user to interact with computer system/server 12; and/or any devices (e.g., network card, modem, etc.) that enable computer system/server 12 to communicate with one or more other computing devices. Such communication can occur via Input/output (I/O) interfaces 22. Still yet, computer system/server 12 can communicate with one or more networks such as a local area network (LAN), a general wide area network (WAN), and/or a public network (e.g., the Internet) via network adapter 20. As depicted, network adapter 20 communicates with the other components of computer system/server 12 via bus 18. It should be understood that although not shown, other hardware and/or software components could be used in conjunction with computer system/server 12. Examples, include, but are not limited to: microcode, device drivers, redundant processing units, external disk drive arrays, RAID systems, tape drives, and data archival storage systems, etc.

[00118] Referring now to FIG. 7, illustrative cloud computing environment 50 is depicted. As shown, cloud computing environment 50 comprises one or more cloud computing nodes 10 with which local computing devices used by cloud consumers, such as, for example, personal digital assistant (PDA) or cellular telephone 54A, desktop computer 54B, laptop computer 54C, and/or automobile computer system 54N may communicate. Nodes 10 may communicate with one another. They may be grouped (not shown) physically or virtually, in one or more networks, such as Private, Community, Public, or Hybrid clouds as described hereinabove, or a combination thereof. This allows cloud computing environment 50 to offer infrastructure, platforms and/or software as services for which a cloud consumer does not need to maintain resources on a local computing device. It is understood that the types of computing devices 54A-N shown in FIG. 7 are intended to be illustrative only and that computing nodes 10 and cloud computing environment 50 can communicate with any type of computerized device over any type of network and/or network addressable connection (e.g., using a web browser).

[00119] Referring now to FIG. 8, a set of functional abstraction layers provided by cloud computing environment 50 (FIG. 7) is shown. It should be understood in advance that the components, layers, and functions shown in FIG. 8 are intended to be illustrative only and embodiments of the invention are not limited thereto. As depicted, the following layers and corresponding functions are provided:

[00120] Hardware and software layer 60 includes hardware and software components. Examples of hardware components include: mainframes 61; RISC (Reduced Instruction Set Computer) architecture based servers 62; servers 63; blade servers 64; storage devices 65; and

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networks and networking components 66. In some embodiments, software components include network application server software 67 and database software 68.

[00121] Virtualization layer 70 provides an abstraction layer from which the following examples of virtual entities may be provided: virtual servers 71; virtual storage 72; virtual networks 73, including virtual private networks; virtual applications and operating systems 74; and virtual clients 75.

[00122] In one example, management layer 80 may provide the functions described below. Resource provisioning 81 provides dynamic procurement of computing resources and other resources that are utilized to perform tasks within the cloud computing environment. Metering and Pricing 82 provide cost tracking as resources are utilized within the cloud computing environment, and billing or invoicing for consumption of these resources. In one example, these resources may comprise application software licenses. Security provides identity verification for cloud consumers and tasks, as well as protection for data and other resources. User portal 83 provides access to the cloud computing environment for consumers and system administrators. Service level management 84 provides cloud computing resource allocation and management such that required service levels are met. Service Level Agreement (SLA) planning and fulfillment 85 provide pre-arrangement for, and procurement of, cloud computing resources for which a future requirement is anticipated in accordance with an SLA.

[00123] Workloads layer 90 provides examples of functionality for which the cloud computing environment may be utilized. Examples of workloads and functions which may be provided from this layer include: mapping and navigation 91; software development and lifecycle management 92; virtual classroom education delivery 93; data analytics processing 94; transaction processing 95; and self-driving vehicle control processing 96 (for selectively setting control of an SDV to manual or autonomous mode as described herein).

[00124] The terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting of the present invention. As used herein, the singular forms "a", "an" and "the" are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will be further understood that the terms "comprises" and/or "comprising," when used in this specification, specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of

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one or more other features, integers, steps, operations, elements, components, and/or groups thereof.

[00125] The corresponding structures, materials, acts, and equivalents of all means or step plus function elements in the claims below are intended to include any structure, material, or act for performing the function in combination with other claimed elements as specifically claimed. The description of various embodiments of the present invention has been presented for purposes of illustration and description, but is not intended to be exhaustive or limited to the present invention in the form disclosed. Many modifications and variations will be apparent to those of ordinary skill in the art without departing from the scope and spirit of the present invention. The embodiment was chosen and described in order to best explain the principles of the present invention and the practical application, and to enable others of ordinary skill in the art to understand the present invention for various embodiments with various modifications as are suited to the particular use contemplated.

[00126] Any methods described in the present disclosure may be implemented through the use of a VHDL (VHSIC Hardware Description Language) program and a VHDL chip. VHDL is an exemplary design-entry language for Field Programmable Gate Arrays (FPGAs), Application Specific Integrated Circuits (ASICs), and other similar electronic devices. Thus, any software-implemented method described herein may be emulated by a hardware-based VHDL program, which is then applied to a VHDL chip, such as a FPGA.

[00127] Having thus described embodiments of the present invention of the present application in detail and by reference to illustrative embodiments thereof, it will be apparent that modifications and variations are possible without departing from the scope of the present invention defined in the appended claims.

[00128] While the invention has been described with reference to an exemplary embodiment(s), it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements thereof without departing from the scope of the invention. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the invention without departing from the essential scope thereof. Therefore, it is intended that the invention not be limited to the particular embodiment(s) disclosed, but that the invention will include all embodiments falling within the scope of the appended claims.

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CLAIM:

1. A computer program product for controlling a driving mode of a self-driving vehicle (SDV), the computer program product comprising a non-transitory computer readable storage medium having program code embodied therewith, the program code readable and executable by a processor to perform a method comprising:

receiving sensor readings from a system of sensors, wherein:

the sensor readings describe a current operational state of a SDV, and

the sensor readings comprise a reading selected from the group consisting of a GPS sensor, a physical movement sensor, a speedometer, or air flow meter.

determining based on the sensor readings, by one or more processors, whether a fault has occurred, the fault selected from the group consisting of a software bug, a firmware bug, a hardware bug, or a single-event upset of the roadway on which the SDV is currently traveling;

determining, by the one or more processors, whether the fault exceeds a threshold for danger, comprising determining a control processor competence level;

determining a corrective action associated with the fault using a fault-remediation table; and

the SDV implementing the corrective action, the corrective action comprising transferring driver controls to manual control and alerting a human driver to take over.

2. The computer program product of claim 1, further comprising:

determining the control processor competence level comprises using a weighted voting system, the weighted voting system comprising:

a first plurality of inputs and a first plurality of weights, wherein the first plurality of inputs comprise sensor readings from a first camera sensor; and

multiplying at least one of the first plurality of inputs by a weight from among the first plurality of weights;

wherein the first plurality of weights are based on active learning data; and

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wherein the active learning data comprises software bug data, firmware bug data, hardware bug data, and single-event upset data from a cohort of other SDVs, wherein the active learning data shares one or more traits with the current fault.

3. The computer program product of claim 2, further comprising:

when the fault does not exceed the threshold for danger, the SDV autonomously controls the driver controls, wherein said driver controls comprise: engine throttle, steering mechanism, braking system, and navigation;

the SDV autonomously maintains a buffer of space from other vehicles around the SDV and the SDV autonomously controls the steering of the SDV while autonomously controlling the driver controls, without requiring the human driver to operate the driver controls; and

when the fault exceeds the threshold for danger, the SDV takes the corrective action.

4. The computer program product of claim 3, further comprising:

determining a competence level of a human driver, comprising using the weighted voting system, the weighted voting system further comprising:

a second plurality of inputs and a second plurality of weights, wherein the second plurality of inputs comprise sensor readings from a second camera sensor; and

multiplying at least one of the second plurality of inputs by a weight from among the second plurality of weights;

wherein the second plurality of weights are based on active learning data that comprises information about a cohort of human drivers of other SDVs.

5. The computer program product of claim 1, wherein:

the fault comprises a road condition, wherein the road condition comprises an absence of lane markings;

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determining whether the fault exceeds a threshold for danger comprises determining a control processor competence level;

the corrective action comprises transferring driver controls to manual control and alerting a human driver to take over.

6. The computer program product of claim 1, further comprising:

updating the fault-remediation table from a central server.

7. A self-driving vehicle (SDV) comprising:

a sensor system comprising a plurality of sensors;

vehicle controls comprising: engine throttle, horn, signals, steering mechanism, and braking system; and

a computer system comprising a processor coupled to a non-transitory computer readable storage medium containing program code, the program code readable and executable by a processor, wherein the computer system is capable of:

receiving a sensor reading from the system of sensors, the system of sensors comprising an operational state detector;

operating the vehicle controls;

determining the operational state of the self-driving vehicle (SDV), the operational state of the SDV comprising a first road condition;

determining a vehicle fault, the vehicle fault comprising an anomalous operational state selected from the group consisting of a failure of the antilock breaking system, a failure of an all wheel traction system, or a faulty braking system;

determining a competence level of the processor;

determining competence level of a human driver;

determining a corrective action using the competence level of the processor and the competence level of the human driver, the corrective action comprising querying a database for the proper action to take;

implementing the corrective action; and

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issuing an alert indicating the corrective action.

8. A computer program product for controlling a driving mode of a self-driving vehicle (SDV), the computer program product comprising a non-transitory computer readable storage medium having program code embodied therewith, the program code readable and executable by a processor to perform a method comprising:

determining a competence level of a processor during an operational anomaly;

reviewing a record of effectiveness of the processor based on a performance of similar SDVs in the operational anomaly;

determining a competence level of a human driver during the operational anomaly;

receiving sensor readings from a system of sensors about the competence level of the human driver, wherein the SDV is operable to provide autonomous control of driver controls comprising: engine throttle, horn, signals, steering mechanism, braking system, and navigation;

determining a corrective action; and

the SDV implementing the corrective action.

9. The computer program product of claim 8, wherein:

the sensor readings comprise a reading from a GPS sensor and a speedometer;

determining the competence level of the processor comprises weighted voting;

determining the competence level of the human driver comprises weighted voting;

determining the corrective action comprises using active learning data, said active learning data comprising information from other SDVs; and

the corrective action comprises querying a database for the proper action to take.

10. The computer program product of claim 8, wherein:

the sensor readings comprise a reading from a GPS sensor, an operational state detector, and a reading from a battery-level sensor;

determining the competence level of the processor comprises weighted voting, wherein a sensor reading comprises a weighted voting parameter;

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the weighted voting parameters comprise a number of inputs (N), an input's weight (w), and a quota (q); and

the corrective action comprises the processor controlling the engine throttle.

11. The computer program product of claim 8, further comprising:

determining the competence level of the human driver comprises using a weighted voting system, the weighted voting system comprising:

a plurality of inputs and a plurality of weights, the plurality of inputs comprising sensor readings from a camera sensor; and

multiplying at least one of the plurality of inputs by a weight from among the plurality of weights, and

wherein the plurality of weights are based on active learning data that comprises information about a cohort of human drivers of other SDVs.

12. The computer program product of claim 11, further comprising:

when the competence level of the human driver is above a first threshold, the SDV autonomously controls the driver controls without requiring the human driver to operate the driver controls;

the SDV autonomously maintains a buffer of space from other vehicles around the SDV and the SDV autonomously controls the steering of the SDV while the SDV autonomously controls the driver controls, without requiring the human driver to operate the driver controls;

when the competence level of the human driver is below a second threshold, determining that a first fault has occurred;

determining the corrective action comprises determining a first corrective action corresponding to the first fault; and

the first corrective action comprises issuing an alert while the SDV provides autonomous control of the driver controls without requiring the human driver to operate the driver controls.

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13. The computer program product of claim 12, further comprising:

when the competence level of the human driver is below a third threshold after taking the first corrective action, determining that a second fault has occurred;

determining the corrective action further comprises determining a second corrective action corresponding to the second fault; and

the second corrective action comprises transferring the driver controls to manual control and alerting the human driver to take over.

14. The computer program product of claim 8, further comprising:

determining the competence level of the processor comprises using a weighted voting system, the weighted voting system comprising:

a plurality of inputs and a plurality of weights, wherein the plurality of inputs comprise a record of effectiveness of the processor based on the performance of similar SDVs and an operational state detector ; and

multiplying at least one of the plurality of inputs by a weight from among the plurality of weights;

wherein the plurality of weights are based on active learning data; and

wherein the active learning data comprises ~~condition~~ data from a cohort of other SDVs, wherein the ~~condition~~ data shares one or more traits with the operational anomaly.

15. The computer program product of claim 8, further comprising:

determining the competence level of the human driver comprises using a weighted voting system with a first plurality of inputs and a first plurality of weights, wherein:

the first plurality of inputs comprises sensor readings from a first camera sensor; and

at least one of the first plurality of inputs is multiplied by a weight from among the first plurality of weights, wherein the first plurality of

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weights are based on first active learning data, the first active learning data comprising information about a cohort of human drivers of other SDVs;

determining the competence level of the processor comprises using the weighted voting system with a second plurality of inputs and a second plurality of weights, wherein:

the second plurality of inputs comprises sensor readings from a second camera sensor; and

at least one of the second plurality of inputs is multiplied by a weight from among the second plurality of weights, wherein the second plurality of weights are based on second active learning data, the second active learning data comprising data from a cohort of other SDVs, wherein the data shares one or more traits with the operational anomaly;

the first camera sensor is different from the second camera sensor, the first plurality of inputs is different from the second plurality of inputs, and the first plurality of weights is different from the second plurality of weights;

when the competence level of the human driver is above a first threshold, the SDV autonomously controls the driver controls without requiring the human driver to operate the driver controls;

the SDV autonomously maintains a buffer of space from other vehicles around the SDV and the SDV autonomously controls the steering of the SDV while the SDV autonomously controls the driver controls, without requiring the human driver to operate the driver controls;

when the competence level of the human driver is below a second threshold, determining that a first fault has occurred;

determining the corrective action comprises determining a first corrective action corresponding to the first fault; and

the first corrective action comprises issuing an alert while the SDV autonomously controls the driver controls without requiring the human driver to operate the driver controls.

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16. The computer program product of claim 15, further comprising:

when the competence level of the human driver is below a third threshold, after taking the first corrective action, determining that a second fault has occurred;

determining the corrective action further comprises determining a second corrective action corresponding to the second fault; and

the second corrective action comprises transferring driver controls to manual control and alerting the human driver to take over.

17. The computer program product of claim 16, further comprising:

when the competence level of the processor is below a fourth threshold, determining that a third fault has occurred;

determining the corrective action further comprises determining a third corrective action corresponding to the third fault;

determining the corrective action further comprises using a fault remediation table; and

the fault remediation table comprises the first fault, the second fault, and the third fault.

18. The computer program product of claim 17, further comprising:

updating the fault-remediation table from a central server.

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CONTROLLING DRIVING MODES OF SELF-DRIVING VEHICLES

ABSTRACT

A computer-implemented method, system, and/or computer program product controls a driving mode of a self-driving vehicle (SDV). One or more processors compare a control processor competence level of an on-board SDV control processor in controlling the SDV to a human driver competence level of a human driver in controlling the SDV while the SDV encounters a current roadway condition which is a result of current weather conditions of the roadway on which the SDV is currently traveling. One or more processors then selectively assign control of the SDV to the SDV control processor or to the human driver while the SDV encounters the current roadway condition based on which of the control processor competence level and the human driver competence level is relatively higher to one another.

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Electronic Patent Application Fee Transmittal

Application Number:	
Filing Date:	
Title of Invention:	CONTROLLING DRIVING MODES OF SELF-DRIVING VEHICLES
First Named Inventor/Applicant Name:	Michael S. Gordon
Filer:	Ian David MacKinnon/Nicole Chambers
Attorney Docket Number:	S0974-P08818US08

Filed as Large Entity

Filing Fees for Utility under 35 USC 111(a)

Description	Fee Code	Quantity	Amount	Sub-Total in USD($)
Basic Filing:				
UTILITY APPLICATION FILING	1011	1	320	320
UTILITY SEARCH FEE	1111	1	700	700
UTILITY EXAMINATION FEE	1311	1	800	800
Pages:				
Claims:				
Miscellaneous-Filing:				
Petition:				
Patent-Appeals-and-Interference:				

Description	Fee Code	Quantity	Amount	Sub-Total in USD($)
Post-Allowance-and-Post-Issuance:				
Extension-of-Time:				
Miscellaneous:				
			Total in USD ($)	**1820**

Electronic Acknowledgement Receipt

EFS ID:	48306063
Application Number:	18222774
International Application Number:	
Confirmation Number:	9586
Title of Invention:	CONTROLLING DRIVING MODES OF SELF-DRIVING VEHICLES
First Named Inventor/Applicant Name:	Michael S. Gordon
Customer Number:	164
Filer:	Ian David MacKinnon
Filer Authorized By:	
Attorney Docket Number:	S0974-P08818US08
Receipt Date:	17-JUL-2023
Filing Date:	
Time Stamp:	16:20:19
Application Type:	Utility under 35 USC 111(a)

Payment information:

Submitted with Payment	yes
Payment Type	DA
Payment was successfully received in RAM	$1820
RAM confirmation Number	E20237GG21365720
Deposit Account	110982
Authorized User	Ian MacKinnon

The Director of the USPTO is hereby authorized to charge indicated fees and credit any overpayment as follows:

37 CFR 1.16 (National application filing, search, and examination fees)

37 CFR 1.17 (Patent application and reexamination processing fees)

37 CFR 1.19 (Document supply fees)

37 CFR 1.20 (Post Issuance fees)

37 CFR 1.21 (Miscellaneous fees and charges)

File Listing:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
1	Application Data Sheet	2023-07-17_ADS_S0974-P08818US08.pdf	1256768 bc9ada4b9508a9ecfe5c92300ea211237e79eb23	no	10
Warnings:					
Information:					
2	Oath or Declaration filed	2023-07-17_DEC_S0974-P08818US08.pdf	741647 d5b606fb6d1bd14d59fb4e4ecc52e6be491971de	no	15
Warnings:					
Information:					
3	Drawings-only black and white line drawings	2023-07-17_DWGS_S0974-P08818US08.pdf	137104 1aa9129d118b73ad838ae8f8d27865142ae8e7e9	no	8
Warnings:					
Information:					
4	Information Disclosure Statement (IDS) Form (SB08)	2023-07-17_IDS_S0974-P08818US08_1.pdf	1044494 883e7fc7f3985e3d94b31c9d851b8c1654689ece	no	33
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5	Power of Attorney	2023-07-17_POA_S0974-P08818US08.pdf	286913 c356be3ccdaa0546cc17fd35b029c5a4e7722f3b	no	2
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6	Non Patent Literature	NPL_acrashriskassesmentmodel-chen_et_al.pdf	677889 3d9932fca324331d46e1712ea4f53f7eb0d24a5a	no	8
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7	Non Patent Literature	NPL_Airlinesinfusetheirplanes-Farrier.pdf	176294 f5be09b7e424001c5c74711cb5251545de91e1c7	no	1
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8	Non Patent Literature	NPL_anon-GooglePtnt.pdf	682552 5e389f26bf41bd9dd08fb92b900900c17c1ec82b	no	8
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9	Non Patent Literature	NPL_Avoiding_Crashes_with_Self-Driving_Cars_Consumer_Reports.pdf	480565 ede10f449793637f02096d54fab2798e191687ce	no	5
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16	Non Patent Literature	NPL_googlenowreporting-selfdrivingcaraccidents-heyitsnotthecarsfault-Crothers.pdf	619214 ebe09f5b20c38c7a55ee622d054e260314b0f9ec	no	6
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21	Non Patent Literature	NPL_Jimenez-ACASVS.pdf	1318775 dae1aee66fa792b15797076117bce97855ecab19	no	14
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23	Non Patent Literature	NPL_Iettherobotdrive-Vanderbilt.pdf	1705218 7591adb87c2efd2390bfc5b2b798b95216ababe5	no	34
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27	Non Patent Literature	NPL_selfdrivingcarssaferthanthosebyhumans-Lutz.pdf	46171 b2d21235eda0a6f326933dbfa17135bed2e58525	no	1
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35	Non Patent Literature	NPL_theinsuranceimplicationsofgooglesselfdrivingcar.pdf	120458 697f95c22ae657149d64fae875d6ca0a4e2081c4	no	2
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37		2023-07-17_CONT_APP_S0974-P08818US08.pdf	192475 3377f779bcbfec5f45be3a4fecd68bdc691d94e3	yes	38

Multipart Description/PDF files in .zip description

Document Description	Start	End
Specification	1	29
Claims	30	37
Abstract	38	38

Warnings:					
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38	Fee Worksheet (SB06)	fee-info.pdf	44101 821a6633e9d716d8a3512de0264d6c8d7324115e	no	2
Warnings:					
Information:					
			Total Files Size (in bytes):	47373445	

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New Applications Under 35 U.S.C. 111

If a new application is being filed and the application includes the necessary components for a filing date (see 37 CFR 1.53(b)-(d) and MPEP 506), a Filing Receipt (37 CFR 1.54) will be issued in due course and the date shown on this Acknowledgement Receipt will establish the filing date of the application.

National Stage of an International Application under 35 U.S.C. 371

If a timely submission to enter the national stage of an international application is compliant with the conditions of 35 U.S.C. 371 and other applicable requirements a Form PCT/DO/EO/903 indicating acceptance of the application as a national stage submission under 35 U.S.C. 371 will be issued in addition to the Filing Receipt, in due course.

New International Application Filed with the USPTO as a Receiving Office

If a new international application is being filed and the international application includes the necessary components for an international filing date (see PCT Article 11 and MPEP 1810), a Notification of the International Application Number and of the International Filing Date (Form PCT/RO/105) will be issued in due course, subject to prescriptions concerning national security, and the date shown on this Acknowledgement Receipt will establish the international filing date of the application.

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Application Data Sheet 37 CFR 1.76	Attorney Docket Number	S0974-P08818US08
	Application Number	
Title of Invention	CONTROLLING DRIVING MODES OF SELF-DRIVING VEHICLES	

The application data sheet is part of the provisional or nonprovisional application for which it is being submitted. The following form contains the bibliographic data arranged in a format specified by the United States Patent and Trademark Office as outlined in 37 CFR 1.76.
This document may be completed electronically and submitted to the Office in electronic format using the Electronic Filing System (EFS) or the document may be printed and included in a paper filed application.

Secrecy Order 37 CFR 5.2:

☐ Portions or all of the application associated with this Application Data Sheet may fall under a Secrecy Order pursuant to 37 CFR 5.2 (Paper filers only. Applications that fall under Secrecy Order may not be filed electronically.)

Inventor Information:

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Residence Information (Select One) ◉ US Residency Non US Residency Active US Military Service

IPR2025-01034
Tesla EX1002 Page 2869

Application Data Sheet 37 CFR 1.76	Attorney Docket Number	S0974-P08818US08
	Application Number	
Title of Invention	CONTROLLING DRIVING MODES OF SELF-DRIVING VEHICLES	

City	New York	State/Province	NY	Country of Residence	US

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City	Yorktown Heights	State/Province	NY
Postal Code	10598	Country	US

All Inventors Must Be Listed - Additional Inventor Information blocks may be generated within this form by selecting the **Add** button. — Add

Correspondence Information:

Enter either Customer Number or complete the Correspondence Information section below.
For further information see 37 CFR 1.33(a).

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Application Data Sheet 37 CFR 1.76	Attorney Docket Number	S0974-P08818US08
	Application Number	
Title of Invention	CONTROLLING DRIVING MODES OF SELF-DRIVING VEHICLES	

Customer Number	164		
Email Address	uspatdocket@kinney.com	Add Email	Remove Email

Application Information:

Title of the Invention	CONTROLLING DRIVING MODES OF SELF-DRIVING VEHICLES		
Attorney Docket Number	S0974-P08818US08	**Small Entity Status Claimed**	☐
Application Type	Nonprovisional		
Subject Matter	Utility		
Total Number of Drawing Sheets (if any)	8	**Suggested Figure for Publication (if any)**	

Filing By Reference:

Only complete this section when filing an application by reference under 35 U.S.C. 111(c) and 37 CFR 1.57(a). Do not complete this section if application papers including a specification and any drawings are being filed. Any domestic benefit or foreign priority information must be provided in the appropriate section(s) below (i.e., "Domestic Benefit/National Stage Information" and "Foreign Priority Information").

For the purposes of a filing date under 37 CFR 1.53(b), the description and any drawings of the present application are replaced by this reference to the previously filed application, subject to conditions and requirements of 37 CFR 1.57(a).

Application number of the previously filed application	Filing date (YYYY-MM-DD)	Intellectual Property Authority or Country

Publication Information:

☐ Request Early Publication (Fee required at time of Request 37 CFR 1.219)

☐ **Request Not to Publish.** I hereby request that the attached application not be published under 35 U.S.C. 122(b) and certify that the invention disclosed in the attached application **has not and will not** be the subject of an application filed in another country, or under a multilateral international agreement, that requires publication at eighteen months after filing.

Representative Information:

Representative information should be provided for all practitioners having a power of attorney in the application. Providing this information in the Application Data Sheet does not constitute a power of attorney in the application (see 37 CFR 1.32).
Either enter Customer Number or complete the Representative Name section below. If both sections are completed the customer Number will be used for the Representative Information during processing.

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Customer Number	164		

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Application Data Sheet 37 CFR 1.76	Attorney Docket Number	S0974-P08818US08
	Application Number	
Title of Invention	CONTROLLING DRIVING MODES OF SELF-DRIVING VEHICLES	

Domestic Benefit/National Stage Information:

This section allows for the applicant to either claim benefit under 35 U.S.C. 119(e), 120, 121, 365(c), or 386(c) or indicate National Stage entry from a PCT application. Providing benefit claim information in the Application Data Sheet constitutes the specific reference required by 35 U.S.C. 119(e) or 120, and 37 CFR 1.78.
When referring to the current application, please leave the "Application Number" field blank.

Prior Application Status	Pending			Remove
Application Number	Continuity Type	Prior Application Number	Filing or 371(c) Date (YYYY-MM-DD)	
	Continuation of	17374656	2021-07-13	

Prior Application Status	Patented			Remove
Application Number	Continuity Type	Prior Application Number	Filing or 371(c) Date (YYYY-MM-DD)	
17374656	Continuation of	16997202	2020-08-19	

Prior Application Status	Abandoned			Remove
Application Number	Continuity Type	Prior Application Number	Filing or 371(c) Date (YYYY-MM-DD)	
16997202	Continuation of	16899407	2020-06-11	

Prior Application Status	Patented			Remove
Application Number	Continuity Type	Prior Application Number	Filing or 371(c) Date (YYYY-MM-DD)	
16997202	Continuation of	15955874	2018-04-18	

Prior Application Status	Patented			Remove
Application Number	Continuity Type	Prior Application Number	Filing or 371(c) Date (YYYY-MM-DD)	
15955874	Continuation of	15341225	2016-11-02	

Prior Application Status	Patented			Remove
Application Number	Continuity Type	Prior Application Number	Filing or 371(c) Date (YYYY-MM-DD)	
15341225	Continuation of	14865393	2015-09-25	

Application Number	Continuity Type	Prior Application Number	Filing Date (YYYY-MM-DD)	Patent Number	Issue Date (YYYY-MM-DD)
17374656	Continuation of	16997202	2020-08-19	11091171	2021-08-17
16997202	Continuation of	15955874	2018-04-18	10717446	2020-07-21
15955874	Continuation of	15341225	2016-11-02	10029701	2018-07-24
15341225	Continuation of	14865393	2015-09-25	9566986	2017-02-14

Additional Domestic Benefit/National Stage Data may be generated within this form by selecting the **Add** button. Add

Foreign Priority Information:

Application Data Sheet 37 CFR 1.76	Attorney Docket Number	S0974-P08818US08
	Application Number	
Title of Invention	CONTROLLING DRIVING MODES OF SELF-DRIVING VEHICLES	

This section allows for the applicant to claim priority to a foreign application. Providing this information in the application data sheet constitutes the claim for priority as required by 35 U.S.C. 119(b) and 37 CFR 1.55. When priority is claimed to a foreign application that is eligible for retrieval under the priority document exchange program (PDX)[i] the information will be used by the Office to automatically attempt retrieval pursuant to 37 CFR 1.55(i)(1) and (2). Under the PDX program, applicant bears the ultimate responsibility for ensuring that a copy of the foreign application is received by the Office from the participating foreign intellectual property office, or a certified copy of the foreign priority application is filed, within the time period specified in 37 CFR 1.55(g)(1).

Remove

Application Number	Country[i]	Filing Date (YYYY-MM-DD)	Access Code[i] (if applicable)

Additional Foreign Priority Data may be generated within this form by selecting the **Add** button. Add

Statement under 37 CFR 1.55 or 1.78 for AIA (First Inventor to File) Transition Applications

☐ This application (1) claims priority to or the benefit of an application filed before March 16, 2013 and (2) also contains, or contained at any time, a claim to a claimed invention that has an effective filing date on or after March 16, 2013.
NOTE: By providing this statement under 37 CFR 1.55 or 1.78, this application, with a filing date on or after March 16, 2013, will be examined under the first inventor to file provisions of the AIA.

Application Data Sheet 37 CFR 1.76	Attorney Docket Number	S0974-P08818US08
	Application Number	
Title of Invention	CONTROLLING DRIVING MODES OF SELF-DRIVING VEHICLES	

Authorization or Opt-Out of Authorization to Permit Access:

When this Application Data Sheet is properly signed and filed with the application, applicant has provided written authority to permit a participating foreign intellectual property (IP) office access to the instant application-as-filed (see paragraph A in subsection 1 below) and the European Patent Office (EPO) access to any search results from the instant application (see paragraph B in subsection 1 below).

Should applicant choose not to provide an authorization identified in subsection 1 below, applicant **must opt-out** of the authorization by checking the corresponding box A or B or both in subsection 2 below.

NOTE: This section of the Application Data Sheet is **ONLY** reviewed and processed with the **INITIAL** filing of an application. After the initial filing of an application, an Application Data Sheet cannot be used to provide or rescind authorization for access by a foreign IP office(s). Instead, Form PTO/SB/39 or PTO/SB/69 must be used as appropriate.

1. Authorization to Permit Access by a Foreign Intellectual Property Office(s)

A. Priority Document Exchange (PDX) - Unless box A in subsection 2 (opt-out of authorization) is checked, the undersigned hereby **grants the USPTO authority** to provide the European Patent Office (EPO), the Japan Patent Office (JPO), the Korean Intellectual Property Office (KIPO), the State Intellectual Property Office of the People's Republic of China (SIPO), the World Intellectual Property Organization (WIPO), and any other foreign intellectual property office participating with the USPTO in a bilateral or multilateral priority document exchange agreement in which a foreign application claiming priority to the instant patent application is filed, access to: (1) the instant patent application-as-filed and its related bibliographic data, (2) any foreign or domestic application to which priority or benefit is claimed by the instant application and its related bibliographic data, and (3) the date of filing of this Authorization. See 37 CFR 1.14(h)(1).

B. Search Results from U.S. Application to EPO - Unless box B in subsection 2 (opt-out of authorization) is checked, the undersigned hereby **grants the USPTO authority** to provide the EPO access to the bibliographic data and search results from the instant patent application when a European patent application claiming priority to the instant patent application is filed. See 37 CFR 1.14(h)(2).

The applicant is reminded that the EPO's Rule 141(1) EPC (European Patent Convention) requires applicants to submit a copy of search results from the instant application without delay in a European patent application that claims priority to the instant application.

2. Opt-Out of Authorizations to Permit Access by a Foreign Intellectual Property Office(s)

☐ A. Applicant **DOES NOT** authorize the USPTO to permit a participating foreign IP office access to the instant application-as-filed. If this box is checked, the USPTO will not be providing a participating foreign IP office with any documents and information identified in subsection 1A above.

☐ B. Applicant **DOES NOT** authorize the USPTO to transmit to the EPO any search results from the instant patent application. If this box is checked, the USPTO will not be providing the EPO with search results from the instant application.

NOTE: Once the application has published or is otherwise publicly available, the USPTO may provide access to the application in accordance with 37 CFR 1.14.

PTO/AIA/14 (02-18)
Approved for use through 11/30/2020. OMB 0651-0032
U.S. Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE
Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it contains a valid OMB control number.

Application Data Sheet 37 CFR 1.76	Attorney Docket Number	S0974-P08818US08
	Application Number	
Title of Invention	CONTROLLING DRIVING MODES OF SELF-DRIVING VEHICLES	

Applicant Information:

Providing assignment information in this section does not substitute for compliance with any requirement of part 3 of Title 37 of CFR to have an assignment recorded by the Office.

Applicant 1 — Remove

If the applicant is the inventor (or the remaining joint inventor or inventors under 37 CFR 1.45), this section should not be completed. The information to be provided in this section is the name and address of the legal representative who is the applicant under 37 CFR 1.43; or the name and address of the assignee, person to whom the inventor is under an obligation to assign the invention, or person who otherwise shows sufficient proprietary interest in the matter who is the applicant under 37 CFR 1.46. If the applicant is an applicant under 37 CFR 1.46 (assignee, person to whom the inventor is obligated to assign, or person who otherwise shows sufficient proprietary interest) together with one or more joint inventors, then the joint inventor or inventors who are also the applicant should be identified in this section.

Clear

● Assignee	Legal Representative under 35 U.S.C. 117	Joint Inventor
Person to whom the inventor is obligated to assign.	Person who shows sufficient proprietary interest	

If applicant is the legal representative, indicate the authority to file the patent application, the inventor is:

Name of the Deceased or Legally Incapacitated Inventor:

If the Applicant is an Organization check here. ☒

Organization Name	Slingshot IOT LLC		
Mailing Address Information For Applicant:			
Address 1	301 South Fremont Avenue		
Address 2			
City	Baltimore	**State/Province**	MD
Country	US	Postal Code	21230
Phone Number		Fax Number	
Email Address			

Additional Applicant Data may be generated within this form by selecting the Add button. Add

Assignee Information including Non-Applicant Assignee Information:

Providing assignment information in this section does not substitute for compliance with any requirement of part 3 of Title 37 of CFR to have an assignment recorded by the Office.

PTO/AIA/14 (02-18)
Approved for use through 11/30/2020. OMB 0651-0032
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Application Data Sheet 37 CFR 1.76	Attorney Docket Number	S0974-P08818US08
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Title of Invention	CONTROLLING DRIVING MODES OF SELF-DRIVING VEHICLES	

Assignee 1

Complete this section if assignee information, including non-applicant assignee information, is desired to be included on the patent application publication. An assignee-applicant identified in the "Applicant Information" section will appear on the patent application publication as an applicant. For an assignee-applicant, complete this section only if identification as an assignee is also desired on the patent application publication.

Remove

If the Assignee or Non-Applicant Assignee is an Organization check here. ☐

Prefix	**Given Name**	Middle Name	**Family Name**	Suffix

Mailing Address Information For Assignee including Non-Applicant Assignee:

Address 1			
Address 2			
City		**State/Province**	
Country i		Postal Code	
Phone Number		Fax Number	
Email Address			

Additional Assignee or Non-Applicant Assignee Data may be generated within this form by selecting the Add button. Add

Signature:

Remove

NOTE: This Application Data Sheet must be signed in accordance with 37 CFR 1.33(b). **However, if this Application Data Sheet is submitted with the INITIAL filing of the application and either box A or B is not checked in subsection 2 of the "Authorization or Opt-Out of Authorization to Permit Access" section, then this form must also be signed in accordance with 37 CFR 1.14(c).**

This Application Data Sheet **must** be signed by a patent practitioner if one or more of the applicants is a **juristic entity** (e.g., corporation or association). If the applicant is two or more joint inventors, this form must be signed by a patent practitioner, **all** joint inventors who are the applicant, or one or more joint inventor-applicants who have been given power of attorney (e.g., see USPTO Form PTO/AIA/81) on behalf of **all** joint inventor-applicants.

See 37 CFR 1.4(d) for the manner of making signatures and certifications.

Signature	/Ian D. MacKinnon/			Date (YYYY-MM-DD)	2023-07-17
First Name	Ian D.	Last Name	MacKinnon	Registration Number	34,660

Additional Signature may be generated within this form by selecting the Add button. Add

PTO/AIA/14 (02-18)
Approved for use through 11/30/2020. OMB 0651-0032
U.S. Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE
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Application Data Sheet 37 CFR 1.76	Attorney Docket Number	S0974-P08818US08
	Application Number	
Title of Invention	CONTROLLING DRIVING MODES OF SELF-DRIVING VEHICLES	

This collection of information is required by 37 CFR 1.76. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.14. This collection is estimated to take 23 minutes to complete, including gathering, preparing, and submitting the completed application data sheet form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. **SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.**

Privacy Act Statement

The Privacy Act of 1974 (P.L. 93-579) requires that you be given certain information in connection with your submission of the attached form related to a patent application or patent. Accordingly, pursuant to the requirements of the Act, please be advised that: (1) the general authority for the collection of this information is 35 U.S.C. 2(b)(2); (2) furnishing of the information solicited is voluntary; and (3) the principal purpose for which the information is used by the U.S. Patent and Trademark Office is to process and/or examine your submission related to a patent application or patent. If you do not furnish the requested information, the U.S. Patent and Trademark Office may not be able to process and/or examine your submission, which may result in termination of proceedings or abandonment of the application or expiration of the patent.

The information provided by you in this form will be subject to the following routine uses:

1 The information on this form will be treated confidentially to the extent allowed under the Freedom of Information Act (5 U.S.C. 552) and the Privacy Act (5 U.S.C. 552a). Records from this system of records may be disclosed to the Department of Justice to determine whether the Freedom of Information Act requires disclosure of these records.

2. A record from this system of records may be disclosed, as a routine use, in the course of presenting evidence to a court, magistrate, or administrative tribunal, including disclosures to opposing counsel in the course of settlement negotiations.

3 A record in this system of records may be disclosed, as a routine use, to a Member of Congress submitting a request involving an individual, to whom the record pertains, when the individual has requested assistance from the Member with respect to the subject matter of the record.

4. A record in this system of records may be disclosed, as a routine use, to a contractor of the Agency having need for the information in order to perform a contract. Recipients of information shall be required to comply with the requirements of the Privacy Act of 1974, as amended, pursuant to 5 U.S.C. 552a(m).

5. A record related to an International Application filed under the Patent Cooperation Treaty in this system of records may be disclosed, as a routine use, to the International Bureau of the World Intellectual Property Organization, pursuant to the Patent CooperationTreaty.

6. A record in this system of records may be disclosed, as a routine use, to another federal agency for purposes of National Security review (35 U.S.C. 181) and for review pursuant to the Atomic Energy Act (42 U.S.C. 218(c)).

7. A record from this system of records may be disclosed, as a routine use, to the Administrator, General Services, or his/her designee, during an inspection of records conducted by GSA as part of that agency's responsibility to recommend improvements in records management practices and programs, under authority of 44 U.S.C. 2904 and 2906. Such disclosure shall be made in accordance with the GSA regulations governing inspection of records for this purpose, and any other relevant (i.e., GSA or Commerce) directive. Such disclosure shall not be used to make determinations about individuals.

8. A record from this system of records may be disclosed, as a routine use, to the public after either publication of the application pursuant to 35 U.S.C. 122(b) or issuance of a patent pursuant to 35 U.S.C. 151. Further, a record may be disclosed, subject to the limitations of 37 CFR 1.14, as a routine use, to the public if the record was filed in an application which became abandoned or in which the proceedings were terminated and which application is referenced by either a published application, an application open to public inspections or an issued patent.

9. A record from this system of records may be disclosed, as a routine use, to a Federal, State, or local law enforcement agency, if the USPTO becomes aware of a violation or potential violation of law or regulation.

IBM DOCKET NUMBER: **YOR920150507US1**

DECLARATION (37 C.F.R. 1.63) FOR UTILITY PATENT APPLICATION USING AN APPLICATION DATA SHEET (37 C.F.R. 1.76) AND ASSIGNMENT

Title of Invention: **CONTROLLING DRIVING MODES OF SELF-DRIVING VEHICLES**

As a below named and undersigned inventor, I hereby declare that:

This declaration is directed to the attached application, or (if following box is checked):

[x] United States application or PCT international application number 14/865,393
filed on September 25, 2015.

The above-identified application was made or authorized to be made by me.

I believe that I am the original inventor or an original joint inventor of a claimed invention in the application.

I have reviewed and understand the contents of the application, including the claims.

I am aware of the duty to disclose to the United States Patent and Trademark Office all information known to me to be material to patentability as defined in 37 CFR Section 1.56.

Whereas, I ("ASSIGNOR") have made certain inventions, improvements, and discoveries (herein referred to as the "Invention") disclosed in the above-identified patent application and further identified by the IBM Docket Number provided above in the header of this document;

Whereas, International Business Machines Corporation (herein referred to as the "ASSIGNEE"), a corporation of New York having a place of business at Armonk, New York, desires to acquire, and I desire to grant to the ASSIGNEE, my entire worldwide right, title, and interest in and to the Invention and in and to any and all patent applications and patents directed thereto;

Now, therefore, for good and valuable consideration, the receipt and sufficiency thereof being hereby acknowledged, I hereby sell or have sold, assign or have assigned, and otherwise transfer or have transferred to the ASSIGNEE, its successors, legal representatives, and assigns, my entire worldwide right, title, and interest in and to the Invention, the above-identified United States patent application, and any and all other patent applications and patents for the invention which may be applied for or granted therefor in the United States and in all foreign countries and jurisdictions, including all divisions, continuations, reissues, reexaminations, renewals, extensions, counterparts, substitutes, and extensions thereof, and all rights of priority resulting from the filing of such applications and granting of such patents. In addition, I hereby authorize and request the Director of the United States Patent and Trademark Office to issue any United States Patent, and foreign patent authorities to issue any foreign patent, granted for the Invention, to the ASSIGNEE, its successors, legal representatives, and assigns, my entire worldwide right, title, and interest in and to the same to be held and enjoyed by the ASSIGNEE, its successors, legal representatives, and assigns to the full end of the terms for which any and all such patents may be granted, as fully and entirely as would have been held and enjoyed by me had this Assignment not been made; and I agree to execute any and all documents and instruments and perform all lawful acts reasonably related to recording this Assignment or perfecting title to the Invention and all related patents and applications, in the ASSIGNEE, its successors, legal representatives, and assigns, whenever requested by the ASSIGNEE, its successors, legal representatives, or assigns.

IPR2025-01034
Tesla EX1002 Page 2879

I acknowledge my prior and ongoing obligations to sell, assign, and transfer my rights under this Assignment to the ASSIGNEE and am unaware of any reason why I may not have the full and unencumbered right to sell, assign, and transfer my rights hereby sold, assigned, and transferred, and have not executed, and will not execute, any document or instrument in conflict herewith. I also hereby grant the ASSIGNEE, its successors, legal representatives, and assigns, the right to insert in this Assignment any further identification (including, but not limited to, patent Application Number) which may be necessary or desirable for recordation of this Assignment. This Assignment is governed by the substantive laws of the State of New York, and any disputes will be resolved in a New York state court or federal court sited in New York.

I hereby acknowledge that any willful false statement made in this declaration is punishable under 18 U.S.C. 1001 by fine or imprisonment of not more than five (5) years, or both.

(1) Legal Name of Inventor: **MICHAEL S. GORDON**

Signature: _____ Date: 9/10/15

(2) Legal Name of Inventor: **JAMES R. KOZLOSKI**

Signature: _____ Date: _____

(3) Legal Name of Inventor: **ASHISH KUNDU**

Signature: _____ Date: _____

(4) Legal Name of Inventor: **PETER K. MALKIN**

Signature: _____ Date: _____

IPR2025-01034
Tesla EX1002 Page 2880

(5) Legal Name of Inventor: **CLIFFORD A. PICKOVER**

Signature:_____ Date:_____

IPR2025-01034
Tesla EX1002 Page 2881

IBM DOCKET NUMBER: **YOR920150507US1**

DECLARATION (37 C.F.R. 1.63) FOR UTILITY PATENT APPLICATION USING AN APPLICATION DATA SHEET (37 C.F.R. 1.76) AND ASSIGNMENT

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Now, therefore, for good and valuable consideration, the receipt and sufficiency thereof being hereby acknowledged, I hereby sell or have sold, assign or have assigned, and otherwise transfer or have transferred to the ASSIGNEE, its successors, legal representatives, and assigns, my entire worldwide right, title, and interest in and to the Invention, the above-identified United States patent application, and any and all other patent applications and patents for the Invention which may be applied for or granted therefor in the United States and in all foreign countries and jurisdictions, including all divisions, continuations, reissues, reexaminations, renewals, extensions, counterparts, substitutes, and extensions thereof, and all rights of priority resulting from the filing of such applications and granting of such patents. In addition, I hereby authorize and request the Director of the United States Patent and Trademark Office to issue any United States Patent, and foreign patent authorities to issue any foreign patent, granted for the Invention, to the ASSIGNEE, its successors, legal representatives, and assigns, my entire worldwide right, title, and interest in and to the same to be held and enjoyed by the ASSIGNEE, its successors, legal representatives, and assigns to the full end of the terms for which any and all such patents may be granted, as fully and entirely as would have been held and enjoyed by me had this Assignment not been made; and I agree to execute any and all documents and instruments and perform all lawful acts reasonably related to recording this Assignment or perfecting title to the Invention and all related patents and applications, in the ASSIGNEE, its successors, legal representatives, and assigns, whenever requested by the ASSIGNEE, its successors, legal representatives, or assigns.

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Tesla EX1002 Page 2882

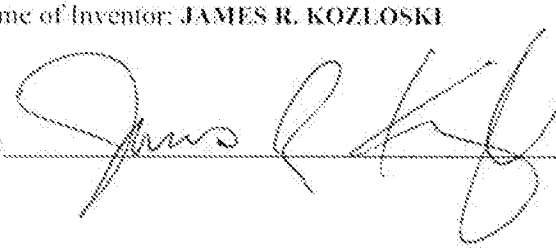
I acknowledge my prior and ongoing obligations to sell, assign, and transfer my rights under this Assignment to the ASSIGNEE and am unaware of any reason why I may not have the full and unencumbered right to sell, assign, and transfer my rights hereby sold, assigned, and transferred, and have not executed, and will not execute, any document or instrument in conflict herewith. I also hereby grant the ASSIGNEE, its successors, legal representatives, and assigns, the right to insert in this Assignment any further identification (including, but not limited to, patent Application Number) which may be necessary or desirable for recordation of this Assignment. This Assignment is governed by the substantive laws of the State of New York, and any disputes will be resolved in a New York state court or federal court sited in New York.

I hereby acknowledge that any willful false statement made in this declaration is punishable under 18 U.S.C. 1001 by fine or imprisonment of not more than five (5) years, or both.

(1) Legal Name of Inventor: **MICHAEL S. GORDON**

Signature:_____ Date:_____

(2) Legal Name of Inventor: **JAMES R. KOZLOSKI**

Signature:  Date: 9/04/15

(3) Legal Name of Inventor: **ASHISH KUNDU**

Signature:_____ Date:_____

(4) Legal Name of Inventor: **PETER K. MALKIN**

Signature:_____ Date:_____

IPR2025-01034
Tesla EX1002 Page 2883

(5) Legal Name of Inventor: **CLIFFORD A. PICKOVER**

Signature:_____ Date:_____

IPR2025-01034
Tesla EX1002 Page 2884

IBM DOCKET NUMBER: **YOR920150507US1**

DECLARATION (37 C.F.R. 1.63) FOR UTILITY PATENT APPLICATION USING AN APPLICATION DATA SHEET (37 C.F.R. 1.76) AND ASSIGNMENT

Title of Invention: **CONTROLLING DRIVING MODES OF SELF-DRIVING VEHICLES**

As a below named and undersigned inventor, I hereby declare that:

This declaration is directed to the attached application, or (if following box is checked):

[X] United States application or PCT international application number 14/865,393 filed on September 25, 2015.

The above-identified application was made or authorized to be made by me.

I believe that I am the original inventor or an original joint inventor of a claimed invention in the application.

I have reviewed and understand the contents of the application, including the claims.

I am aware of the duty to disclose to the United States Patent and Trademark Office all information known to me to be material to patentability as defined in 37 CFR Section 1.56.

Whereas, I ("ASSIGNOR") have made certain inventions, improvements, and discoveries (herein referred to as the "Invention") disclosed in the above-identified patent application and further identified by the IBM Docket Number provided above in the header of this document;

Whereas, International Business Machines Corporation (herein referred to as the "ASSIGNEE"), a corporation of New York having a place of business at Armonk, New York, desires to acquire, and I desire to grant to the ASSIGNEE, my entire worldwide right, title, and interest in and to the Invention and in and to any and all patent applications and patents directed thereto;

Now, therefore, for good and valuable consideration, the receipt and sufficiency thereof being hereby acknowledged, I hereby sell or have sold, assign or have assigned, and otherwise transfer or have transferred to the ASSIGNEE, its successors, legal representatives, and assigns, my entire worldwide right, title, and interest in and to the Invention, the above-identified United States patent application, and any and all other patent applications and patents for the Invention which may be applied for or granted therefor in the United States and in all foreign countries and jurisdictions, including all divisions, continuations, reissues, reexaminations, renewals, extensions, counterparts, substitutes, and extensions thereof, and all rights of priority resulting from the filing of such applications and granting of such patents. In addition, I hereby authorize and request the Director of the United States Patent and Trademark Office to issue any United States Patent, and foreign patent authorities to issue any foreign patent, granted for the Invention, to the ASSIGNEE, its successors, legal representatives, and assigns, my entire worldwide right, title, and interest in and to the same to be held and enjoyed by the ASSIGNEE, its successors, legal representatives, and assigns to the full end of the terms for which any and all such patents may be granted, as fully and entirely as would have been held and enjoyed by me had this Assignment not been made; and I agree to execute any and all documents and instruments and perform all lawful acts reasonably related to recording this Assignment or perfecting title to the Invention and all related patents and applications, in the ASSIGNEE, its successors, legal representatives, and assigns, whenever requested by the ASSIGNEE, its successors, legal representatives, or assigns.

IPR2025-01034
Tesla EX1002 Page 2885

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(1) Legal Name of Inventor: **MICHAEL S. GORDON**

Signature:_____ Date:_____

(2) Legal Name of Inventor: **JAMES R. KOZLOSKI**

Signature:_____ Date:_____

(3) Legal Name of Inventor: **ASHISH KUNDU**

Signature: Ashish Kundu Date: 09/10/2015

(4) Legal Name of Inventor: **PETER K. MALKIN**

Signature:_____ Date:_____

IPR2025-01034
Tesla EX1002 Page 2886

(5) Legal Name of Inventor: **CLIFFORD A. PICKOVER**

Signature:_____ Date:_____

IPR2025-01034
Tesla EX1002 Page 2887

DECLARATION (37 C.F.R. 1.63) FOR UTILITY PATENT APPLICATION USING AN APPLICATION DATA SHEET (37 C.F.R. 1.76) AND ASSIGNMENT

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Whereas, I ("ASSIGNOR") have made certain inventions, improvements, and discoveries (herein referred to as the "Invention") disclosed in the above-identified patent application and further identified by the IBM Docket Number provided above in the header of this document;

Whereas, International Business Machines Corporation (herein referred to as the "ASSIGNEE"), a corporation of New York having a place of business at Armonk, New York, desires to acquire, and I desire to grant to the ASSIGNEE, my entire worldwide right, title, and interest in and to the Invention and in and to any and all patent applications and patents directed thereto;

Now, therefore, for good and valuable consideration, the receipt and sufficiency thereof being hereby acknowledged, I hereby sell or have sold, assign or have assigned, and otherwise transfer or have transferred to the ASSIGNEE, its successors, legal representatives, and assigns, my entire worldwide right, title, and interest in and to the Invention, the above-identified United States patent application, and any and all other patent applications and patents for the Invention which may be applied for or granted therefor in the United States and in all foreign countries and jurisdictions, including all divisions, continuations, reissues, reexaminations, renewals, extensions, counterparts, substitutes, and extensions thereof, and all rights of priority resulting from the filing of such applications and granting of such patents. In addition, I hereby authorize and request the Director of the United States Patent and Trademark Office to issue any United States Patent, and foreign patent authorities to issue any foreign patent, granted for the Invention, to the ASSIGNEE, its successors, legal representatives, and assigns, my entire worldwide right, title, and interest in and to the same to be held and enjoyed by the ASSIGNEE, its successors, legal representatives, and assigns to the full end of the terms for which any and all such patents may be granted, as fully and entirely as would have been held and enjoyed by me had this Assignment not been made; and I agree to execute any and all documents and instruments and perform all lawful acts reasonably related to recording this Assignment or perfecting title to the Invention and all related patents and applications, in the ASSIGNEE, its successors, legal representatives, and assigns, whenever requested by the ASSIGNEE, its successors, legal representatives, or assigns.

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Tesla EX1002 Page 2888

I acknowledge my prior and ongoing obligations to sell, assign, and transfer my rights under this Assignment to the ASSIGNEE and am unaware of any reason why I may not have the full and unencumbered right to sell, assign, and transfer my rights hereby sold, assigned, and transferred, and have not executed, and will not execute, any document or instrument in conflict herewith. I also hereby grant the ASSIGNEE, its successors, legal representatives, and assigns, the right to insert in this Assignment any further identification (including, but not limited to, patent Application Number) which may be necessary or desirable for recordation of this Assignment. This Assignment is governed by the substantive laws of the State of New York, and any disputes will be resolved in a New York state court or federal court sited in New York.

I hereby acknowledge that any willful false statement made in this declaration is punishable under 18 U.S.C. 1001 by fine or imprisonment of not more than five (5) years, or both.

(1) Legal Name of Inventor: **MICHAEL S. GORDON**

Signature:_____ Date:_____

(2) Legal Name of Inventor: **JAMES R. KOZLOSKI**

Signature:_____ Date:_____

(3) Legal Name of Inventor: **ASHISH KUNDU**

Signature:_____ Date:_____

(4) Legal Name of Inventor: **PETER K. MALKIN**

Signature: Peter K Malkin Date: 9/24/15

IPR2025-01034
Tesla EX1002 Page 2889

(5) Legal Name of Inventor: **CLIFFORD A. PICKOVER**

Signature:_____ Date:_____

IPR2025-01034
Tesla EX1002 Page 2890

IBM DOCKET NUMBER: **YOR920150507US1**

DECLARATION (37 C.F.R. 1.63) FOR UTILITY PATENT APPLICATION USING AN APPLICATION DATA SHEET (37 C.F.R. 1.76) AND ASSIGNMENT

Title of Invention: **CONTROLLING DRIVING MODES OF SELF-DRIVING VEHICLES**

As a below named and undersigned inventor, I hereby declare that:

This declaration is directed to the attached application, or (if following box is checked):

[X] United States application or PCT international application number 14/865,393 filed on September 25, 2015.

The above-identified application was made or authorized to be made by me.

I believe that I am the original inventor or an original joint inventor of a claimed invention in the application.

I have reviewed and understand the contents of the application, including the claims.

I am aware of the duty to disclose to the United States Patent and Trademark Office all information known to me to be material to patentability as defined in 37 CFR Section 1.56.

Whereas, I ("ASSIGNOR") have made certain inventions, improvements, and discoveries (herein referred to as the "Invention") disclosed in the above-identified patent application and further identified by the IBM Docket Number provided above in the header of this document;

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Tesla EX1002 Page 2891

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Signature:_____ Date:_____

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Signature:_____ Date:_____

(3) Legal Name of Inventor: **ASHISH KUNDU**

Signature:_____ Date:_____

(4) Legal Name of Inventor: **PETER K. MALKIN**

Signature:_____ Date:_____

IPR2025-01034
Tesla EX1002 Page 2892

(5) Legal Name of Inventor: **CLIFFORD A. PICKOVER**

Signature: _____ Date: 9-10-15

IPR2025-01034
Tesla EX1002 Page 2893

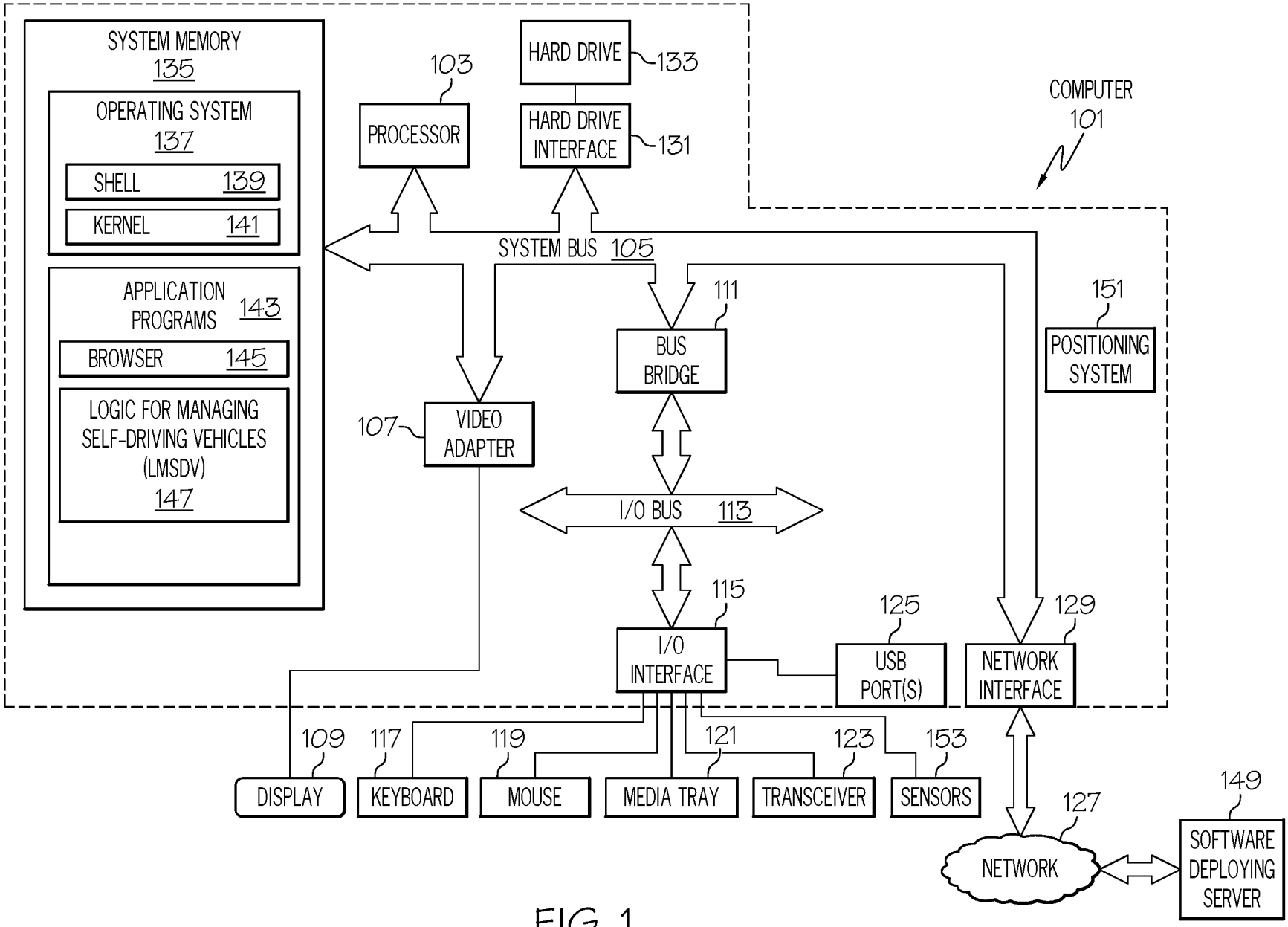

SYSTEM MEMORY
135
OPERATING SYSTEM
137
SHELL 139
KERNEL 141
APPLICATION PROGRAMS 143
BROWSER 145
LOGIC FOR MANAGING SELF-DRIVING VEHICLES (LMSDV)
147
103
PROCESSOR
HARD DRIVE
133
HARD DRIVE INTERFACE
131
COMPUTER
101
SYSTEM BUS 105
111
BUS BRIDGE
151
POSITIONING SYSTEM
107
VIDEO ADAPTER
I/O BUS 113
115
I/O INTERFACE
125
USB PORT(S)
129
NETWORK INTERFACE
109
DISPLAY
117
KEYBOARD
119
MOUSE
121
MEDIA TRAY
123
TRANSCEIVER
153
SENSORS
127
NETWORK
149
SOFTWARE DEPLOYING SERVER

FIG. 1

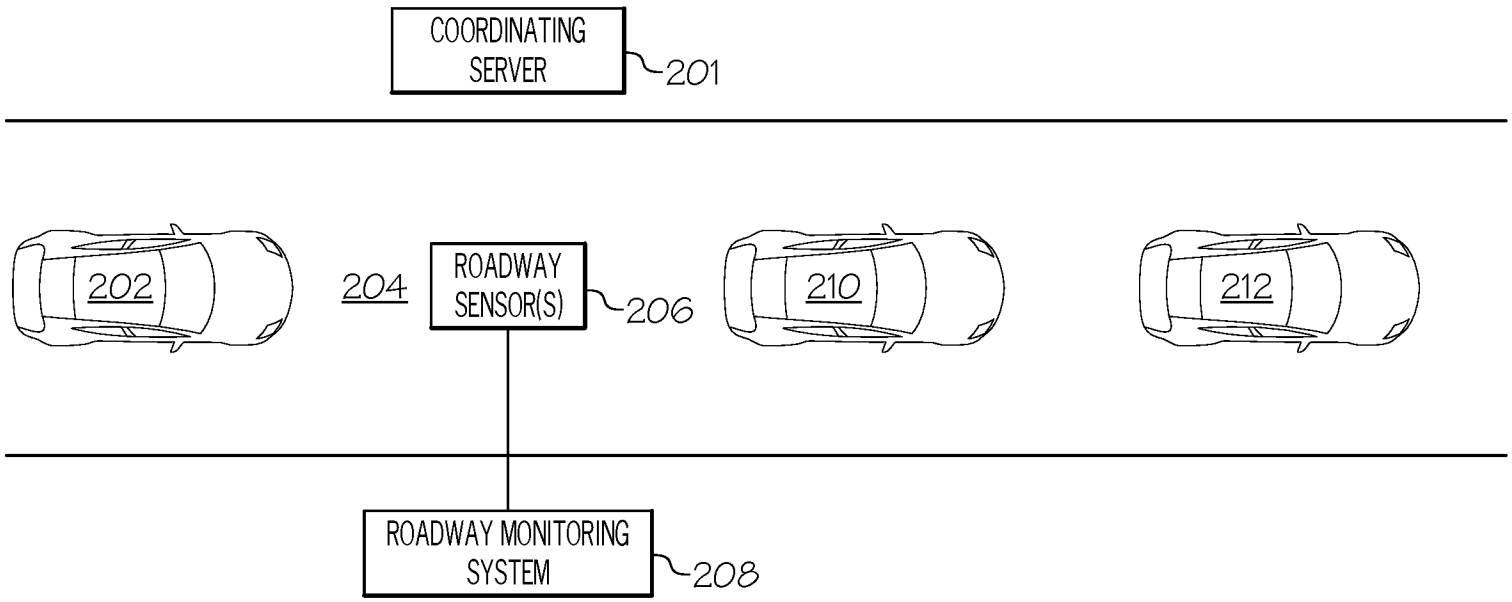

COORDINATING SERVER
201
202
204
ROADWAY SENSOR(S)
206
210
212
ROADWAY MONITORING SYSTEM
208

FIG. 2

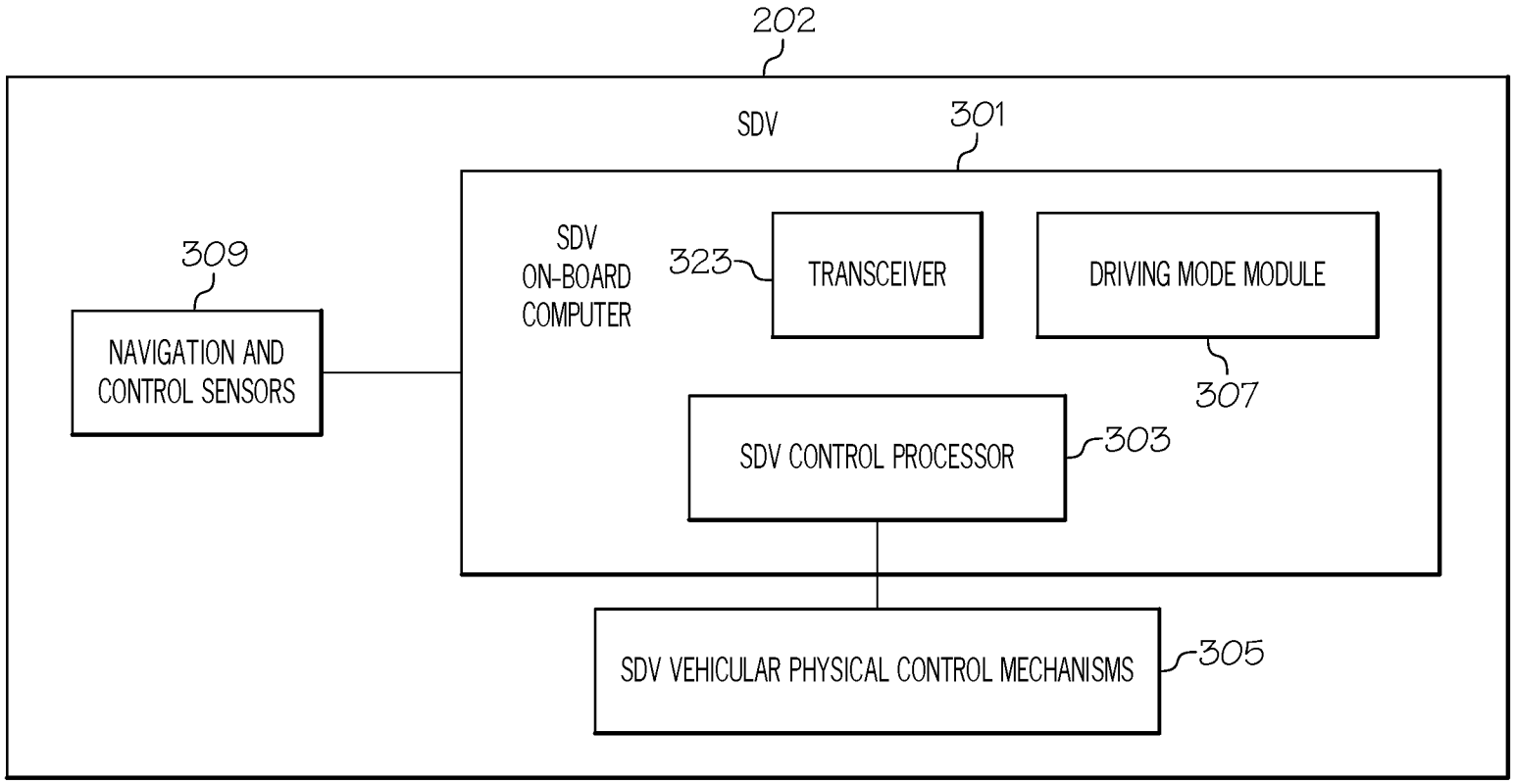

202
SDV
301
309
NAVIGATION AND CONTROL SENSORS
SDV ON-BOARD COMPUTER
323
TRANSCEIVER
DRIVING MODE MODULE
307
SDV CONTROL PROCESSOR
303
SDV VEHICULAR PHYSICAL CONTROL MECHANISMS
305

FIG. 3

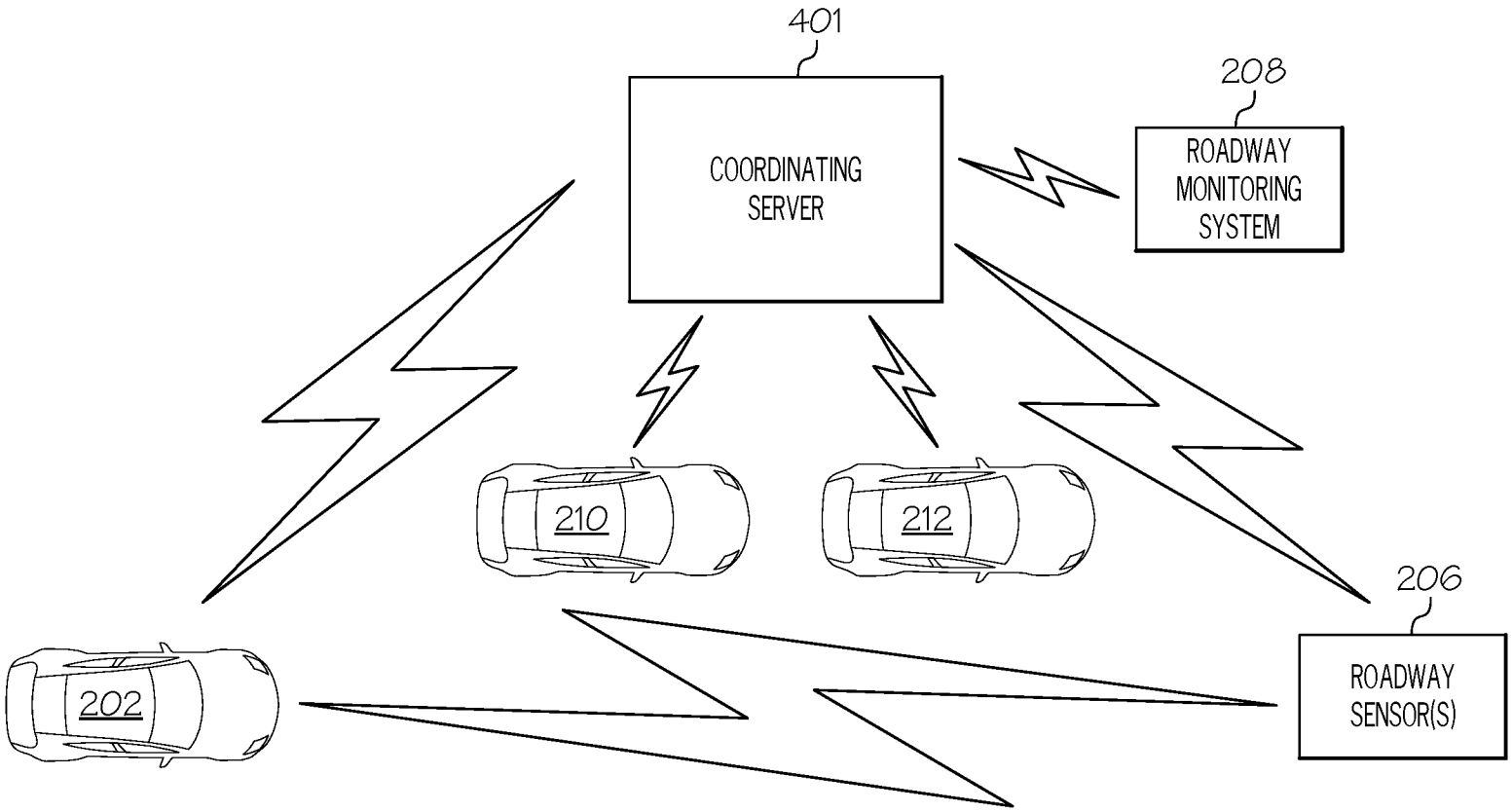

401
COORDINATING SERVER
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ROADWAY MONITORING SYSTEM
210
212
206
ROADWAY SENSOR(S)
202

FIG. 4

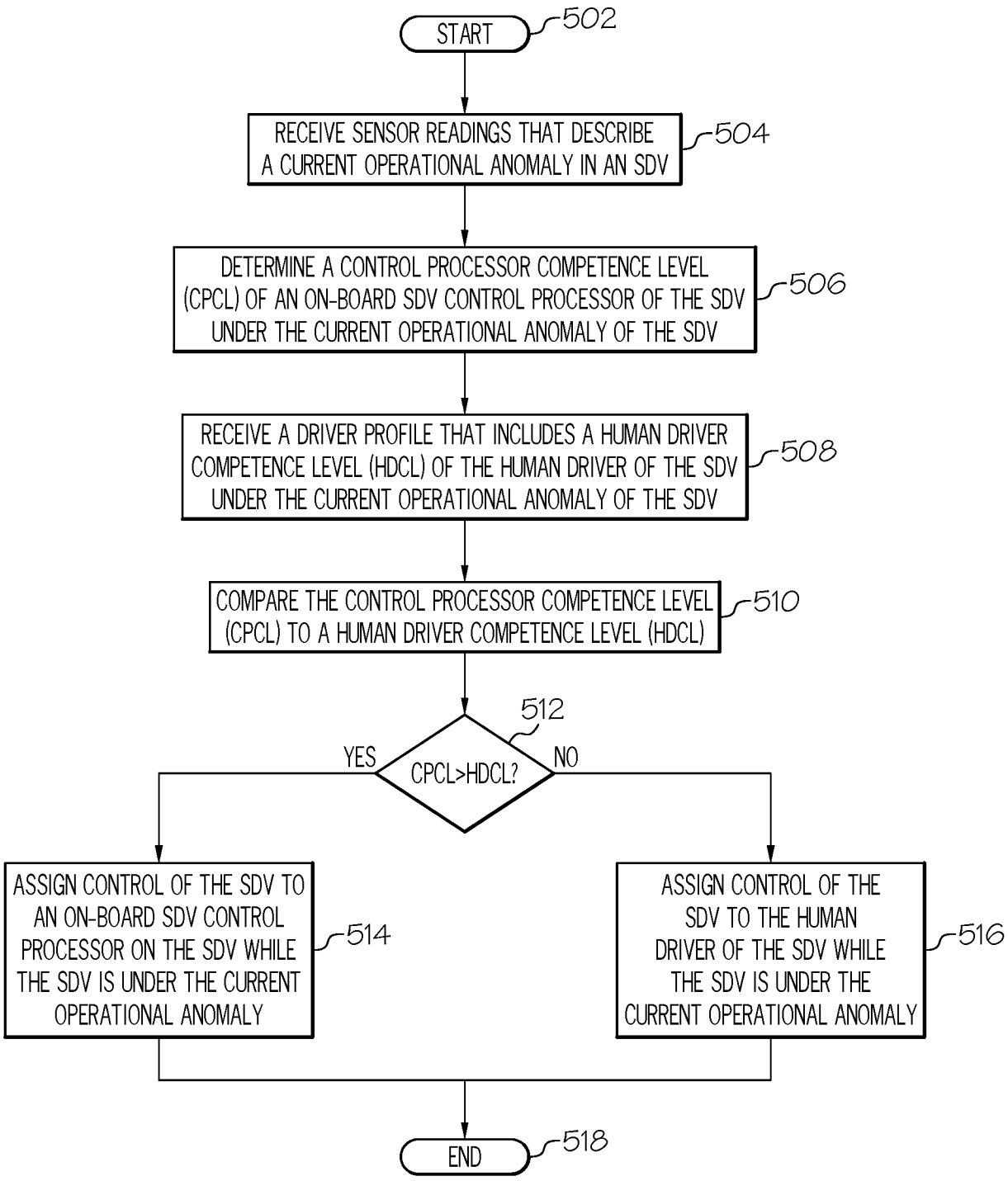

START
502
RECEIVE SENSOR READINGS THAT DESCRIBE A CURRENT OPERATIONAL ANOMALY IN AN SDV
504
DETERMINE A CONTROL PROCESSOR COMPETENCE LEVEL (CPCL) OF AN ON-BOARD SDV CONTROL PROCESSOR OF THE SDV UNDER THE CURRENT OPERATIONAL ANOMALY OF THE SDV
506
RECEIVE A DRIVER PROFILE THAT INCLUDES A HUMAN DRIVER COMPETENCE LEVEL (HDCL) OF THE HUMAN DRIVER OF THE SDV UNDER THE CURRENT OPERATIONAL ANOMALY OF THE SDV
508
COMPARE THE CONTROL PROCESSOR COMPETENCE LEVEL (CPCL) TO A HUMAN DRIVER COMPETENCE LEVEL (HDCL)
510
512
CPCL>HDCL?
YES
NO
ASSIGN CONTROL OF THE SDV TO AN ON-BOARD SDV CONTROL PROCESSOR ON THE SDV WHILE THE SDV IS UNDER THE CURRENT OPERATIONAL ANOMALY
514
ASSIGN CONTROL OF THE SDV TO THE HUMAN DRIVER OF THE SDV WHILE THE SDV IS UNDER THE CURRENT OPERATIONAL ANOMALY
516
END
518

FIG. 5

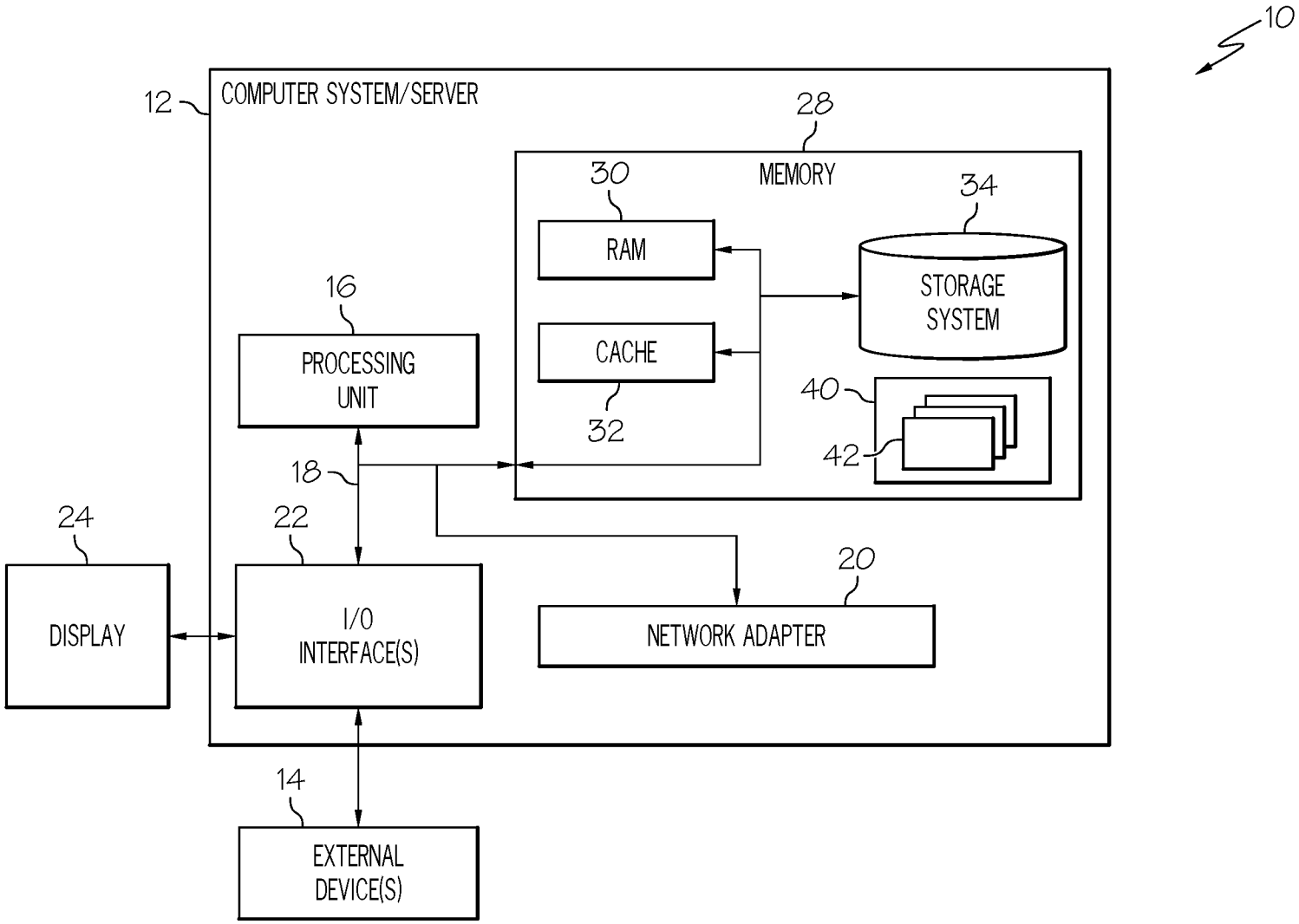

10
12
COMPUTER SYSTEM/SERVER
28
MEMORY
30
RAM
34
STORAGE SYSTEM
16
PROCESSING UNIT
CACHE
32
40
42
18
24
22
20
DISPLAY
I/O INTERFACE(S)
NETWORK ADAPTER
14
EXTERNAL DEVICE(S)

FIG. 6

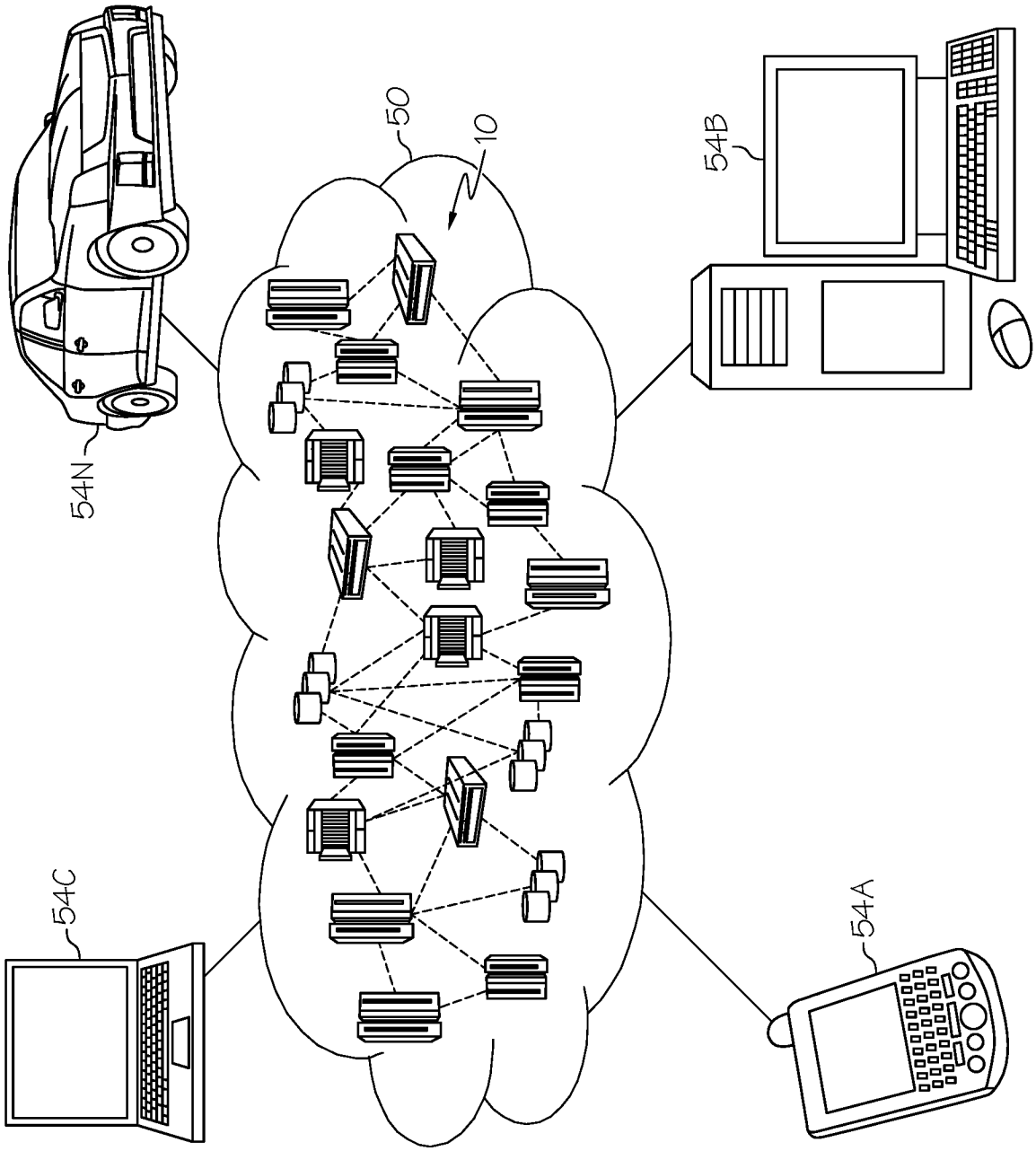


FIG. 7

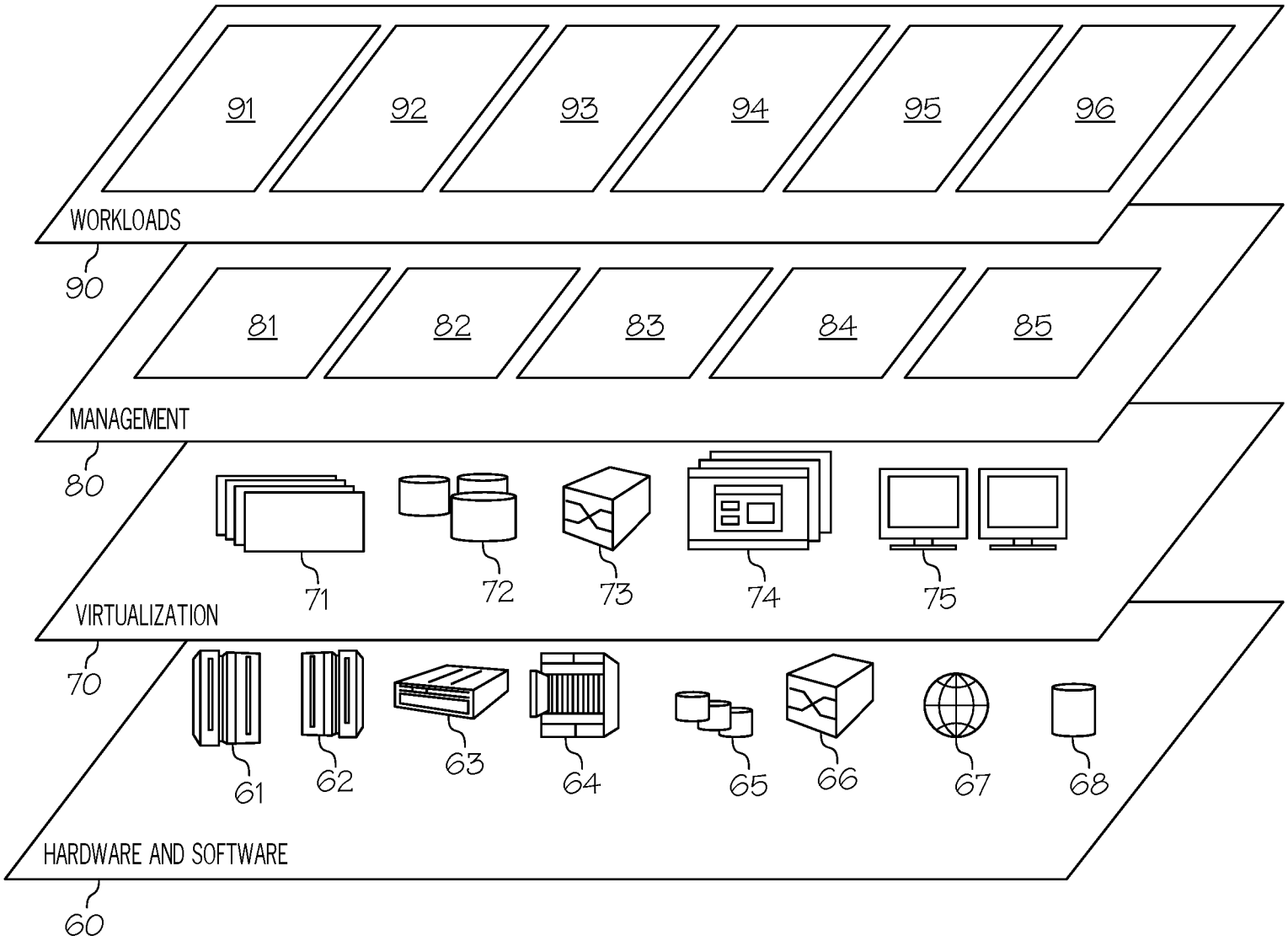

91
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WORKLOADS
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MANAGEMENT
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VIRTUALIZATION
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HARDWARE AND SOFTWARE
60

FIG. 8

PTO/SB/08a (02-18)
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INFORMATION DISCLOSURE STATEMENT BY APPLICANT

(Not for submission under 37 CFR 1.99)

Application Number	
Filing Date	
First Named Inventor	Michael S. Gordon
Art Unit	
Examiner Name	
Attorney Docket Number	S0974-P08818US08

U.S.PATENTS Remove

Examiner Initial*	Cite No	Patent Number	Kind Code[1]	Issue Date	Name of Patentee or Applicant of cited Document	Pages,Columns,Lines where Relevant Passages or Relevant Figures Appear
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	2	4908988	A	1990-03-20	YAMAMURA, et al.	
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	5	6201318	B1	2001-03-13	GUILLORY	
	6	6326903	B1	2001-12-04	GROSS, et al.	
	7	6393362	B1	2002-05-21	BURNS	
	8	6502035	B2	2002-12-31	LEVINE	

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	12	6731202	B1	2004-05-04	KLAUS	
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	15	7124088	B2	2006-10-17	BAUER, et al.	
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	17	7580782	B2	2009-08-25	BREED, et al.	
	18	7769544	B2	2010-08-03	BLESENER, et al.	
	19	7877269	B2	2011-01-25	BAUER, et al.	

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	20	7894951	B2	2011-02-22	NORRIS, et al.	
	21	7979173	B2	2011-07-12	BREED	
	22	8031062	B2	2011-10-04	SMITH	
	23	8045455	B1	2011-10-25	AGRONOW, et al.	
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	30	8180322	B2	2012-05-15	NAKAE, et al.	

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	32	8352112	B2	2013-01-08	MUDALIGE	
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	38	8660734	B2	2014-02-25	ZHU, et al.	
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	40	8678701	B1	2014-03-25	ALDASEM	
	41	8786461	B1	2014-07-22	DAUDELIN	

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	42	8793046	B2	2014-07-29	LOMBROZO, et al.	
	43	8810392	B1	2014-08-19	TELLER, et al.	
	44	8816857	B2	2014-08-26	NORDIN, et al.	
	45	8825258	B2	2014-09-02	CULLINANE, et al.	
	46	8849494	B1	2014-09-30	HERBACH, et al.	
	47	8874305	B2	2014-10-28	DOLGOV, et al.	
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	50	8923890	B1	2014-12-30	WHITE, et al.	
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	52	8948955	B2	2015-02-03	ZHU, et al.	

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	53	8949016	B1	2015-02-03	FERGUSON, et al.	
	54	8954217	B1	2015-02-10	MONTEMERLO, et al.	
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	Attorney Docket Number	S0974-P08818US08

	64	9024787	B2	2015-05-05	ALSHINNAWI, et al.	
	65	9082239	B2	2015-07-14	RICCI	
	66	9090260	B2	2015-07-28	CLARKE, et al.	
	67	9120484	B1	2015-09-01	FERGUSON, et al.	
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	72	9170327	B2	2015-10-27	CHOE, et al.	
	73	9189897	B1	2015-11-17	STENNETH	
	74	9194168	B1	2015-11-24	LU, et al.	

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	75	9195895	B1	2015-11-24	KAPACH, et al.	
	76	9205835	B2	2015-12-08	STEIN, et al.	
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	82	9272709	B2	2016-03-01	BEN SHALOM	
	83	9286520	B1	2016-03-15	LO, et al.	
	84	9297641	B2	2016-03-29	STEIN	
	85	9305411	B2	2016-04-05	RICCI	

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	87	9342074	B2	2016-05-17	DOLGOV, et al.	
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	89	9381915	B1	2016-07-05	CROMBEZ, et al.	
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	91	9393998	B2	2016-07-19	CLARKE, et al.	
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	Examiner Name	
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	97	9454152	B2	2016-09-27	KOPETZ	
	98	9463805	B2	2016-10-11	KIRSCH, et al.	
	99	9483948	B1	2016-11-01	GORDON, et al.	
	100	9552735	B2	2017-01-24	PILUTTI, et al.	
	101	9566958	B2	2017-02-14	WALDMANN	
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	Examiner Name	
	Attorney Docket Number	S0974-P08818US08

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	109	9671243	B2	2017-06-06	STEIN	
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	Examiner Name	
	Attorney Docket Number	S0974-P08818US08

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Name/Print	Ian D. MacKinnon	Registration Number	34,660

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Application Number:	18222774
International Application Number:	
Confirmation Number:	9586
Title of Invention:	CONTROLLING DRIVING MODES OF SELF-DRIVING VEHICLES
First Named Inventor/Applicant Name:	Michael S. Gordon
Customer Number:	164
Filer:	Ian David MacKinnon
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Attorney Docket Number:	S0974-P08818US08
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Application Type:	Utility under 35 USC 111(a)

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Systems and methods for mimicking leading vehicle

Inventor(s): CLARKE ANNA; BAGON EYAL; NIR GAL ± (A·克拉克, ; E·宝葛, ; G·尼尔)

Applicant(s): MOBILEYE VISION TECHNOLOGIES LTD ± (移动眼视力科技有限公司)

Classification: **- international:** ***B60W30/14; B60W60/00; G06K9/00***

- cooperative: **B60K31/0066 (US)**; **B60R1/00 (US)**; **B60T13/662 (EP)**; **B60T7/12 (US)**; **B60T7/22 (EP, US)**; **B60T8/32 (US)**; **B60T8/321 (EP)**; **B60W10/18 (US)**; **B60W10/20 (US)**; **B60W30/00 (US)**; **B60W30/08 (US)**; **B60W30/09 (US)**; **B60W30/0953 (US)**; **B60W30/12 (US)**; **B60W30/14 (US)**; **B60W30/143 (US)**; **B60W30/165 (EP, US)**; **B60W30/18154 (EP, US)**; **B60W30/18163 (EP, US)**; **B60W40/06 (US)**; **B60W40/072 (US)**; **B60W40/076 (US)**; **B60W50/14 (US)**; **B62D15/025 (EP)**; **B62D15/0255 (EP)**; **B62D15/0265 (EP, US)**; **G01C11/04 (US)**; **G01C21/10 (US)**; **G01C21/26 (US)**; **G01C21/30 (EP, US)**; **G05D1/0088 (US)**; **G05D1/0246 (US)**; **G06K9/00798 (EP, US)**; **G06K9/00805 (EP)**; **G06K9/00825 (EP)**; **G06T7/285 (US)**; **G06T7/292 (US)**; **G06T7/70 (US)**; **G06T7/97 (US)**; **G08G1/09623 (EP, US)**; **G08G1/166 (EP, US)**; **G08G1/167 (EP, US)**; **H04N5/247 (US)**; B60K2031/0025 (US); B60T2201/022 (EP, US); B60T2201/03 (EP); B60T2201/08 (EP, US); B60T2210/34 (EP, US); B60W2050/0075 (EP, US); B60W2420/403 (US); B60W2420/42 (EP, US); B60W2510/0604 (US); B60W2510/18 (US); B60W2510/20 (US); B60W2520/14 (US); B60W2552/30 (EP); B60W2554/4041 (EP, US); B60W2554/80 (US); B60W2556/10 (EP, US); B60W2556/50 (EP, US); B60W2710/18 (US); B60W2710/20 (US); B62D15/0255 (US); B62D6/00 (US); G01S5/0027 (US); G05D1/0214 (US); G05D1/0253 (US); G05D1/0278 (US); G06T2207/10028 (US); G06T2207/30256 (US); G06T2207/30261 (US); G08G1/09 (US); G08G1/22 (EP, US); H04N7/18 (US)

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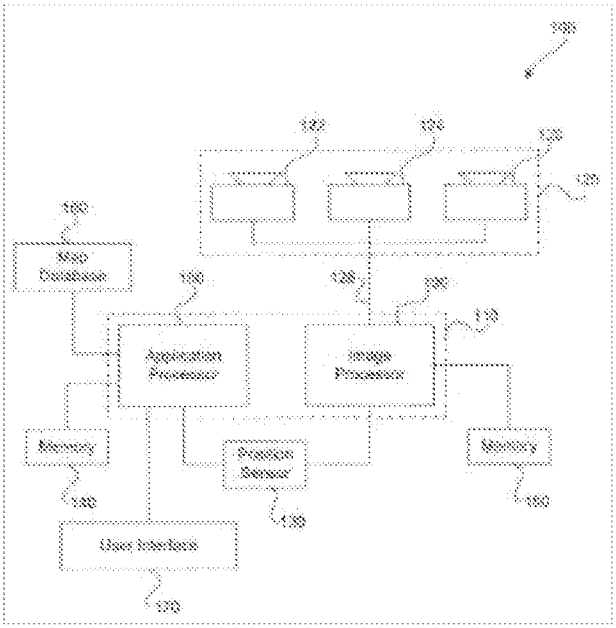
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Priority number(s): US201361911490P 20131204 ; US201461993084P 20140514 ; US201461993111P 20140514 ; US201462015524P 20140623 ; US201462022221P 20140709 ; US201462040224P 20140821 ; US201462040269P 20140821 ; CN20148074153 20141204

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Abstract of CN111027420 (A)

The present invention relates to systems and methods for mimicking a leading vehicle. Systems and methods use cameras to provide autonomous navigation features. In one implementation, a driver assistnavigation system used for a main vehicle is provided and may include at least one image capture device configured to acquire a plurality of images of an area nearby the main vehicle; a data interface; and at least one processing device. The at least one processing device may be configured to locate the leading vehicle in the plurality of images; determine at least one action taken by the leadingvehicle based on the plurality of images; and cause the main vehicle to mimic the at least one action of the leading vehicle.



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DESCRIPTION CN111027420A

System and method for imitating the preceding vehicle

[0001]

This application is a divisional application for a patent application whose filing date is December 4, 2014, the application number is 201480074153.9 (PCT/IB2014/003151), and the invention title is "System and method for imitating the preceding vehicle".

[0002]

Technical field

[0003]

The present disclosure generally relates to autonomous vehicle navigation, and more specifically, to systems and methods that use cameras to provide autonomous vehicle navigation features.

[0004]

Background technique

[0005]

With the continuous advancement of technology, the goal of a fully autonomous vehicle capable of navigating on the road is about to be reached.

First, the autonomous vehicle can recognize its environment and navigate without operator input.

Autonomous vehicles can also consider various factors and make appropriate decisions based on these factors to safely and accurately reach the intended destination.

For example, when a vehicle habitually travels on a road, it encounters various objects such as other vehicles and pedestrians.

The autonomous driving system can recognize these objects in the vehicle environment and take appropriate and timely actions to avoid collisions. In addition, the autonomous drive system can recognize other indicators, such as traffic signals, traffic signs, and lane markings, which regulate vehicle movement (for example, when the vehicle must stop and can drive, the vehicle must not exceed the speed, the vehicle must be positioned On the road, etc.). Autonomous drive systems may need to determine when the vehicle should change lanes, turn at intersections, change roads, and so on. It is obvious from these examples that many factors may need to be addressed in order to provide an autonomous vehicle that can navigate safely and accurately.

[0006]

Summary of the invention

[0007]

Embodiments consistent with the present disclosure provide systems and methods for autonomous vehicle navigation.

The disclosed embodiments may use cameras to provide autonomous vehicle navigation features.

For example, consistent with the disclosed embodiments, the disclosed system may include one, two or more cameras for monitoring the vehicle environment and generating based on the analysis of the images captured by one or more of the cameras. Navigation response.

[0008]

Consistent with the disclosed embodiments, a driver assistance navigation system for a vehicle is provided.

The system may include: at least one image capturing device configured to acquire a plurality of images of an area near the vehicle; a data interface; and at least one processing device. The at least one processing device may be configured to: receive the plurality of images via the data interface; determine the first lane constraint on the first side of the vehicle based on the plurality of images; Determine a second lane constraint on a second side of the vehicle opposite to the first side of the vehicle, wherein the first lane constraint and the second lane constraint define the lane in which the vehicle travels, and wherein The first distance corresponds to the distance between the first side of the vehicle and the first lane constraint, and the second distance corresponds to the distance between the second side of the vehicle and the second lane constraint的 distance; based on the multiple images to determine whether the lane offset condition exists on the first side of the vehicle; if the lane offset condition exists on the first side of the vehicle, cause all The vehicle travels within the first lane constraint and the second lane constraint, so that the first distance is greater than the second distance; based on the multiple images, it is determined whether a lane offset condition exists in all of the vehicle. And if a lane offset condition exists on the second side of the vehicle, then cause the vehicle to travel within the first and second lane constraints, so that the first The distance is smaller than the second distance.

[0009]

Consistent with the disclosed embodiment, the at least one processing device may be further configured to, if it is determined based on the plurality of images that a lane shift condition exists on both the first side and the second side of the vehicle, then As a result, the first distance and the second distance are substantially the same.

The at least one processing device may be configured to determine, based on the plurality of images, whether a lane deviation condition is substantially non-existent, and if the lane deviation condition is substantially non-existent, cause the vehicle to be in the first The lane constraint and the second lane constraint travel within such that the first distance is substantially equal to the second distance. If the driver assistance navigation system determines that a lane deviation condition exists, the at least one processing device may be configured to cause the first distance to be at least 1.25 times greater than the second distance. Alternatively, the at least one processing device may be further configured to cause the first distance to be at least 2 times greater than the second distance. If the driver assistance navigation system determines that the lane deviation condition includes a curved road, the at least one processing device may be configured to cause the vehicle to travel within the first lane constraint and the second lane constraint, so that the The first distance is toward the outside of the curve relative to the vehicle, and the second distance is toward the inside of the curve relative to the vehicle. If the driver assistance navigation system determines that the lane offset condition includes the presence of one or more objects on one side of the lane, the at least one processing device may be configured to cause the vehicle to be in the first The lane constraint and the second lane constraint travel within such that the first distance greater than the second distance is provided toward the one or more objects. The one or more objects may include parked cars, walls, and/or pedestrians, and may have a height greater than 10 cm from the road surface. At least one of the first lane constraint and the second lane constraint may include a line marked on the road surface, a curb of the road surface, or a determined midpoint of a road surface width. Determining whether a lane deviation condition exists on the first side of the vehicle may be performed based on the position of the target object on the first side of the vehicle. Causing the vehicle to travel within the first lane constraint and the second lane constraint such that the first distance is greater than the second distance may be revoked based on the input of the driver of the vehicle.

[0010]

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Consistent with another disclosed embodiment, a vehicle may include: a first vehicle side; a second vehicle side opposite to the first vehicle side; at least one image capturing device, the at least one image capturing device being configured To obtain multiple images of the area near the vehicle; a data interface; and at least one processing device.

The at least one processing device may be configured to: receive the plurality of images via the data interface; determine a first lane constraint on the first vehicle side based on the plurality of images; determine based on the plurality of images A second lane constraint on the second vehicle side, wherein the first lane constraint and the second lane constraint define the lane in which the vehicle travels, and wherein the first distance corresponds to the first vehicle side and the The distance between the first lane constraint, and the second distance corresponds to the distance between the second vehicle side and the second lane constraint; based on the plurality of images, it is determined whether a lane offset condition exists in the On the first vehicle side; if the lane offset condition exists on the first vehicle side, the vehicle is caused to travel within the first lane constraint and the second lane constraint, so that the first distance is greater than the Second distance; based on the multiple images to determine whether the lane offset condition exists on the second vehicle side; and if the lane offset condition exists on the second vehicle side, cause the vehicle to be at all The first lane constraint and the second lane constraint travel within such that the first distance is smaller than the second distance.

[0011]

Consistent with the disclosed embodiment, the at least one processing device may be further configured to cause all lane offset conditions to exist on both the first vehicle side and the second vehicle side based on the plurality of images. The first distance is substantially the same as the second distance.

The at least one processing device may be configured to determine, based on the plurality of images, whether a lane deviation condition is substantially non-existent, and if the lane deviation condition is substantially non-existent, cause the vehicle to be in the first The lane constraint and the second lane constraint travel within such that the first distance is substantially equal to the second distance. The lane deviation condition may include a curved road, and the at least one processing device may be configured to cause the vehicle to travel within the first lane constraint and the second lane constraint such that the first distance faces the opposite of the curve. On the outside of the vehicle, and the second distance is toward the inside of the curve relative to the vehicle. The lane deviation condition may include the presence of one or more objects on one side of the lane, and the at least one processing device may be configured to cause the vehicle to be within the first lane constraint and the second lane constraint Travel such that the first distance greater than the second distance is provided toward the one or more objects. At least one of the first lane constraint and the second lane constraint may include a curb of the road surface and/or a determined midpoint of the road surface width. Determining whether a lane deviation condition exists on the first side of the vehicle may be performed based on the position of the target object on the first side of the vehicle. Causing the vehicle to travel within the first lane constraint and the second lane constraint such that the first distance is greater than the second distance may be revoked based on the input of the driver of the vehicle.

[0012]

Consistent with another disclosed embodiment, a method for navigating a vehicle is provided.

The method may include: using at least one image capturing device to acquire a plurality of images of a region near the vehicle; determining a first lane constraint on a first side of the vehicle based on the plurality of images; determining based on the plurality of images A second lane constraint on a second side of the vehicle opposite to the first side of the vehicle, wherein the first lane constraint and the second lane constraint define the lane in which the vehicle travels, and wherein the first lane constraint The distance corresponds to the distance between the first side of the vehicle and the first lane constraint, and the second distance corresponds to the distance between the second side of the vehicle and the second lane constraint Based on the plurality of images to determine whether the lane offset condition exists on the first side of the vehicle; if the lane offset condition exists on the first side of the vehicle, cause the vehicle Travel within the first lane constraint and the second lane constraint so that the first distance is greater than the second distance; based on the plurality of images, it is determined whether a lane offset condition exists in the first lane of the vehicle And if the lane offset condition exists on the second side of the vehicle, causing the vehicle to travel within the first lane constraint and the second lane constraint, such that the first distance is less than The second distance.

[0013]

Consistent with the disclosed embodiments, a driver assistance navigation system for a vehicle is provided.

The system may include: at least one image capturing device configured to acquire a plurality of images of an area near the vehicle; a data interface; and at least one processing device. The at least one processing device may be configured to: receive the plurality of images via the data interface; determine the current travel lane among the plurality of available travel lanes based on the plurality of images; and if the current travel lane is consistent with a predetermined If the default lanes of travel are not the same, the vehicle will change lanes.

[0014]

Consistent with the disclosed embodiment, the predetermined default travel lane may be the rightmost lane among the plurality of available travel lanes.

The at least one processing device may be configured to activate a turn signal before causing the vehicle to change lanes. The at least one processing device may be configured to generate a voice notification before causing the vehicle to change lanes. The at least one processing device may be configured to generate a voice instruction before causing the vehicle to change lanes. The predetermined default lane of travel may be determined based on the plurality of images of the area near the vehicle, based on data received from a global positioning system, and/or based on input received from a user.

[0015]

Consistent with another disclosed embodiment, a vehicle may include: a main body; at least one image capturing device configured to acquire a plurality of images of an area near the vehicle; a data interface; and at least one processing Device.

The at least one processing device may be configured to: receive the plurality of images via the data interface; determine the current travel lane among the plurality of available travel lanes based on the plurality of images; and if the current travel lane is consistent with a predetermined If the default lanes of travel are not the same, the vehicle will change lanes.

[0016]

Consistent with the disclosed embodiment, the predetermined default travel lane may be the rightmost lane among the plurality of available travel lanes.

The at least one processing device may be configured to activate a turn signal before causing the vehicle to change lanes. The at least one processing device may be configured to generate a voice notification before causing the vehicle to change lanes. The at least one processing device may be configured to generate a voice instruction before causing the vehicle to change lanes. The predetermined default lane of travel may be determined based on the plurality of images of the area near the vehicle, based on data received from a global positioning system, and/or based on input received from a user.

[0017]

Consistent with another disclosed embodiment, a method for navigating a vehicle is provided.

The method may include: using at least one image capturing device to acquire a plurality of images of the area near the vehicle; determining the current travel lane among a plurality of available travel lanes based on the plurality of images; and if the current travel lane is consistent with a predetermined If the default lanes of travel are not the same, the vehicle will change lanes.

[0018]

Consistent with the disclosed embodiment, the predetermined default travel lane may be the rightmost lane among the plurality of available travel lanes.

The turn signal may be activated before causing the vehicle to change lanes. The predetermined default lane of travel may be determined based on the plurality of images of the area near the vehicle.

[0019]

Consistent with the disclosed embodiments, a driver assistance navigation system for a vehicle is provided.

The system may include: at least one image capturing device configured to acquire a plurality of images of an area near the vehicle; a data interface; and at least one processing device. The at least one processing device may be configured to: receive

the plurality of images via the data interface; identify the curve to be navigated based on map data and vehicle position information; and at least based on the curve reflected in the map data A characteristic to determine the initial target speed of the vehicle; adjust the speed of the vehicle to the initial target speed; determine one or more observed characteristics of a curve based on the multiple images; The observed one or more characteristics of the road are used to determine the updated target speed; and the speed of the vehicle is adjusted to the updated target speed.

[0020]

Consistent with the disclosed embodiments, at least one characteristic of the curve may include an expected radius of curvature of the curve determined according to the map data.

The initial target speed may be determined based on the expected radius of curvature and the lateral acceleration limit of the curve. The lateral acceleration limit may be between about 0.2 m/s2 and 3.0 m/s2. Alternatively, the lateral acceleration limit may be between about 1.5 m/s2 and 3.0 m/s2. The lateral acceleration limit may be adjusted based on the road width determined by the plurality of images. The observed one or more characteristics of the curve may include the actual radius of curvature of the curve determined by analyzing the plurality of images. The updated target speed may be determined based on the actual radius of curvature and the lateral acceleration limit of the curve. The observed one or more characteristics of the curve may include a rate of change of the actual radius of curvature of the curve determined by analyzing the plurality of images. The observed one or more characteristics of the curve may include a curve inclination associated with the curve determined by analyzing the plurality of images. The observed one or more characteristics of the curve may include information related to the curve conveyed by one or more road signs determined by analyzing the plurality of images. The initial target speed may also be based on the focal length range of the at least one image capture device. The initial target speed may also be based on determining whether a traffic light is positioned along the curve. The initial target speed may also be based on determining whether the traffic light is within a predetermined distance behind the curve.

[0021]

Consistent with another disclosed embodiment, a vehicle may include: a main body; at least one image capturing device configured to acquire a plurality of images of an area near the vehicle; a data interface; and at least one processing Device.

The at least one processing device may be configured to: receive the plurality of images via the data interface; identify the curve to be navigated based on map data and vehicle position information; and at least based on the curve reflected in the map data A characteristic to determine the initial target speed of the vehicle; adjust the speed of the vehicle to the initial target speed; determine one or more observed characteristics of a curve based on the multiple images; The observed one or more characteristics of the road are used to determine the updated target speed; and the speed of the vehicle is adjusted to the updated target speed.

[0022]

Consistent with the disclosed embodiments, at least one characteristic of the curve may include an expected radius of curvature of the curve determined according to the map data.

The initial target speed may be determined based on the expected radius of curvature and the lateral acceleration limit of the curve. The lateral acceleration limit may be adjusted based on the road width determined by the plurality of images. The observed one or more characteristics of the curve may include the actual radius of curvature of the curve determined by analyzing the plurality of images. The updated target speed may be determined based on the actual radius of curvature and the lateral acceleration limit of the curve. The observed one or more characteristics of the curve may include a rate of change of the actual radius of curvature of the curve determined by analyzing the plurality of images. The observed one or more characteristics of the curve may include a curve inclination associated with the curve determined by analyzing the plurality of images. The observed one or more characteristics of the curve may include information related to the curve conveyed by one or more road signs determined by analyzing the plurality of images. The initial target speed may also be based on the focal length range of the at least one image capture device. The initial target speed may also be based on determining whether a traffic light is positioned along the curve. The initial target speed may also be based on determining whether the traffic light is within a predetermined distance behind the curve.

[0023]

Consistent with another disclosed embodiment, a method for navigating a vehicle is provided.

The method may include: using at least one image capturing device to acquire a plurality of images of the area near the vehicle; identifying the curve to be navigated based on map data and vehicle position information; and at least based on the curve reflected in the map data A characteristic to determine the initial target speed of the vehicle; adjust the speed of the vehicle to the initial target speed; determine one or more observed characteristics of a curve based on the multiple images; The observed one or more characteristics of the road are used to determine the updated target speed; and the speed of the vehicle is adjusted to the updated target speed.

[0024]

Consistent with the disclosed embodiments, a driver-assisted navigation system for a host vehicle is provided.

The system may include: at least one image capturing device configured to acquire a plurality of images of a region near the host vehicle; a data interface; and at least one processing device. The at least one processing device may be configured to: receive the plurality of images via the data interface; determine the first lane constraint on the first side of the host vehicle according to at least some of the plurality of images; The second lane constraint on the second side of the host vehicle opposite to the first side of the host vehicle is determined according to at least some of the images, wherein the first lane constraint and the first side A two-lane constraint defines the lane in which the host vehicle travels; causes the host vehicle to travel within the first lane constraint and the second lane constraint; locates the vehicle ahead in the multiple images; and based on the multiple images Determining at least one action taken by the preceding vehicle; and causing the host vehicle to imitate the at least one action of the preceding vehicle.

[0025]

Consistent with the disclosed embodiment, at least one of the first lane restriction and the second lane restriction may include a line marked on the road surface.

At least one of the first lane constraint and the second lane constraint may include a curb of a road surface. At least one of the first lane constraint and the second lane constraint may include a determined midpoint of the road surface width. The at least one action taken by the preceding vehicle may include a turn, and the at least one processing device may cause the host vehicle to perform a similar turn that starts at a location where the preceding vehicle initiates its turn. The at least one action taken by the preceding vehicle may include acceleration. The at least one action taken by the preceding vehicle may include braking. The at least one action taken by the preceding vehicle may include providing a first offset distance on the side of the preceding vehicle adjacent to the first lane constraint, the first offset distance being different from the preceding vehicle The second offset distance of the side adjacent to the second lane constraint. The at least one processing device may be further configured to determine whether the vehicle in front is turning at the intersection based on the plurality of images or based on map data and location information, and reject if it is determined that the vehicle in front is turning at the intersection imitating the turning of the preceding vehicle. The at least one processing device may be configured to determine whether the preceding vehicle is turning at the intersection based on the plurality of images or based on map data and location information, determining whether the preceding vehicle is changing lanes within the intersection, and if it is determined If the vehicle in front turns at an intersection and does not change lanes in the intersection, then imitate the turn of the vehicle in front, and if it is determined that the vehicle in front turns at the intersection but changes lanes within the intersection, then Refuse to imitate the turn of the preceding vehicle. The at least one processing device may be configured to acquire a first vehicle ahead based on the multiple images, acquire a second vehicle ahead based on the multiple images, and if the first vehicle ahead is determined based on the multiple images The turning radius of the path on which the vehicle continues to travel is smaller than the path followed by the second preceding vehicle, which causes the host vehicle to imitate the first preceding vehicle. The at least one processing device may be configured to determine the position information of the preceding vehicle and compare the position information with predetermined map data, by tracking the movement of the preceding vehicle relative to the predetermined map data as the preceding vehicle A navigation history is created, and based on the navigation history of the preceding vehicle, it is determined whether to cause the host vehicle to imitate the at least one action of the preceding vehicle. The at least one processing device may be configured to: when the navigation history indicates that the preceding vehicle has successfully navigated at least one forward turn, even when a turn is not detected based on the plurality of images, cause the host vehicle to imitate the turning of the vehicle in front.

[0026]

Consistent with another disclosed embodiment, a host vehicle may include: a main body; at least one image capturing device configured to acquire a plurality of images of an area near the host vehicle; a data interface; and at least A processing device.

The at least one processing device may be configured to: receive the plurality of images via the data interface; determine the first lane constraint on the first side of the host vehicle according to at least some of the plurality of images Determine the second lane constraint on the second side of the host vehicle opposite to the first side of the host vehicle according to at least some of the images, wherein the first lane constraint And the second lane constraint define the lane in which the host vehicle travels; cause the host vehicle to travel within the first lane constraint and the second lane constraint; locate the preceding vehicle in the multiple images; based on the multiple image to determine at least one action taken by the preceding vehicle; and causing the host vehicle to imitate the at least one action of the preceding vehicle.

[0027]

Consistent with the disclosed embodiment, at least one of the first lane restriction and the second lane restriction may include a line marked on the road surface.

At least one of the first lane constraint and the second lane constraint may include a curb of a road surface. At least one of the first lane constraint and the second lane constraint may include a determined midpoint of the road surface width. The at least one action taken by the preceding vehicle may include a turn, and the at least one processing device may cause the host vehicle to perform a similar turn that starts at a location where the preceding vehicle initiates its turn. The at least one action taken by the preceding vehicle may include acceleration. The at least one action taken by the preceding vehicle may include braking. The at least one action taken by the preceding vehicle may include providing a first offset distance on the side of the preceding vehicle adjacent to the first lane constraint, the first offset distance being different from the preceding vehicle The second offset distance of the side adjacent to the second lane constraint. The at least one processing device may be further configured to determine whether the vehicle in front is turning at the intersection based on the plurality of images or based on map data and location information, and reject if it is determined that the vehicle in front is turning at the intersection Imitating the turning of the preceding vehicle. The at least one processing device may be configured to determine whether the preceding vehicle is turning at the intersection based on the plurality of images or based on map data and location information, determining whether the preceding vehicle is changing lanes within the intersection, and if it is determined If the vehicle in front turns at an intersection and does not change lanes in the intersection, then imitate the turn of the vehicle in front, and if it is determined that the vehicle in front turns at the intersection but changes lanes within the intersection, then Refuse to imitate the turn of the preceding vehicle. The at least one processing device may be configured to acquire a first vehicle ahead based on the multiple images, acquire a second vehicle ahead based on the multiple images, and if the first vehicle ahead is determined based on the multiple images The turning radius of the path on which the vehicle continues to travel is smaller than the path followed by the second preceding vehicle, which causes the host vehicle to imitate the first preceding vehicle. The at least one processing device may be configured to determine the position information of the preceding vehicle and compare the position information with predetermined map data, by tracking the movement of the preceding vehicle relative to the predetermined map data as the preceding vehicle A navigation history is created, and based on the navigation history of the preceding vehicle, it is determined whether to cause the host vehicle to imitate the at least one action of the preceding vehicle. The at least one processing device may be configured to: when the navigation history indicates that the preceding vehicle has successfully navigated at least one forward turn, even when a turn is not detected based on the plurality of images, cause the host vehicle to imitate the turning of the vehicle in front.

[0028]

Consistent with another disclosed embodiment, a method for navigating a host vehicle is provided.

The method may include: using at least one image capturing device to acquire a plurality of images of the vicinity of the host vehicle; and determining the first lane on the first side of the host vehicle based on at least some of the images Constraints; determine a second lane constraint on a second side of the host vehicle opposite to the first side of the host vehicle according to at least some of the images, wherein the first lane The constraint and the second lane constraint define the lane in which the host vehicle travels; cause the host vehicle to travel within the first lane constraint and the second lane constraint; locate the preceding vehicle in the multiple images; based on the multiple images to determine at least one action taken by the preceding vehicle; and causing the host vehicle to imitate the at least one action of the preceding vehicle.

[0029]

Consistent with the disclosed embodiments, a driver-assisted navigation system for a user's vehicle is provided.

The system may include: at least one image capturing device configured to acquire a plurality of images of an area near the user's vehicle; a data interface; and at least one processing device. The at least one processing device may be configured to: receive the plurality of images via the data interface; determine the first lane constraint on the first side of the user's vehicle according to the plurality of images; The image determines the second lane constraint on the second side of the user vehicle opposite to the first side of the user vehicle, wherein the first lane constraint and the second lane constraint define the travel of the user vehicle Lane; acquiring a target vehicle based on the plurality of images; if it is determined that the lane in which the target vehicle travels is different from the lane in which the user vehicle travels, the user vehicle is enabled to pass the target vehicle; based on the plurality of images To monitor the position of the target vehicle; and if it is determined that the target vehicle is entering the lane where the user vehicle is traveling, causing the user vehicle to abort the overtaking before completing the overtaking.

[0030]

Consistent with the disclosed embodiments, the step of causing the user's vehicle to suspend the overtaking may include causing the brake in the user's vehicle to be applied.

The step of causing the user vehicle to abort the overtaking may include generating a voice notification. The step of causing the user vehicle to stop the overtaking may include causing the user vehicle to stop accelerating. The step of monitoring the position of the target vehicle may include estimating the speed of the target vehicle. At least one of the first lane constraint and the second lane constraint may include a line marked on the road surface, a curb of the road surface, and/or a determined midpoint of the road surface width.

[0031]

Consistent with another disclosed embodiment, a user vehicle may include: at least one image capture device configured to acquire a plurality of images of a region near the user vehicle; a data interface; and at least one processing Device.

The at least one processing device may be configured to: receive the plurality of images via the data interface; determine the first lane constraint on the first side of the user's vehicle according to the plurality of images; The image determines a second lane constraint on a second side of the user vehicle opposite to the first side of the user vehicle, wherein the first lane constraint and the second lane constraint define the travel of the user vehicle Lane; acquiring a target vehicle based on the plurality of images; if it is determined that the lane in which the target vehicle travels is different from the lane in which the user vehicle travels, the user vehicle is enabled to pass the target vehicle; based on the plurality of images To monitor the position of the target vehicle; and if it is determined that the target vehicle is entering the lane where the user vehicle is traveling, causing the user vehicle to abort the overtaking before completing the overtaking.

[0032]

Consistent with the disclosed embodiments, causing the user's vehicle to abort the overtaking may include causing application of a brake in the user's vehicle.

Causing the user vehicle to abort the overtaking may include generating a voice notification. Causing the user vehicle to abort the overtaking may include causing the user vehicle to stop accelerating. Monitoring the location of the target vehicle may include estimating the speed of the target vehicle. At least one of the first lane constraint and the second lane constraint may include a line marked on the road surface, a curb of the road surface, and/or a determined midpoint of the road surface width.

[0033]

Consistent with another disclosed embodiment, a method for navigating a user's vehicle is provided.

The method may include: using at least one image capturing device to acquire a plurality of images of an area near the user's vehicle; determining a first lane constraint on the first side of the user's vehicle based on the plurality of images; Images determine a second lane constraint on a second side of the user vehicle opposite to the first side of the user vehicle, wherein the first lane constraint and the second lane constraint define the user vehicle to travel Based on the multiple images to obtain the target vehicle; if it is determined that the lane in which the target vehicle travels is different from the lane in which the user vehicle travels, then the user vehicle can overtake the target vehicle; based on the multiple images to monitor the location of the

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target vehicle; and if it is determined that the target vehicle is entering the lane where the user vehicle is traveling, causing the user vehicle to abort the overtaking before completing the overtaking.

[0034]

Consistent with the disclosed embodiments, the step of causing the user's vehicle to suspend the overtaking may include causing the brake in the user's vehicle to be applied.

The step of causing the user vehicle to stop the overtaking may include causing the user vehicle to stop accelerating. At least one of the first lane constraint and the second lane constraint may include a line marked on the road surface, a curb of the road surface, and/or a determined midpoint of the road surface width.

[0035]

Consistent with the disclosed embodiments, a driver-assisted navigation system for a user's vehicle is provided.

The system may include: at least one image capturing device configured to acquire a plurality of images of an area near the user's vehicle; a data interface; and at least one processing device. The at least one processing device may be configured to: receive the plurality of images via the data interface; determine the first lane constraint on the first side of the user's vehicle according to the plurality of images; The image determines the second lane constraint on the second side of the user vehicle opposite to the first side of the user vehicle, wherein the first lane constraint and the second lane constraint define the travel of the user vehicle Lane; determining whether an intruding vehicle approaches from one side of the user vehicle based on the plurality of images; and causing the user vehicle to maintain the current speed and travel within the first lane constraint and the second lane constraint, so that The first distance on the side of the user vehicle where the intruding vehicle is approaching is greater than the second distance.

[0036]

Consistent with the disclosed embodiment, the at least one processing device may be further configured to cause the user vehicle to take an evasive action if the analysis of the multiple images indicates that the intruding vehicle has crossed at least one collision threshold.

The avoidance action may include changing lanes, changing routes, and/or braking. The at least one collision threshold may include a minimum predetermined distance maintained between the user vehicle and the intruding vehicle. The at least one collision threshold may include the time to collision. The at least one processing device may be configured to cause the user vehicle to return to the center of the lane where the user vehicle originally traveled after completing the avoidance action. The at least one image capturing device may have a field of view of at least 140 degrees. The at least one processing device may be configured to cause the user's vehicle to return to a preset speed after braking in response to the intruding vehicle. The at least one processing device may be configured to cause the user vehicle to return to the lane location within the first lane constraint and the second lane constraint, so that after changing the route in response to the intruding vehicle, the user vehicle and the The first distance between first lane constraints is substantially equal to the second distance between the user vehicle and the second lane constraints.

[0037]

Consistent with another disclosed embodiment, a user vehicle may include: at least one image capture device configured to acquire a plurality of images of a region near the user vehicle; a data interface; and at least one processing Device.

The at least one processing device may be configured to: receive the plurality of images via the data interface; determine the first lane constraint on the first side of the user's vehicle according to the plurality of images; The image determines the second lane constraint on the second side of the user vehicle opposite to the first side of the user vehicle, wherein the first lane constraint and the second lane constraint define the travel of the user vehicle Lane; determining whether an intruding vehicle approaches from one side of the user vehicle based on the plurality of images; and causing the user vehicle to maintain the current speed and travel within the first lane constraint and the second lane constraint, so that The first distance on the side of the user vehicle where the intruding vehicle is approaching is greater than the second distance.

[0038]

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Consistent with the disclosed embodiments, the at least one processing device may be further configured to cause the user vehicle to take an evasive action if the analysis of the multiple images indicates that the intruding vehicle has crossed at least one collision threshold.

The avoidance action may include changing lanes, changing routes, and/or braking. The at least one collision threshold may include a minimum predetermined distance maintained between the user vehicle and the intruding vehicle. The at least one collision threshold may include the time to collision. The at least one processing device may be configured to cause the user vehicle to return to the center of the lane where the user vehicle originally traveled after completing the avoidance action. The at least one image capturing device may have a field of view of at least 140 degrees. The at least one processing device may be configured to cause the user's vehicle to return to a preset speed after braking in response to the intruding vehicle. The at least one processing device may be configured to cause the user vehicle to return to the lane location within the first lane constraint and the second lane constraint, so that after changing the route in response to the intruding vehicle, the user vehicle and the The first distance between first lane constraints is substantially equal to the second distance between the user vehicle and the second lane constraints.

[0039]

Consistent with another disclosed embodiment, a method for navigating a user's vehicle is provided.

The method may include: using at least one image capturing device to acquire a plurality of images of an area near the user's vehicle; determining a first lane constraint on the first side of the user's vehicle based on the plurality of images; Images determine a second lane constraint on a second side of the user vehicle opposite to the first side of the user vehicle, wherein the first lane constraint and the second lane constraint define the user vehicle to travel Determining whether an intruding vehicle approaches from one side of the user vehicle based on the multiple images; and causing the user vehicle to maintain the current speed and travel within the first lane constraint and the second lane constraint, The first distance on the side of the user's vehicle where the invading vehicle is approaching is made greater than the second distance.

[0040]

Consistent with the disclosed embodiments, a driver-assisted navigation system for a host vehicle is provided.

The system may include: at least one image capturing device configured to acquire a plurality of images of a region near the host vehicle; a data interface; and at least one processing device. The at least one processing device may be configured to: receive the plurality of images via the data interface; identify the target object in the plurality of images; monitor the movement of the target object and the host via the plurality of images The distance between the vehicle and the target object; an indicator that determines the interception time between the host vehicle and the target object based on the monitored movement and the distance between the host vehicle and the target object; and The response of the host vehicle is generated based on the comparison of the interception time with a plurality of predetermined interception thresholds.

[0041]

Consistent with the disclosed embodiment, the target object may be a target vehicle traveling in a lane different from the host vehicle.

The interception time may be based on an indicator of the speed of the tracked object determined by the plurality of images. The interception time may be based on an indicator of the acceleration of the tracked object determined by the plurality of images. The at least one processing device may be further configured to determine whether the target object is traveling in the same lane as the host vehicle, and if it is determined that the target object is traveling in a different lane from the host vehicle, abandon the The response of the host vehicle. Determining whether the target object is traveling in the same lane as the host vehicle may be based on the plurality of images. Determining whether the target object is traveling in the same lane as the host vehicle may be based on at least one of predetermined map data or yaw rate of the host vehicle. If the indicator of interception time indicates that the target object is outside the first interception threshold relative to the vehicle, the response may be based on an average motion profile associated with the target object. If the indicator of the interception time indicates that the target object is between the first interception threshold and the second interception threshold relative to the vehicle, the response may be based on the actual movement of the target object. If the indicator of interception time indicates that the target object is within the second interception threshold, the response may include an emergency avoidance action. The emergency avoidance action may include lane change and/or emergency braking.

[0042]

Consistent with another disclosed embodiment, a host vehicle may include: a main body; at least one image capturing device configured to acquire a plurality of images of an area near the host vehicle; a data interface; and at least A processing device.

The at least one processing device may be configured to: receive the plurality of images via the data interface; identify the target object in the plurality of images; monitor the movement of the target object and the host via the plurality of images The distance between the vehicle and the target object; an indicator that determines the interception time between the host vehicle and the target object based on the monitored movement and the distance between the host vehicle and the target object; and The response of the host vehicle is generated based on the comparison of the interception time with a plurality of predetermined interception thresholds.

[0043]

Consistent with the disclosed embodiment, the target object may be a target vehicle traveling in a lane different from the host vehicle.

The interception time may be based on an indicator of the speed of the tracked object determined by the plurality of images. The interception time may be based on an indicator of the acceleration of the tracked object determined by the plurality of images. The at least one processing device may be further configured to determine whether the target object is traveling in the same lane as the host vehicle, and if it is determined that the target object is traveling in a different lane from the host vehicle, abandon the The response of the host vehicle. Determining whether the target object is traveling in the same lane as the host vehicle may be based on the plurality of images. Determining whether the target object is traveling in the same lane as the host vehicle may be based on at least one of predetermined map data or yaw rate of the host vehicle. If the indicator of interception time indicates that the target object is outside the first interception threshold relative to the vehicle, the response may be based on an average motion profile associated with the target object. If the indicator of the interception time indicates that the target object is between the first interception threshold and the second interception threshold relative to the vehicle, the response may be based on the actual movement of the target object. If the indicator of interception time indicates that the target object is within the second interception threshold, the response may include an emergency avoidance action. The emergency avoidance action may include lane change and/or emergency braking.

[0044]

Consistent with another disclosed embodiment, a method for navigating a host vehicle may include: acquiring a plurality of images of an area near the host vehicle via at least one image capturing device; identifying a target object in the plurality of images; based on The plurality of images are used to monitor the movement of the target object and the distance between the host vehicle and the target object; determine the movement based on the monitored movement and the distance between the host vehicle and the target object An indicator of the interception time between the host vehicle and the target object; and generating the response of the host vehicle based on a comparison of the interception time with a plurality of predetermined interception thresholds.

[0045]

Consistent with the disclosed embodiments, a driver assistance navigation system for a vehicle is provided.

The system may include: at least one image capturing device configured to acquire a plurality of images of an area near the vehicle; a data interface; and at least one processing device.

The at least one processing device may be configured to: receive the plurality of images via the data interface; identify a trigger for stopping the vehicle based on analysis of the plurality of images; and the trigger based on the identification , Causing the vehicle to stop according to the braking profile, as determined based on the analysis of the plurality of images, the braking profile including a first section associated with a first deceleration rate, having a The second section of the second deceleration rate of the speed and the third section where the braking level is reduced when approaching the target stopping point.

[0046]

Consistent with the disclosed embodiments, reaching the target stopping point may be accompanied by the release of brake pressure.

The trigger may include an object. The object may include another vehicle in front of the vehicle. The trigger may include a traffic light signal, a stop sign, and/or a speed limit sign. The at least one processing device may be further configured to provide a voice notification identifying the trigger. The at least one processing device may be configured to generate a voice notification indicating that the vehicle is braking.

[0047]

Consistent with another disclosed embodiment, a vehicle may include: a main body; at least one image capturing device configured to acquire a plurality of images of an area near the vehicle; a data interface; and at least one processing Device.

The at least one processing device may be configured to: receive the plurality of images via the data interface; identify a trigger for stopping the vehicle based on analysis of the plurality of images; and the trigger based on the identification A device to cause the vehicle to stop according to a braking profile, as determined based on the analysis of the plurality of images, the braking profile includes a first section associated with a first deceleration rate, and has a The second section of the second deceleration rate of the speed and the third section where the braking level is reduced when approaching the target stopping point.

[0048]

Consistent with the disclosed embodiments, reaching the target stopping point may be accompanied by the release of brake pressure.

The trigger may include an object. The object may include another vehicle in front of the vehicle. The trigger may include a traffic light signal, a stop sign, and/or a speed limit sign. The at least one processing device may be further configured to provide a voice notification identifying the trigger. The at least one processing device may be configured to generate a voice notification indicating that the vehicle is braking.

[0049]

Consistent with another disclosed embodiment, a method for navigating a vehicle is provided.

The method may include: acquiring a plurality of images of an area near the vehicle via at least one image capturing device; identifying a trigger for stopping the vehicle based on analysis of the plurality of images; and the trigger based on the identification , Causing the vehicle to stop according to the braking profile, as determined based on the analysis of the plurality of images, the braking profile includes a first section associated with a first deceleration rate, and has a first section that is less than the first deceleration rate The second section of the second deceleration rate and the third section that reduces the braking level when approaching the target stopping point.

[0050]

Consistent with other disclosed embodiments, a non-transitory computer-readable storage medium may store program instructions, which are executed by at least one processing device and execute any method described herein.

[0051]

The foregoing general description and the following detailed description are only exemplary and illustrative and do not limit the claims.

[0052]

Description of the drawings

[0053]

The drawings incorporated in and forming a part of the present disclosure illustrate various disclosed embodiments.

In the picture:

[0054]

Figure 1 is a schematic representation of an exemplary system consistent with the disclosed embodiments.

[0055]

Figure 2A is a schematic side view representation of an exemplary vehicle including a system consistent with the disclosed embodiments.

[0056]

Figure 2B is a schematic top view representation of the vehicle and system shown in Figure 2A consistent with the disclosed embodiment.

[0057]

Figure 2C is a schematic top view representation of another embodiment of a vehicle including a system consistent with the disclosed embodiment.

[0058]

Figure 2D is a schematic top view representation of another embodiment of a vehicle including a system consistent with the disclosed embodiment.

[0059]

Figure 2E is a schematic top view representation of yet another embodiment of a vehicle including a system consistent with the disclosed embodiment.

[0060]

Figure 2F is a schematic representation of an exemplary vehicle control system consistent with the disclosed embodiments.

[0061]

Figure 3A is a schematic representation of the interior of a vehicle consistent with the disclosed embodiment, including a rearview mirror and a user interface for the vehicle imaging system.

[0062]

3B is an illustration of an example of a camera mount configured to be positioned behind the rearview mirror and against the windshield of the vehicle consistent with the disclosed embodiment.

[0063]

FIG. 3C is an illustration of a camera mount with a different viewing angle shown in FIG. 3B consistent with the disclosed embodiment.

[0064]

3D is an illustration of an example of a camera mount configured to be positioned behind the rearview mirror and against the windshield of the vehicle consistent with the disclosed embodiment.

[0065]

4 is an exemplary block diagram of a memory configured to store instructions for performing one or more operations consistent with the disclosed embodiments.

[0066]

FIG. 5A is a flowchart showing an exemplary process for generating one or more navigation responses based on monocular image analysis consistent with the disclosed embodiments.

[0067]

FIG. 5B is a flowchart showing an exemplary process for detecting one or more vehicles and/or pedestrians in a set of images consistent with the disclosed embodiments.

[0068]

FIG. 5C is a flowchart showing an exemplary process for detecting road signs and/or lane geometric information in a set of images consistent with the disclosed embodiments.

[0069]

FIG. 5D is a flowchart showing an exemplary process for detecting traffic lights in a set of images consistent with the disclosed embodiments.

[0070]

FIG. 5E is a flowchart showing an exemplary process for generating one or more navigation responses based on a vehicle path consistent with the disclosed embodiment.

[0071]

FIG. 5F is a flowchart showing an exemplary process for determining whether the vehicle in front changes lanes, consistent with the disclosed embodiment.

[0072]

FIG. 6 is a flowchart showing an exemplary process for generating one or more navigation responses based on stereoscopic image analysis consistent with the disclosed embodiments.

[0073]

FIG. 7 is a flowchart showing an exemplary process for generating one or more navigation responses based on three sets of image analysis consistent with the disclosed embodiments.

[0074]

Figure 8A is a schematic representation of an exemplary vehicle traveling within a first lane constraint and a second lane constraint consistent with the disclosed embodiment, where the lane offset condition exists on the first vehicle side.

[0075]

FIG. 8B is a schematic representation of an exemplary vehicle traveling within the first lane constraint and the second lane constraint consistent with the disclosed embodiment, where the lane offset condition exists on the second vehicle side.

[0076]

FIG. 8C is a schematic representation of an exemplary vehicle traveling within a first lane constraint and a second lane constraint on a curved road consistent with the disclosed embodiment.

[0077]

8D is a schematic representation of an exemplary vehicle traveling within the first lane constraint and the second lane constraint consistent with the disclosed embodiment, wherein the lane offset condition exists on both the first vehicle side and the second vehicle side .

[0078]

Figure 9 is a schematic representation of the memory of an exemplary navigation system consistent with the disclosed embodiments.

[0079]

FIG. 10 is a flowchart of an exemplary method for navigating a vehicle consistent with the disclosed embodiment.

[0080]

Figure 11 is a schematic representation of an exemplary vehicle including a navigation system traveling in a default lane consistent with the disclosed embodiments.

[0081]

Figure 12A is a schematic representation of the memory of an exemplary navigation system consistent with the disclosed embodiments.

[0082]

FIG. 12B is a flowchart of an exemplary process for navigating a vehicle consistent with the disclosed embodiment.

[0083]

Figures 13A and 13B are schematic representations of an exemplary vehicle approaching and navigating a curve having one or more characteristics consistent with the disclosed embodiments.

[0084]

FIG. 14 is an exemplary block diagram of a memory configured to store instructions for performing one or more operations consistent with the disclosed embodiments.

[0085]

FIG. 15 is a flowchart showing an exemplary process for controlling the vehicle speed based on the detected curve and the observed curve characteristic consistent with the disclosed embodiment.

[0086]

16A to 16D are schematic representations of a host vehicle that imitates one or more actions of the preceding vehicle consistent with the disclosed embodiment.

[0087]

FIG. 17 is an exemplary block diagram of a memory configured to store instructions for performing one or more operations consistent with the disclosed embodiments.

[0088]

FIG. 18 is a flowchart showing an exemplary process for causing the host vehicle to imitate one or more actions of the preceding vehicle consistent with the disclosed embodiment.

[0089]

FIG. 19 is a flowchart showing an exemplary process for causing the host vehicle to refuse to imitate the turn of the preceding vehicle consistent with the disclosed embodiment.

[0090]

FIG. 20 is a flowchart showing an exemplary process for causing the host vehicle to imitate or refuse the turn of the preceding vehicle consistent with the disclosed embodiment.

[0091]

FIG. 21 is a flowchart showing another exemplary process for causing the host vehicle to imitate one or more actions of the preceding vehicle consistent with the disclosed embodiment.

[0092]

FIG. 22 is a flowchart showing an exemplary process for causing the host vehicle to imitate one or more actions of the preceding vehicle based on the navigation history, consistent with the disclosed embodiment.

[0093]

FIG. 23 is a schematic representation of an exemplary vehicle traveling within a first lane constraint and a second lane constraint on a road along which another vehicle is traveling, consistent with the disclosed embodiment.

[0094]

FIG. 24A is a schematic representation of a memory that stores instructions for navigating the vehicle in an invading vehicle consistent with the disclosed embodiment.

[0095]

FIG. 24B is a flowchart of an exemplary process for navigating a vehicle among an invading vehicle consistent with the disclosed embodiment.

[0096]

FIG. 25 is a schematic representation of an exemplary vehicle traveling within a first lane constraint and a second lane constraint on a road along which another vehicle is traveling, consistent with the disclosed embodiment.

[0097]

Fig. 26 is a schematic representation of a memory storing instructions for detecting and responding to lateral intrusion of vehicle traffic consistent with the disclosed embodiment.

[0098]

FIG. 27 is a flowchart of an exemplary process for detecting and responding to lateral intrusion of vehicle traffic consistent with the disclosed embodiments.

[0099]

28A and 28B are schematic representations of generating a host vehicle response consistent with the disclosed embodiment.

[0100]

FIG. 29 is an exemplary block diagram of a memory configured to store instructions for performing one or more operations consistent with the disclosed embodiments.

[0101]

FIG. 30 is a flowchart showing an exemplary process for generating a host vehicle response consistent with the disclosed embodiment.

[0102]

FIG. 31 is a flowchart showing an exemplary process for refusing to generate a host vehicle response consistent with the disclosed embodiment.

[0103]

FIG. 32A is a schematic representation of an exemplary vehicle in which an object exists in the vicinity of the vehicle consistent with the disclosed embodiment.

[0104]

Figure 32B illustrates an exemplary braking profile consistent with the disclosed embodiment.

[0105]

Figure 33 is a schematic representation of the memory of an exemplary navigation system consistent with the disclosed embodiments.

[0106]

FIG. 34 is a flowchart of an exemplary method for implementing a braking profile while navigating a vehicle, consistent with the disclosed embodiment.

[0107]

Detailed ways

[0108]

The following detailed description refers to the accompanying drawings.

Where possible, the same reference signs are used in the figures and in the following description to refer to the same or similar parts.

Although several illustrative embodiments have been described herein, modifications, adaptations, and other implementations are possible.

For example, substitutions, additions, or modifications can be made to the components illustrated in the figures, and the illustrative methods described herein can be modified by substituting, reordering, removing, or adding steps to the disclosed methods.

Therefore, the following detailed description is not limited to the disclosed embodiments and examples.

Instead, the proper scope is defined by the appended claims.

[0109]

The disclosed embodiments provide systems and methods that use cameras to provide autonomous navigation features.

In various embodiments, the system may include one, two, or more cameras that monitor the environment of the vehicle.

In one embodiment, the system can monitor and adjust the free space between the vehicle and the lane boundary in which the vehicle travels.

In another embodiment, the system can select a specific lane as the default lane used by the vehicle while traveling.

In another embodiment, the system can control the speed of the vehicle in different scenarios, such as when turning.

In yet another embodiment, the system can mimic the actions of the preceding vehicle.

In yet another embodiment, the system may mo. itor the target vehicle and enable the vehicle to pass the target vehicle under certain conditions (for example, if the lane in which the target vehicle travels is different from the lane in which the vehicle travels).

In yet another embodiment, the system may generate a natural feel in response to a lateral intrusion into a vehicle, such as a vehicle attempting to enter the lane in which the vehicle is traveling.

[0110]

Figure 1 is a block diagram representation of a system 100 consistent with an exemplary disclosed embodiment.

Depending on the requirements of a particular implementation, the system 100 may include various components.

In some embodiments, the system 100 may include a processing unit 110, an image acquisition unit 120, a position sensor 130, one or more memory units 140, 150, a map database 160, and a user interface 170.

The processing unit 110 may include one or more processing devices.

In some embodiments, the processing unit 110 may include an application processor 180, an image processor 190, or any other suitable processing device.

Similarly, depending on the requirements of a particular application, the image acquisition unit 120 may include any number of image acquisition devices and components.

In some embodiments, the image capturing unit 120 may include one or more image capturing devices (for example, cameras), such as the image capturing device 122, the image capturing device 124, and the image capturing device 126.

The system 100 may further include a data interface 128 that communicatively connects the processing device 110 and the image acquisition device 120.

For example, the data interface 128 may include any one or more wired and/or wireless links for sending the image data acquired by the image acquisition device 120 to the processing unit 110.

[0111]

Both the application processor 180 and the image processor 190 may include various types of processing devices.

For example, either or both of the application processor 180 and the image processor 190 may include a microprocessor, a pre-processor (such as an image pre-processor), a graphics processor, a central processing unit (CPU), support circuits, Digital signal processor, integrated circuit, memory or any other type of device suitable for running application programs and image processing and analysis.

In some embodiments, the application processor 180 and/or the image processor 190 may include any type of single-core or multi-core processors, mobile device microcontrollers, central processing units, and so on.

Various processing devices may be used, including, for example, processors available from manufacturers such as , and may include various structures (for example, x86 processors, , etc.).

[0112]

In some embodiments, the application processor 180 and/or the image processor 190 may include any EyeQ series processor chips available from .

These processor designs each include multiple processing units with local memory and instruction sets.

Such a processor may include a video input for receiving image data from a plurality of image sensors, and may also include a video output function.

In one example, uses 90 nanometer micron technology operating at 332Mhz.

The structure of is as follows: two floating-point, hyper-threaded 32-bit RISC CPU (core), five visual computing engines (VCE), three vector microcode processors Denali 64-bit mobile DDR controller, 128-bit internal Supersonic interconnection, dual 16-bit video input controller and 18-bit video output controller, 16-channel DMA and several peripherals.

The MIPS34K CPU manages five VCEs, three VMPTMs and DMA, a second MIPS34K CPU and multi-channel DMA, and other peripherals.

Five VCEs, three and MIPS34K CPUs can perform the intensive visual calculations required by multifunctional bundled applications.

In another example, , which is a third-generation processor and six times more powerful than , can be used in the disclosed implementation.

[0113]

Although Figure 1 depicts two separate processing devices included in the processing unit 110, more or fewer processing devices may be used.

For example, in some embodiments, a single processing device may be used to complete the tasks of the application processor 180 and the image processor 190.

In other embodiments, these tasks may be performed by more than two processing devices.

[0114]

The processing unit 110 may include various types of devices.

For example, the processing unit 110 may include various devices, such as a controller, an image preprocessor, a central processing unit (CPU), a support circuit, a digital signal processor, an integrated circuit, a memory, or any other type for image processing and analysis. installation.

The image preprocessor may include a video processor for capturing, digitizing, and processing images from the image sensor.

The CPU may include any number of microcontrollers or microprocessors.

The support circuit can be any number of circuits generally known in the art, including cache, power supply, clock, and input and output circuits.

The memory can store software that, when executed by the processor, controls the operation of the system.

The memory may include a database and image processing software.

The memory may include any number of random access memory, read-only memory, flash memory, disk drives, optical storage media, tape storage media, removable storage media, and other types of storage media.

In one example, the memory may be detached from the processing unit 110.

In another example, the memory may be integrated into the processing unit 110.

[0115]

Each memory 140, 150 may include software instructions that, when executed by a processor (for example, the application processor 180 and/or the image processor 190), can control various aspects of the operation of the system 100.

These memory units may include various databases and image processing software.

The memory unit may include random access memory, read-only memory, flash memory, disk drives, optical storage media, tape storage media, removable storage media, and/or any other types of storage media.

In some embodiments, the memory units 140, 150 may be separated from the application processor 180 and/or the image processor 190.

In other embodiments, these memory units may be integrated into the application processor 180 and/or the image processor 190.

[0116]

The position sensor 130 may include any type of device suitable for determining a location associated with at least one component of the system 100.

In some embodiments, the location sensor 130 may include a GPS receiver.

Such a receiver can determine the user's location and speed by processing signals propagated by GPS satellites.

The position information from the position sensor 130 can be used by the application processor 180 and/or the image processor 190.

[0117]

The user interface 170 may include any device suitable for providing information to or for receiving input from one or more users of the system 100.

In some embodiments, the user interface 170 may include user input devices, including, for example, a touch screen, a microphone, a keyboard, a pointing device, a tracking wheel, a camera, a knob, a button, and so on.

In the case of such an input device, the user can provide information input or commands to the system 100 through the following means: typing instructions or information, providing voice commands, using buttons, pointers, or eye-tracking functions to select menu options on the screen or using Any other suitable technology for communicating information with the system 100.

[0118]

The user interface 170 may be equipped with one or more processing devices configured to provide information to or receive information from the user and process the information for use by the application processor 180, for example.

In some embodiments, such a processing device can execute instructions to recognize and track eye movements, receive and interpret voice commands, recognize and interpret touches and/or gestures made on the touch screen, and respond to keyboard input or menu selection ,and many more.

In some embodiments, the user interface 170 may include a display, a speaker, a haptic device, and/or any other device for providing output information to the user.

[0119]

The map database 160 may include any type of database for storing map data useful to the system 100.

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In some embodiments, the map database 160 may include location-related data in a reference coordinate system for various items, including roads, water features, geographic features, businesses, points of interest, restaurants, gas stations, etc. .

The map database 160 can store not only the locations of such items, but also descriptive words related to these items (including, for example, names associated with any stored features).

In some embodiments, the map database 160 may be physically located with other components of the system 100.

Alternatively or in addition, the map database 160 or a portion thereof may be remotely located relative to other components of the system 100 (e.g., the processing unit 110).

In such an embodiment, the information from the map database 160 may be downloaded through a wired or wireless data connection of the network (for example, through a cellular network and/or the Internet, etc.).

[0120]

The image capture devices 122, 124, and 126 may each include any type of device suitable for capturing at least one image from the environment.

Moreover, any number of image capture devices can be used to capture images for input to the image processor.

Some embodiments may include only a single image capture device, while other embodiments may include two, three, or even more than four image capture devices.

The image capturing devices 122, 124, and 126 will be further described below with reference to FIGS. 2B to 2E.

[0121]

The system 100 or its various components can be integrated into a variety of different platforms.

In some embodiments, the system 100 may be included on a vehicle 200 as shown in FIG. 2A.

For example, as described above with respect to FIG. 1, the vehicle 200 may be equipped with the processing unit 110 and any other components of the system 100.

While in some embodiments, the vehicle 200 may only be equipped with a single image capture device (eg, a camera), in other embodiments such as those discussed in conjunction with FIGS. 2B to 2E, multiple image capture devices may be used.

For example, any one of the image capturing devices 122 and 124 of the vehicle 200 as shown in FIG. 2A may be part of an ADAS (Advanced Driver Assistance System) imaging group.

[0122]

The image capturing device included on the vehicle 200 as a part of the image capturing unit 120 may be located at any suitable location.

In some embodiments, as shown in FIGS. 2A to 2E and 3A to 3C, the image capture device 122 may be located near the rearview mirror.

This location can provide a line of sight (similar to the line of sight of the driver of the vehicle 200), which can help determine what is visible to the driver and what is invisible.

The image capture device 122 can be positioned anywhere near the rear view mirror, but placing the image capture device 122 on the side of the mirror that is on the driver can further help obtain an image representing the driver's field of view and/or line of sight.

[0123]

For the image capturing device of the image capturing unit 120, other locations may also be used.

For example, the image capture device 124 may be located on or in the bumper of the vehicle 200.

Such a location may be particularly suitable for image capture devices with a wide field of view.

The line of sight of the image capturing device located on the bumper may be different from the line of sight of the driver, and therefore, the bumper image capturing device and the driver may not always see the same object.

Image capture devices (e.g., image capture devices 122, 124, and 126) may also be located in other locations.

For example, the image capture device can be located on or in one or two side mirrors of the vehicle 200, on the roof of the vehicle 200, on the hood of the vehicle 200, on the trunk of the vehicle 200, or on the side of the vehicle 200. On any window of the vehicle 200, positioned behind or in front of any window of the vehicle 200, installed in or near the light map on the front and/or back of the vehicle 200, and so on.

[0124]

In addition to the image capture device, the vehicle 200 may include various other components of the system 100.

For example, the processing unit 110 may be included in the vehicle 200, and may be integrated or separated from an engine control unit (ECU) of the vehicle.

The vehicle 200 may also be equipped with a position sensor 130 such as a GPS receiver, and may also include a map database 160 and memory units 140 and 150.

[0125]

Figure 2A is a schematic side view representation of an exemplary vehicle imaging system consistent with the disclosed embodiments.

Fig. 2B is a schematic top view illustration of the embodiment shown in Fig. 2A. As illustrated in FIG. 2B, the disclosed embodiment may include a vehicle 200 that includes a system 100 in its body, the system 100 having a first image capture positioned near the rearview mirror and/or near the driver of the vehicle 200 The device 122, the second image capturing device 124 positioned on or in the bumper area (for example, one of the bumper areas 210) of the vehicle 200, and the processing unit 110.

[0126]

As illustrated in FIG. 2C, both the image capture devices 122 and 124 may be positioned near the rearview mirror and/or near the driver of the vehicle 200.

In addition, although two image capture devices 122 and 124 are shown in FIGS. 2B and 2C, it should be understood that other embodiments may include more than two image capture devices. For example, in the embodiments shown in FIGS. 2D and 2E, the first image capturing device 122, the second image capturing device 124, and the third image capturing device 126 are included in the system 100 of the vehicle 200.

[0127]

As illustrated in FIG. 2D, the image capture device 122 may be located near the rearview mirror and/or near the driver of the vehicle 200, and the image capture devices 124 and 126 may be located in the bumper area of the vehicle 200 (e.g., bumper One of the regions 210) above or in the middle.

And as shown in FIG. 2E, the image capturing devices 122, 124, and 126 may be positioned near the rearview mirror and/or near the driver's seat of the vehicle 200. The disclosed embodiments are not limited to any specific number and configuration of image capture devices, and the image capture devices may be located in any suitable location within and/or on the vehicle 200.

[0128]

It should be understood that the disclosed embodiments are not limited to vehicles and can be applied in other contexts.

It should also be understood that the disclosed embodiments are not limited to a particular type of vehicle 200 and can be applied to all types of vehicles, including automobiles, trucks, trailers, and other types of vehicles.

[0129]

The first image capture device 122 may include any suitable type of image capture device.

The image capture device 122 may include an optical axis. In one example, the image capture device 122 may include an Aptina M9V024WVGA sensor with a global shutter. In other embodiments, the image capture device 122 may provide a resolution of 1280×960 pixels and may include a rolling shutter. The image capturing device 122 may include various optical elements. In some embodiments, for example, one or more lenses may be included to provide a desired focal length and field of view for the image capture device. In some embodiments, the image capture device 122 may be associated with a 6mm lens or a 12mm lens. In some embodiments, as illustrated in FIG. 2D, the image capture device 122 may be configured to capture an image having a desired field of view (FOV) 202. For example, the image capturing device 122 may be configured to have a conventional FOV, such as in the range of 40 degrees to 56 degrees, including 46 degrees FOV, 50 degrees FOV, and 52 degrees FOV or more. Alternatively, the image capturing device 122 may be configured to have a narrow FOV in the range of 23 degrees to 40 degrees, such as a 28-degree FOV or a 36-degree FOV. In addition, the image capturing device 122 may be configured to have a wide FOV in the range of 100 degrees to 180 degrees. In some embodiments, the image capture device 122 may include a wide-angle bumper camera or have a FOV up to 180 degrees.

[0130]

The first image capturing device 122 may acquire a plurality of first images with respect to a scene associated with the vehicle 200.

Each of the plurality of first images can be acquired as a series of image scan lines that can be captured using a rolling shutter. Each scan line may include multiple pixels.

[0131]

The first image capture device 122 may have a scan rate associated with acquiring each of the scan lines of the first series of images.

The scan rate may refer to a rate at which the image sensor can acquire image data associated with each pixel included in a specific scan line.

[0132]

For example, the image capture devices 122, 124, and 126 may include any suitable type and number of image sensors, including CCD sensors or CMOS sensors.

In one embodiment, a CMOS image sensor can be used together with a rolling shutter, so that each pixel in a row is read one at a time, and the scanning of the row is performed on a line by line basis until the entire image frame has been captured . In some embodiments, the row can be captured sequentially from top to bottom with respect to the frame.

[0133]

Using a rolling shutter can cause pixels in different rows to be exposed and captured at different times, which can cause skew and other image artifacts in the captured image frame.

On the other hand, when the image capture device 122 is configured to operate with a global or synchronized shutter, all pixels can be exposed for the same amount of time and in a common exposure period. As a result, the image data of the frames collected from the system using the global shutter represents a snapshot of the entire FOV (such as FOV 202) at a specific time. In contrast, in a rolling shutter application, each line in the frame is exposed and the data is captured at different times. As a result, the moving object may appear to be distorted in an image capture device with a rolling shutter. This phenomenon will be described in more detail below.

[0134]

The second image capturing device 124 and the third image capturing device 126 may be any types of image capturing devices.

Like the first image capture device 122, each of the image capture devices 124 and 126 may include an optical axis. In one embodiment, each of the image capture devices 124 and 126 may include an Aptina M9V024 WVGA sensor with a global shutter. Alternatively, each of the image capture devices 124 and 126 may include a rolling shutter. Like the image capturing

device 122, the image capturing devices 124 and 126 may be configured to include various lenses and optical elements. In some embodiments, the lenses associated with image capture devices 124 and 126 may provide FOVs (such as FOVs 204 and 206) that are equal to or narrower than the FOV associated with image capture device 122 (such as FOV 202). For example, the image capture devices 124 and 126 may have a FOV of 40 degrees, 30 degrees, 26 degrees, 23 degrees, 20 degrees or less.

[0135]

The image capturing devices 124 and 126 may acquire a plurality of second images and third images with respect to the scene associated with the vehicle 200.

Each of the plurality of second images and third images can be acquired as scan lines of the second series and the third series that can be captured using a rolling shutter. Each scan line or row can have multiple pixels. The image capturing devices 124 and 126 may have a second scan rate and a third scan rate associated with acquiring each image scan line included in the second series and the third series.

[0136]

Each image capture device 122, 124, and 126 can be positioned in any suitable position and orientation relative to the vehicle 200.

The relative positioning of the image capture devices 122, 124, and 126 can be selected to help merge the information acquired from the image capture devices. For example, in some embodiments, the FOV associated with the image capture device 124 (such as FOV 204) may be partially related to the FOV associated with the image capture device 122 (such as FOV 202) and the FOV associated with the image capture device 126 (such as FOV 206). Or completely overlap.

[0137]

The image capture devices 122, 124, and 126 may be located at any suitable relative height on the vehicle 200.

In one example, there may be a height difference between the image capture devices 122, 124, and 126, which may provide sufficient disparity information to enable stereo analysis. For example, as shown in FIG. 2A, the two image capturing devices 122 and 124 are at different heights. For example, there may also be a lateral displacement difference between the image capturing devices 122, 124, and 126, which provides additional disparity information for the stereo analysis of the processing unit 110. The lateral displacement difference can be recorded as dx, as shown in Figure 2C and Figure 2D. In some embodiments, front-to-back displacement (eg, range displacement) may exist between the image capture devices 122, 124, and 126. For example, the image capture device 122 may be located 0.5 meters to more than 2 meters behind the image capture device 124 and/or the image capture device 126. This type of displacement enables one of the image capture devices to cover the potential blind spot of the other image capture device.

[0138]

The image capture device 122 may have any suitable resolution function (for example, the number of pixels associated with the image sensor), and the resolution of the image sensor associated with the image capture device 122 may be greater than, less than, or equal to that of the image capture devices 124 and 126 The resolution of the associated image sensor.

In some embodiments, the image sensors associated with image capture device 122 and/or image capture devices 124 and 126 may have a resolution of 640 x 480, 1024 x 768, 1280 x 960, or have any other suitable resolution.

[0139]

The frame rate (for example, the rate at which the image capture device acquires a set of pixel data for an image frame before moving to capture the pixel data associated with the next image frame) may be controllable.

The frame rate associated with image capture device 122 may be greater than, less than, or equal to the frame rate associated with image capture devices 124 and 126. The frame rate associated with the image capture devices 122, 124, and 126 may depend on various factors that may affect the timing of the frame rate. For example, one or more of the image capture devices 122, 124, and 126 may include information imposed before or after acquiring image data associated with one or more pixels of the image sensor in the image capture device 122, 124, and/or 126. Optional pixel delay period. Generally, the image data

corresponding to each pixel can be acquired according to the clock rate of the device (for example, one pixel per clock cycle). In addition, in embodiments that include rolling shutters, one or more of the image capture devices 122, 124, and 126 may be included in acquiring a row of pixels associated with the image sensor in the image capture devices 122, 124, and/or 126. An optional horizontal blanking period imposed before or after the image data. Further, one or more of the image capture devices 122, 124, and/or 126 may include an optional vertical blanking period that is imposed before or after the image data associated with the image frames of the image capture devices 122, 124, and 126 are acquired.

[0140]

These timing controls can synchronize the frame rates associated with image capture devices 122, 124, and 126, even when the line scan rate of each image capture device is different.

In addition, as will be discussed in more detail below, among other factors (e.g., image sensor resolution, maximum line scan rate, etc.), these optional timing controls can make the FOV of the image capture device 122 and image capture The image capture of the area where one or more FOVs of the devices 124 and 126 overlap is synchronized, even when the field of view of the image capture device 122 is different from the FOV of the image capture devices 124 and 126.

[0141]

The frame rate timing of the image capture devices 122, 124, and 126 may depend on the resolution of the associated image sensor.

For example, assuming that two devices have similar line scan rates, if one device includes an image sensor with a resolution of 640 x 480 and the other device includes an image sensor with a resolution of 1280 x 960, it will take more time to obtain data from Frames of image data with higher resolution sensors.

[0142]

Another factor that can affect the timing of image data acquisition by the image capture devices 122, 124, and 126 is the maximum line scan rate.

For example, acquiring one line of image data of the image sensors included in the image capture devices 122, 124, and 126 will require some minimum amount of time. Assuming no pixel delay period is added, this minimum amount of time to acquire one line of image data will be related to the maximum line scan rate of a particular device. Devices that provide a higher maximum line scan rate potentially provide a larger frame rate than devices that have a smaller maximum line scan rate. In some embodiments, the maximum line scan rate of one or more of the image capture devices 124 and 126 may be greater than the maximum line scan rate associated with the image capture device 122. In some embodiments, the maximum line scan rate of the image capture device 124 and/or 126 may be 1.25 times, 1.5 times, 1.75 times, or more than 2 times the maximum line scan rate of the image capture device 122.

[0143]

In another embodiment, the image capture devices 122, 124, and 126 may have the same maximum line scan rate, but the image capture device 122 may operate at a scan rate less than or equal to its maximum scan rate.

The system may be configured such that one or more of the image capture devices 124 and 126 operate at a line scan rate equal to the line scan rate of the image capture device 122. In other examples, the system may be configured such that the line scan rate of the image capture device 124 and/or the image capture device 126 may be 1.25 times, 1.5 times, 1.75 times, or more than 2 times the line scan rate of the image capture device 122 .

[0144]

In some embodiments, the image capture devices 122, 124, and 126 may be asymmetrical.

That is, they may include cameras with different fields of view (FOV) and focal lengths. For example, the field of view of the image capture devices 122, 124, and 126 may include any desired area relative to the environment of the vehicle 200. In some embodiments, one or more of the image capture devices 122, 124, and 126 may be configured to acquire image data from the environment in front of the vehicle 200, behind the vehicle 200, from the side of the vehicle 200, or a combination thereof.

[0145]

Further, the focal length associated with each image capture device 122, 124, and/or 126 may be optional (for example, by including an appropriate lens, etc.) so that each device captures a desired distance range relative to the vehicle 200 The image of the object at the location.

For example, in some embodiments, the image capture devices 122, 124, and 126 may acquire images of close-up objects within a few meters of the vehicle. The image capturing devices 122, 124, and 126 may also be configured to acquire images of objects farther away from the vehicle (for example, 25m, 50m, 100m, 150m or more). Further, the focal lengths of the image capturing devices 122, 124, and 126 can be selected so that one image capturing device (for example, the image capturing device 122) can acquire images of objects relatively close to the vehicle (for example, within 10 m or within 20 m), and other images Capture devices (eg, image capture devices 124 and 126) can capture images of objects farther from the vehicle 200 (eg, greater than 20m, 50m, 100m, 150m, etc.).

[0146]

According to some embodiments, the FOV of one or more image capture devices 122, 124, and 126 may have a wide angle.

For example, especially for image capturing devices 122, 124, and 126 that can be used to capture images of areas near the vehicle 200, it may be advantageous to have a FOV of 140 degrees. For example, the image capture device 122 may be used to capture an image of an area on the right or left of the vehicle 200, and in such an embodiment, the image capture device 122 may desirably have a wide FOV (e.g., at least 140 degrees).

[0147]

The field of view associated with each of the image capture devices 122, 124, and 126 may depend on the corresponding focal length.

For example, as the focal length increases, the corresponding field of view decreases.

[0148]

The image capture devices 122, 124, and 126 may be configured to have any suitable field of view.

In a specific example, the image capture device 122 may have a horizontal FOV of 46 degrees, the image capture device 124 may have a horizontal FOV of 23 degrees, and the image capture device 126 may have a horizontal FOV between 23 degrees and 46 degrees. In another example, the image capture device 122 may have a horizontal FOV of 52 degrees, the image capture device 124 may have a horizontal FOV of 26 degrees, and the image capture device 126 may have a horizontal FOV between 26 degrees and 52 degrees. In some embodiments, the ratio of the FOV of the image capture device 122 to the FOV of the image capture device 124 and/or the image capture device 126 may vary from 1.5 to 2.0. In other embodiments, the ratio can vary between 1.25 and 2.25.

[0149]

The system 100 may be configured such that the field of view of the image capture device 122 and the field of view of the image capture device 124 and/or the image capture device 126 at least partially or completely overlap.

In some embodiments, the system 100 may be configured such that the field of view of the image capture devices 124 and 126, for example, falls within (eg, narrower than) the field of view of the image capture device 122 and shares a common field with the field of view of the image capture device 122. center. In other embodiments, the image capture devices 122, 124, and 126 may capture adjacent FOVs, or may have their FOVs partially overlap. In some embodiments, the field of view of the image capture devices 122, 124, and 126 may be aligned so that the center of the narrower FOV image capture device 124 and/or 126 may be located in the lower half of the field of view of the wider FOV device 122 .

[0150]

Figure 2F is a schematic representation of an exemplary vehicle control system consistent with the disclosed embodiments.

As indicated in FIG. 2F, the vehicle 200 may include a throttle system 220, a braking system 230, and a steering system 240. The system 100 can be connected to one of the throttle system 220, the braking system 230, and the steering system 240 via one or more data links (for example, any wired and/or wireless one or more links used to transmit data). Or more provide inputs (e.g., control signals). For example, based on the analysis of the images acquired by the image capture devices 122, 124, and/or 126, the system 100 may provide control signals to one or more of the throttle system 220, the braking system 230, and the steering system 240 to (For example, by causing acceleration, turning, lane shifting, etc.) to navigate the vehicle 200. Further, the system 100 may receive input from one or more of the throttle system 220, the braking system 230, and the steering system 240 to indicate the operating conditions of the vehicle 200 (for example, speed, whether the vehicle 200 is braking and/or turning, and many more). Below, further details are provided in conjunction with FIGS. 4-7.

[0151]

As shown in FIG. 3A, the vehicle 200 may also include a user interface 170 for interacting with the driver or passenger of the vehicle 200.

For example, in a vehicle application, the user interface 170 may include a touch screen 320, a knob 330, a button 340, and a microphone 350. The driver or passenger of the vehicle 200 may also use a handle (for example, located on or near the steering column of the vehicle 200, including, for example, a turn signal handle), buttons (for example, located on the steering wheel of the vehicle 200), etc., to interact with the system 100 . In some embodiments, the microphone 350 may be positioned adjacent to the rear view mirror 310. Similarly, in some embodiments, the image capture device 122 may be located near the rear view mirror 310. In some embodiments, the user interface 170 may also include one or more speakers 360 (eg, speakers of a vehicle audio system). For example, the system 100 may provide various notifications (e.g., prompts) via the speaker 360.

[0152]

3B to 3D are illustrations of an exemplary camera mount 370 consistent with the disclosed embodiments. The camera mount 370 is configured to be positioned behind the rearview mirror (for example, the rearview mirror 310) and against the vehicle block Wind glass.

As shown in FIG. 3B, the camera mount 370 may include image capture devices 122, 124, and 126. The image capturing devices 124 and 126 may be positioned behind the light shield 380, which may be flush with the windshield of the vehicle and include a combination of films and/or anti-reflective materials. For example, the shading plate 380 may be positioned so that it is aligned against a vehicle windshield with a matching slope. In some embodiments, for example, as depicted in FIG. 3D, each of the image capture devices 122, 124, and 126 may be positioned behind the light shield 380. The disclosed embodiments are not limited to the image capturing devices 122, 124, and 126, the camera mount 370, and the light shielding plate 380 of any specific configuration. FIG. 3C is an illustration of the camera mount 370 shown in FIG. 3B from a front view.

[0153]

As those skilled in the art who benefit from the present disclosure will understand, many variations and/or modifications can be made to the previously disclosed embodiments.

For example, not all components are critical to the operation of the system 100. Further, any component can be located in any suitable part of the system 100, and the components can be rearranged into various configurations while providing the functionality of the disclosed embodiments. Therefore, the foregoing configuration is an example and regardless of the configuration discussed above, the system 100 can provide a wide range of functionality for analyzing the surrounding environment of the vehicle 200 and navigating the vehicle 200 in response to the analysis.

[0154]

As discussed in further detail below and consistent with various disclosed embodiments, the system 100 may provide various features related to autonomous driving and/or driver assistance technology.

For example, the system 100 may analyze image data, location data (for example, GPS location information), map data, speed data, and/or data from sensors included in the vehicle 200. The system 100 may collect data from, for example, the image acquisition unit 120, the position sensor 130, and other sensors for analysis. Further, the system 100 may analyze the collected data to determine whether the vehicle 200 should take certain actions, and then automatically take certain actions without human intervention. For example, when the vehicle 200 is navigating without human intervention, the system 100 can

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automatically control the vehicle 200 (for example, by sending a control signal to one or more of the throttle system 220, the braking system 230, and the steering system 240). Braking, acceleration and/or steering. Further, the system 100 may analyze the collected data and issue a warning, and/or prompt the vehicle driver and occupant based on the analysis of the collected data.

[0155]

Further, consistent with the disclosed embodiments, the functionality provided by the system 100 may cause the vehicle 200 to take different actions to navigate the vehicle 200 within the lane and/or relative to other vehicles and/or objects.

For example, the system 100 may adjust the positioning of the vehicle 200 relative to the lane in which the vehicle 200 travels and/or relative to objects located near the vehicle 200, select a specific lane for the vehicle 200 to use while traveling, and respond to intrusive vehicles such as The vehicle attempting to enter the lane in which the vehicle 200 is traveling) takes action. In addition, the system 100 can control the speed of the vehicle 200 in different scenarios, such as when the vehicle 200 makes a turn. The system 100 may further cause the vehicle 200 to imitate the actions of the preceding vehicle or monitor the target vehicle, and guide the vehicle 200 to overtake the target vehicle. Additional details regarding the various implementations provided by the system 100 are provided below.

[0156]

Forward multi-imaging system

[0157]

As discussed above, the system 100 may provide driving assistance functionality using a multi-camera system.

The multi-camera system may use one or more cameras facing the forward direction of the vehicle.

In other embodiments, the multi-camera system may include one or more cameras facing the side of the vehicle or the rear of the vehicle. In one embodiment, for example, the system 100 may use a dual camera imaging system, in which the first camera and the second camera (for example, the image capture devices 122 and 124) may be positioned in front of and/or in front of the vehicle (for example, the vehicle 200). side. The field of view of the first camera may be larger, smaller than, or partially overlap with the field of view of the second camera. In addition, the first camera can be connected to the first image processor to perform monocular image analysis of the image provided by the first camera, and the second camera can be connected to the second image processor to perform the image provided by the second camera Monocular image analysis. The outputs (for example, processed information) of the first image processor and the second image processor may be combined. In some embodiments, the second image processor may receive images from both the first camera and the second camera to perform stereo analysis. In another embodiment, the system 100 may use a three-camera imaging system, where each camera has a different field of view. Therefore, such a system can make decisions based on information obtained from objects located at varying distances in both the front and the sides of the vehicle. Reference to monocular image analysis may refer to an instance in which image analysis is performed based on images captured from a single observation point (for example, from a single camera). Stereoscopic image analysis may refer to an instance in which image analysis is performed based on two or more images captured with one or more variations of image capture parameters. For example, a captured image suitable for performing stereoscopic image analysis may include an image captured using two or more different positions, from different fields of view, using different focal lengths, combining parallax information, and so on.

[0158]

For example, in one embodiment, the system 100 may implement a three-camera configuration using image capture devices 122-126.

In such a configuration, the image capture device 122 can provide a narrow field of view (for example, 34 degrees, or other values selected from the range of about 20 degrees to 45 degrees, etc.), and the image capture device 124 can provide a wide field of view (for example, , 150 degrees or other values selected from the range of about 100 degrees to about 180 degrees), and the image capture device 126 may provide an intermediate field of view (for example, 46 degrees or other values selected from the range of about 35 degrees to about 60 degrees). In some embodiments, the image capture device 126 may act as a main camera or a main camera. The image capture devices 122-126 may be positioned behind the rear view mirror 310 and positioned substantially side by side (e.g , 6 cm spacing). Further, in some embodiments, as discussed above, one or more of

the image capture devices 122-126 may be installed behind a light shield 380 that is flush with the windshield of the vehicle 200. Such shading can minimize the impact of any reflections from the vehicle on the image capturing devices 122-126.

[0159]

In another embodiment, as discussed above in connection with FIGS. 3B and 3C, a wide field of view camera (e.g., the image capture device 124 in the above example) may be installed lower than a narrow main field of view camera (e.g., the above example The image devices 122 and 126 in the).

This configuration can provide free line of sight from a wide field of view camera. In order to reduce reflections, the camera may be installed close to the windshield of the vehicle 200, and may include a polarizer on the camera to suppress reflected light.

[0160]

The three-camera system can provide certain performance characteristics.

For example, some embodiments may include the ability to verify the detection of an object by one camera based on the detection result of another camera. In the three-camera configuration discussed above, the processing unit 110 may include, for example, three processing devices (e.g., three EyeQ series processor chips, as discussed above), each of which is dedicated to processing by the image capture device 122 -One or more of the captured images in 126.

[0161]

In the three-camera system, the first processing device can receive images from both the main camera and the narrow field of view camera, and perform the visual processing of the narrow FOV camera to detect other vehicles, pedestrians, lane markings, traffic signs, and traffic lights, for example And other road objects.

Further, the first processing device may calculate the pixel gap between the images of the main camera and the narrow camera and create a three-dimensional reconstruction of the environment of the vehicle 200. Then, the first processing device may combine the three-dimensional reconstruction with the three-dimensional map data, or with the three-dimensional information calculated based on the information of another camera.

[0162]

The second processing device may receive images from the main camera and perform visual processing to detect other vehicles, pedestrians, lane markings, traffic signs, traffic lights, and other road objects.

In addition, the second processing device may calculate the camera displacement, and based on the displacement, calculate the pixel gap between consecutive images and create a three-dimensional reconstruction of the scene (for example, according to the structure of the motion). The second processing device may send the structure from the motion-based three-dimensional reconstruction to the first processing device to be combined with the stereoscopic three-dimensional image.

[0163]

The third processing device may receive images from a wide FOV camera and process the images to detect vehicles, pedestrians, lane markings, traffic signs, traffic lights, and other road objects.

The third processing device may further execute additional processing instructions to analyze the image to identify objects moving in the image, such as vehicles that change lanes, pedestrians, and so on.

[0164]

In some embodiments, enabling image-based information streams to be independently captured and processed can provide opportunities for system redundancy.

For example, such redundancy may include using a first image capturing device and images processed from the device to verify and/or supplement information obtained by capturing and processing at least image information from the second image capturing device.

[0165]

In some embodiments, the system 100 may use two image capture devices (eg, image capture devices 122 and 124) to provide navigation assistance to the vehicle 200, and a third image capture device (eg, image capture device 126) to provide Redundant and verify the analysis of the data received from the other two image capture devices.

For example, in such a configuration, the image capture devices 122 and 124 can provide images for the stereo analysis of the system 100 to navigate the vehicle 200, and the image capture device 126 can provide images for the monocular analysis of the system 100 to provide redundancy and verify information obtained from images captured by the image capture device 122 and/or the image capture device 124. That is, the image capture device 126 (and corresponding processing device) may be considered to provide a redundant subsystem to provide a check on the analysis obtained from the image capture devices 122 and 124 (for example, provide an automatic emergency braking (AEB) system) .

[0166]

Those skilled in the art will recognize that the above camera configuration, camera placement, number of cameras, camera location, etc. are just examples.

These components and other components described with respect to the overall system can be assembled and used in a variety of different configurations without departing from the scope of the disclosed embodiments. Below are further details on the use of multi-camera systems to provide driver assistance and/or autonomous vehicle functionality.

[0167]

4 is an exemplary functional block diagram of the memory 140 and/or 150 consistent with the disclosed embodiments. The memory 140 and/or 150 may store/program instructions for performing one or more operations.

Although the following refers to the memory 140, those skilled in the art will recognize that the instructions can be stored in the memory 140 and/or 150.

[0168]

As shown in FIG. 4, the memory 140 can store a monocular image analysis module 402, a stereo image analysis module 404, a speed and acceleration module 406, and a navigation response module 408.

The disclosed embodiments are not limited to the memory 140 of any particular configuration. Further, the application processor 180 and/or the image processor 190 can execute instructions stored in any of the modules 402-408 included in the memory 140. Those skilled in the art will understand that references to the processing unit 110 in the following discussion may refer to the application processor 180 and the image processor 190 individually or collectively. Therefore, the steps of any of the following processes may be executed by one or more processing devices.

[0169]

In one embodiment, the monocular image analysis module 402 may store instructions (such as computer vision software). When executed by the processing unit 110, the instructions execute a set of images acquired by one of the image capture devices 122, 124, and 126. Monocular image analysis.

In some embodiments, the processing unit 110 may combine information from a set of images with additional sensory information (for example, information from radar) to perform monocular image analysis. As described below in conjunction with FIGS. 5A to 5D, the monocular image analysis module 402 may include a set of features for detecting a set of images (such as lane markings, vehicles, pedestrians, road signs, highway exit ramps, traffic lights, Dangerous objects and any other characteristics associated with the vehicle environment) instructions. Based on this analysis, the system 100 (for example, via the processing unit 110) can generate one or more navigation responses in the vehicle 200, such as turning, lane shifting, acceleration changes, etc., which are discussed in conjunction with the navigation response module 408 below.

[0170]

In one embodiment, the stereoscopic image analysis module 404 may store instructions (such as computer vision software). When executed by the processing unit 110, the instructions are executed by a combination of image capture devices selected from any image capture device 122, 124, and 126. And the acquired stereo image analysis of the first group and the second group of images.

In some embodiments, the processing unit 110 may combine information from the first and second sets of images with additional sensory information (for example, information from radar) to perform stereoscopic image analysis. For example, the stereoscopic image analysis module 404 may include instructions for performing stereoscopic image analysis based on the first set of images acquired by the image capture device 124 and the second set of images acquired by the image capture device 126. As described below in conjunction with FIG. 6, the stereo image analysis module 404 may include a set of features for detecting the first and second sets of images (such as lane markings, vehicles, pedestrians, road signs, highway exit ramps, traffic Lights, dangerous objects, etc.) instructions. Based on this analysis, the processing unit 110 may generate one or more navigation responses in the vehicle 200, such as turning, lane shifting, acceleration changes, etc., which are discussed below in conjunction with the navigation response module 408.

[0171]

In one embodiment, the speed and acceleration module 406 may store software configured to analyze data received from one or more computer electrical devices of the vehicle 200 that are configured to cause the speed and/or acceleration of the vehicle 200 Change.

For example, the processing unit 110 may execute instructions associated with the speed and acceleration module 406 to calculate the target speed of the vehicle 200 based on data obtained from executing the monocular image analysis module 402 and/or the stereo image analysis module 404. For example, such data may include: target position, speed and/or acceleration; position and/or speed of vehicle 200 relative to nearby vehicles, pedestrians or road objects; position information of vehicle 200 relative to lane markings of the road, and so on. In addition, the processing unit 110 may calculate the vehicle based on sensory input (for example, information from radar) and input from other systems of the vehicle 200 (such as the throttle system 220, the braking system 230, and/or the steering system 240 of the vehicle 200). A target speed of 200. Based on the calculated target speed, the processing unit 110 may send electronic signals to the throttle system 220, the braking system 230, and/or the steering system 240 of the vehicle 200 to be triggered by, for example, physically depressing the brake or releasing the accelerator of the vehicle 200 Changes in speed and/or acceleration.

[0172]

In one embodiment, the navigation response module 408 may store software executable by the processing unit 110 to determine the desired navigation response based on data obtained from the execution of the monocular image analysis module 402 and/or the stereo image analysis module 404.

Such data may include location and speed information associated with nearby vehicles, pedestrians, and road objects, target location information of the vehicle 200, and the like. In addition, in some embodiments, the navigation response may be (partially or completely) based on map data, the predetermined location of the vehicle 200, and/or the execution of the vehicle 200 and the slave monocular image analysis module 402 and/or the stereo image analysis module 404. The relative velocity or relative acceleration between the detected one or more objects. The navigation response module 408 may also determine the desired navigation response based on sensory input (e.g., information from radar) and input from other systems of the vehicle 200 (such as the throttle system 220, braking system 230, and steering system 240 of the vehicle 200) . Based on the desired navigation response, the processing unit 110 may send electronic signals to the throttle system 220, the braking system 230, and the steering system 240 of the vehicle 200 to trigger the desired navigation response, for example, by turning the steering wheel of the vehicle 200 to achieve the predetermined Angle rotation. In some embodiments, the processing unit 110 may use the output of the navigation response module 408 (eg, desired navigation response) as an input to execute the speed and acceleration module 406 to calculate the speed change of the vehicle 200.

[0173]

FIG. 5A is a flowchart illustrating an exemplary process 500A for generating one or more navigation responses based on monocular image analysis consistent with the disclosed embodiments.

In step 510, the processing unit 110 may receive a plurality of images via the data interface 128 between the processing unit 110 and the image acquisition unit 120. For example, a camera included in the image acquisition unit 120 (such as an image

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capture device 122 having a field of view 202) can capture multiple images of an area in front of the vehicle 200 (for example, or the side or back of the vehicle) and be connected via data. The image is sent to the processing unit 110 (for example, digital, wired, USB, wireless, Bluetooth, etc.). In step 520, the processing unit 110 may execute the monocular image analysis module 402 to analyze multiple images, which is described in further detail below in conjunction with FIGS. 5B to 5D. By performing the analysis, the processing unit 110 can detect a set of features in a set of images, such as lane markings, vehicles, pedestrians, road signs, highway exit ramps, traffic lights, and so on.

[0174]

In step 520, the processing unit 110 may also execute the monocular image analysis module 402 to detect various road hazards, for example, a part of a truck tire, a fallen road sign, loose goods, small animals, and so on.

Road hazards may have changes in structure, shape, size, and color, which may make detecting such hazards more challenging. In some embodiments, the processing unit 110 can execute the monocular image analysis module 402 to perform multi-frame analysis on multiple images to detect road hazards. For example, the processing unit 110 may estimate the camera motion between consecutive image frames, and calculate the pixel gap between the frames to construct a three-dimensional map of the road. Then, the processing unit 110 may use the three-dimensional map to detect the road surface and the hazards existing above the road surface.

[0175]

In step 530, the processing unit 110 may execute the navigation response module 408 to generate one or more navigation responses of the vehicle 200 based on the analysis performed in step 520 and the technique described above in conjunction with FIG. 4.

For example, the navigation response may include turns, lane shifts, acceleration changes, and so on. In some embodiments, the processing unit 110 may use data obtained from the execution speed and acceleration module 406 to generate one or more navigation responses. In addition, multiple navigation responses can occur simultaneously, sequentially, or in any combination thereof. For example, the processing unit 110 may cause the vehicle 200 to change a lane, and then accelerate by sequentially sending control signals to the steering system 240 and the throttle system 220 of the vehicle 200, for example. Alternatively, the processing unit 110 may cause the vehicle 200 to brake while simultaneously changing lanes by, for example, sending a control signal to the braking system 230 and the steering system 240 of the vehicle 200 at the same time.

[0176]

Figure 5B is a flowchart illustrating an exemplary process 500B for detecting one or more vehicles and/or pedestrians in a set of images consistent with the disclosed embodiments.

The processing unit 110 may execute the monocular image analysis module 402 to implement the process 500B. In step 540, the processing unit 110 may determine a set of candidate objects representing possible vehicles and/or pedestrians. For example, the processing unit 110 may scan one or more images, compare the images with one or more predetermined patterns, and identify the possibility that the object of interest (for example, a vehicle, a pedestrian, or a part thereof) may be included in each image. Place. The predetermined pattern can be designed in such a way as to achieve a high rate of "false hits" and a low rate of "misses". For example, the processing unit 110 may use the similarity with a predetermined pattern low threshold to identify the candidate object as a possible vehicle or pedestrian. Doing so may allow the processing unit 110 to reduce the probability of not hitting (e.g., not identifying) a candidate object representing a vehicle or pedestrian.

[0177]

In step 542, the processing unit 110 may filter this set of candidate objects to exclude certain candidates (for example, irrelevant or less relevant objects) based on the classification criteria.

Such criteria can be derived from various attributes associated with object types stored in a database (e.g., a database stored in memory 140). The attributes may include object shape, size, texture, position (for example, relative to vehicle 200), and the like. Thus, the processing unit 110 may use one or more sets of criteria to reject erroneous candidates from a set of candidate objects.

[0178]

In step 544, the processing unit 110 may analyze multiple frames of the image to determine whether an object in a set of candidate objects represents a vehicle and/or a pedestrian.

For example, the processing unit 110 may track the detected candidate object across consecutive frames and accumulate frame-by-frame data (eg, size, position relative to the vehicle 200, etc.) associated with the detected object. In addition, the processing unit 110 may estimate the parameters of the detected object and compare the frame-by-frame position data of the object with the predicted position.

[0179]

In step 546, the processing unit 110 may construct a set of measurement results of the detected object.

For example, such measurement results may include position, velocity, and acceleration values (relative to the vehicle 200) associated with the detected object. In some embodiments, the processing unit 110 may construct measurement results based on the following techniques: based on estimation techniques using a series of time-based observations (such as Kalman filter or linear quadratic estimation (LQE)); and/or based on different objects Modeling data available for types (for example, cars, trucks, pedestrians, bicycles, road signs, etc.). The Kalman filter may be based on a measurement result of the scale of the object, where the scale measurement is proportional to the time to collision (for example, the amount of time the vehicle 200 will reach the object). Thus, by performing steps 540-546, the processing unit 110 can identify vehicles and pedestrians appearing in a set of captured images and obtain information (for example, position, speed, size) associated with the vehicles and pedestrians. Based on the identified and obtained information, the processing unit 110 may generate one or more navigation responses of the vehicle 200, which are described above in conjunction with FIG. 5A.

[0180]

In step 548, the processing unit 110 may perform optical flow analysis of one or more images to reduce the probability of detecting "false hits" and not hitting candidate objects representing vehicles or pedestrians.

Optical flow analysis may refer to, for example, analyzing the motion pattern of the vehicle 200 in one or more images associated with other vehicles and pedestrians, and distinguishing it from road surface motion. The processing unit 110 may calculate the motion of the candidate object by observing different positions of the object across multiple image frames (captured at different times). The processing unit 110 may use the position and time values as inputs for calculating the mathematical model of the motion of the candidate object. Thus, optical flow analysis can provide another method for detecting vehicles and pedestrians near the vehicle 200. The processing unit 110 can be combined with steps 540-546 to perform optical flow analysis, provide redundancy for detecting vehicles and pedestrians, and increase the reliability of the system 100.

[0181]

5C is a flowchart illustrating an exemplary process 500C for detecting road signs and/or lane geometric information in a set of images consistent with the disclosed embodiments.

The processing unit 110 may execute the monocular image analysis module 402 to implement the process 500C. In step 550, the processing unit 110 may detect a group of objects by scanning one or more images. In order to detect a section of lane markings, lane geometry information, and other related road signs, the processing unit 110 may filter a set of objects to exclude these objects that are determined to be irrelevant (for example, slight potholes, small rocks, etc.). In step 552, the processing unit 110 may group the sections detected in step 550 that belong to the same road signs or lane markings. Based on the grouping, the processing unit 110 can build a model representing the detected section, such as a mathematical model.

[0182]

In step 554, the processing unit 110 may construct a set of measurement results associated with the detected section.

In some embodiments, the processing unit 110 may create a projection of the detected segment from the image plane to the real world plane. The projection can be characterized using a third polynomial with coefficients corresponding to physical properties such as position, slope, curvature, and curvature derived from the detected road. When generating the projection, the processing unit 110 may consider road surface changes and pitch and yaw rates associated with the vehicle 200. In addition, the processing unit 110 may model the road elevation by analyzing the position and motion cues existing on the road surface.

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Further, the processing unit 110 may estimate the pitch and yaw rate associated with the vehicle 200 by tracking a set of feature points in one or more images.

[0183]

In step 556, the processing unit 110 may perform multi-frame analysis by, for example, tracking the detected section across consecutive image frames and accumulating frame-by-frame data associated with the detected section.

When the processing unit 110 performs multi-frame analysis, the set of measurement results constructed in step 554 may become more reliable and associated with a higher confidence level. Thus, by performing steps 550-556, the processing unit 110 can identify road signs appearing in a set of captured images and obtain lane geometry information. Based on the identification and the obtained information, the processing unit 110 can generate one or more navigation responses of the vehicle 200, which are described above in conjunction with FIG. 5A.

[0184]

In step 558, the processing unit 110 may consider additional information sources to further establish a safety model of the vehicle 200 in the context of its surrounding environment.

The processing unit 110 may use a safety model to define the following background, that is, the system 100 may adopt a safe manner to perform autonomous control of the vehicle 200. In order to establish a safety model, in some embodiments, the processing unit 110 may consider the position and movement of other vehicles, the curbs and obstacles of the detected road, and/or the overall road shape extracted from map data (such as the data of the map database 160) describe. By considering additional information sources, the processing unit 110 can provide redundancy to detect road signs and lane geometry and increase the reliability of the system 100.

[0185]

FIG. 5D is a flowchart showing an exemplary process 500D for detecting traffic lights in a set of images consistent with the disclosed embodiments.

The processing unit 110 may execute the monocular image analysis module 402 to implement the process 500D. In step 560, the processing unit 110 may scan a set of images and identify objects appearing at locations in the images that may contain traffic lights. For example, the processing unit 110 may filter the recognized objects to construct a set of candidate objects, and exclude those objects that are unlikely to correspond to traffic lights. Filtering can be done based on various attributes associated with traffic lights, such as shape, size, texture, position (e.g., relative to vehicle 200, etc.). Such attributes can be based on multiple examples of traffic lights and traffic control signals and stored in a database. In some embodiments, the processing unit 110 may perform multi-frame analysis on a set of candidate objects reflecting possible traffic lights. For example, the processing unit 110 may track candidate objects across consecutive image frames, estimate the real-world position of the candidate objects, and filter out those objects that are moving (which cannot be traffic lights). In some embodiments, the processing unit 110 may perform color analysis of the candidate object, and identify the relative position of the detected color that appears inside the possible traffic light.

[0186]

In step 562, the processing unit 110 may analyze the geometry of the hub.

The analysis can be based on any combination of: (i) the number of lanes detected on either side of the vehicle 200; (ii) markings detected on the road (such as arrow markings); and (iii) from map data (such as The data of the map database 160) extract the description of the hub. The processing unit 110 may use the information obtained from the execution of the monocular analysis module 402 for analysis. In addition, the processing unit 110 may determine the correspondence between the traffic light detected in step 560 and the lane appearing in the vicinity of the vehicle 200.

[0187]

When the vehicle 200 approaches the hub, in step 564, the processing unit 110 may update the confidence level associated with the analyzed hub geometry and the detected traffic light.

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For example, compared with the number of traffic lights actually appearing at the hub, the estimated number of traffic lights appearing at the hub may affect the confidence level. Thus, based on the confidence level, the processing unit 110 may authorize the driver of the vehicle 200 to perform control in order to improve safety conditions. By performing steps 560-564, the processing unit 110 can identify traffic lights appearing in a set of captured images and analyze the hub geometry information. Based on the identification and analysis, the processing unit 110 can generate one or more navigation responses of the vehicle 200, which are described above in conjunction with FIG. 5A.

[0188]

5E is a flowchart illustrating an exemplary process 500E for generating one or more navigation responses in the vehicle 200 based on the vehicle path consistent with the disclosed embodiments.

In step 570, the processing unit 110 may construct an initial vehicle path associated with the vehicle 200. The vehicle path may be represented by a set of points expressed in coordinates (x, z), and the distance di between two points of the set of points may fall within the range of 1 meter to 5 meters. In one embodiment, the processing unit 110 may use two polynomials such as left and right road polynomials to construct the initial vehicle path. The processing unit 110 may calculate the geometric midpoint between the two polynomials, and if there is an offset, offset each point included in the resulting vehicle path by a predetermined offset (for example, smart lane offset), (Zero offset may correspond to traveling in the middle of the lane). The direction of the offset may be perpendicular to the section between any two points in the vehicle path. In another embodiment, the processing unit 110 may use a polynomial and the estimated lane width to offset each point of the vehicle path by: half of the estimated lane width plus a predetermined offset (for example, smart lane offset) .

[0189]

In step 572, the processing unit 110 may update the vehicle path constructed in step 570.

The processing unit 110 may use a higher resolution to reconstruct the vehicle path constructed in step 570 so that the distance dk between two points representing a set of points of the vehicle path is smaller than the distance di described above. For example, the distance dk may fall within the range of 0.1 meters to 0.3 meters. The processing unit 110 may use a parabolic spline algorithm to reconstruct the vehicle path, which may generate a cumulative distance vector S corresponding to the total length of the vehicle path (ie, based on a set of points representing the vehicle path).

[0190]

In step 574, the processing unit 110 may determine a look-ahead point (expressed in coordinates (xl, zl)) based on the updated vehicle path constructed in step 572.

The processing unit 110 may extract a look-ahead point from the accumulated distance vector S, and the look-ahead point may be associated with the look-ahead distance and the look-ahead time. The lower limit range can be from 10 meters to 20 meters, the forward distance can be calculated as the product of the speed of the vehicle 200 and the forward time. For example, as the speed of the vehicle 200 decreases, the look-ahead distance may also decrease (e.g., until the look-ahead distance reaches a lower limit). The look-ahead time, which may range from 0.5 seconds to 1.5 seconds, may be inversely proportional to the gain of one or more control loops associated with generating a navigation response in the vehicle 200 (such as tracking the heading error of the control loop). For example, the gain of the heading error of the tracking control loop may depend on the bandwidth of the yaw rate loop, the steering actuator loop, the lateral dynamics of the vehicle, and so on. Therefore, the larger the gain of the heading error of the tracking control loop, the shorter the look-ahead time.

[0191]

In step 576, the processing unit 110 may determine the heading error and the yaw rate command based on the look-ahead point determined in step 574.

The processing unit 110 may determine the heading error by calculating the arctangent of the look-ahead point (for example, arctan(xl/zl)). The processing unit 110 may determine the yaw rate command as the product of the heading error and the high-level control gain. If the look-ahead distance is not at the lower limit, the high-level control gain can be equal to: (2/look-ahead time). In other ways, the high-level control gain can be equal to: (2 times the speed of the vehicle 200/forward distance).

[0192]

FIG. 5F is a flowchart illustrating an exemplary process 500F for determining whether the vehicle in front changes lanes, consistent with the disclosed embodiment.

In step 580, the processing unit 110 may determine navigation information associated with the preceding vehicle (for example, a vehicle traveling before the vehicle 200). For example, the processing unit 110 may use the technique described above in conjunction with FIGS. 5A and 5B to determine the position, speed (for example, direction and speed), and/or acceleration of the preceding vehicle. The processing unit 110 may also use the technique described above in conjunction with FIG. 5E to determine one or more road polynomials, forward-looking points (associated with the vehicle 200), and/or slow-moving traces (for example, a set of points describing the path taken by the preceding vehicle).).

[0193]

In step 582, the processing unit 110 may analyze the navigation information determined in step 580.

In one embodiment, the processing unit 110 may calculate the distance between the slow-moving trail and the road polynomial (for example, along the trail). If the variance of the distance along the trail exceeds a predetermined threshold (e.g. 0.1 m to 0.2 m on a straight road, 0.3 m to 0.4 m on a moderately curved road, and 0.5 m to 0.6 m on a sharply curved road) , The processing unit 110 may determine that the vehicle in front may change lanes. In a case where it is detected that there are multiple vehicles traveling in front of the vehicle 200, the processing unit 110 may compare the slow-moving traces associated with each vehicle. Based on the comparison, the processing unit 110 may determine that a vehicle whose slow-moving trace does not match the slow-moving trace of other vehicles may change lanes. The processing unit 110 may additionally compare the curvature of the slow-moving trace (associated with the preceding vehicle) with the expected curvature of the road section traveled by the preceding vehicle. The expected curvature can be extracted from map data (for example, data of the map database 160), road polynomials, slow-moving traces of other vehicles, existing knowledge about the road, and the like. If the curvature difference between the slow moving trace and the expected curvature of the road section exceeds a predetermined threshold, the processing unit 110 may determine that the vehicle in front may change lanes.

[0194]

In another embodiment, the processing unit 110 may compare the instantaneous position of the preceding vehicle with the look-ahead point (associated with the vehicle 200) within a specific time period (for example, 0.5 seconds to 1.5 seconds).

If the distance between the instantaneous position of the preceding vehicle and the forward-looking point changes during a specific time period, and the cumulative sum of the changes exceeds a predetermined threshold (for example, 0.3 m to 0.4 m on a straight road, 0.7 m to 0.8 on a moderately curved road Meters, and 1.3 meters to 1.7 meters on a sharply curved road), the processing unit 110 may determine that the vehicle in front may change lanes. In another embodiment, the processing unit 110 may analyze the geometry of the slow-moving trail by comparing the lateral distance traveled along the trail with the expected curvature of the slow-moving trail. The expected radius of curvature can be determined according to the following calculation: (δz2+δx2)/2/(δx), where δx represents the lateral distance traveled, and δz represents the longitudinal distance traveled. If the difference between the lateral distance traveled and the expected curvature exceeds a predetermined threshold (for example, 500 meters to 700 meters), the processing unit 110 may determine that the vehicle in front may change lanes. In another embodiment, the processing unit 110 may analyze the position of the preceding vehicle. If the position of the preceding vehicle conceals the road polynomial (for example, the preceding vehicle covers the top of the road polynomial), the processing unit 110 may determine that the preceding vehicle may change lanes. In the case where the position of the preceding vehicle is such that another vehicle is detected in front of the preceding vehicle and the slow-moving traces of the two vehicles are not parallel, the processing unit 110 may determine that the (closer) preceding vehicle may change lanes.

[0195]

In step 584, the processing unit 110 may determine whether the preceding vehicle 200 changes lanes based on the analysis performed in step 582.

For example, the processing unit 110 may make the determination based on the weighted average of the various analyses performed in step 582. Under such a scheme, for example, the decision that the preceding vehicle may change lanes made by the processing unit 110 based on a specific type of analysis may be assigned the value "1" (and "0" indicates that it is determined that the preceding vehicle is unlikely to change lanes). The different analyses performed in step 582 may be

assigned different weights, and the disclosed embodiments are not limited to any particular combination of analyses and weights.

[0196]

FIG. 6 is a flowchart illustrating an exemplary process 600 for generating one or more navigation responses based on stereoscopic image analysis consistent with the disclosed embodiments.

In step 610, the processing unit 110 may receive the first and second plurality of images via the data interface 128. For example, a camera included in the image acquisition unit 120 (such as image capture devices 122 and 124 with fields of view 202 and 204) may capture the first and second multiple images of the area in front of the vehicle 200 and be digitally connected (e.g., USB, wireless, Bluetooth, etc.) send the first and second plurality of images to the processing unit 110. In some embodiments, the processing unit 110 may receive the first and second plurality of images via two or more data interfaces. The disclosed embodiments are not limited to any specific data interface structure or protocol.

[0197]

In step 620, the processing unit 110 can execute the stereo image analysis module 404 to perform stereo image analysis of the first and second plurality of images to create a three-dimensional map of the road ahead of the vehicle and detect features in the image, such as lane markings, vehicles, Pedestrians, road signs, highway exit ramps, traffic lights, road hazards, etc.

The stereoscopic image analysis can be performed in a manner similar to the steps described above in conjunction with FIGS. 5A to 5D. For example, the processing unit 110 may execute the stereoscopic image analysis module 404 to detect candidate objects (for example, vehicles, pedestrians, road signs, traffic lights, road hazards, etc.) in the first and second plurality of images, based on various standards. Filter out a subset of candidates, perform multi-frame analysis, construct measurement results, and determine the confidence level of the remaining candidates. When performing the above steps, the processing unit 110 may consider information from both the first and second plurality of images, rather than information from a set of images alone. For example, the processing unit 110 may analyze differences in pixel level data (or other subsets of data from the two captured image streams) for candidate objects appearing in both the first and second plurality of images. As another example, the processing unit 110 may estimate the candidate object by observing that the object appears in one of the multiple images but does not appear in the other or other differences that may exist relative to the objects appearing in the two image streams. (E.g., relative to vehicle 200) position and/or speed. For example, the position, speed, and/or acceleration relative to the vehicle 200 may be determined based on the trajectory, position, movement characteristics, etc. of features associated with objects appearing in one or both of the image streams.

[0198]

In step 630, the processing unit 110 may execute the navigation response module 408 based on the analysis performed in step 620 and the technique described above in conjunction with FIG. 4 to generate one or more navigation responses in the vehicle 200.

For example, the navigation response may include turns, lane shifts, acceleration changes, speed changes, braking, etc. In some embodiments, the processing unit 110 may use data obtained from the execution speed and acceleration module 406 to generate one or more navigation responses. In addition, multiple navigation responses can occur simultaneously, sequentially, or in any combination thereof.

[0199]

FIG. 7 is a flowchart illustrating an exemplary process 700 for generating one or more navigation responses based on the analysis of three sets of images consistent with the disclosed embodiments.

In step 710, the processing unit 110 may receive the first, second, and third plurality of images via the data interface 128. For example, a camera included in the image capturing unit 120 (such as image capturing devices 122, 124, and 126 having fields of view 202, 204, and 206) can capture the first, second, and second regions of the front and/or side of the vehicle 200. Three more images and the first, second, and third plurality of images are sent to the processing unit 110 via a digital connection (for example, USB, wireless, Bluetooth, etc.). In some embodiments, the processing unit 110 may receive the first, second, and third multiple images via more than three data interfaces. For example, each of the image capturing devices 122, 124, 126 may have

an associated data interface for communicating data with the processing unit 110. The disclosed embodiments are not limited to any specific data interface structure or protocol.

[0200]

In step 720, the processing unit 110 may analyze the first, second, and third images to detect features in the images, such as lane markings, vehicles, pedestrians, road signs, highway exit ramps, traffic lights, road hazards, etc. .

This analysis can be performed in a manner similar to the steps described above in conjunction with FIGS. 5A to 5D and FIG. 6. For example, the processing unit 110 may perform monocular image analysis on each of the first, second, and third plurality of images (for example, via executing the monocular image analysis module 402 and based on the steps described above in conjunction with FIGS. 5A to 5D). Alternatively, the processing unit 110 may perform stereoscopic image analysis on the first and second plurality of images, the second and third plurality of images, and/or the first and third plurality of images (for example, via the execution of the stereoscopic image analysis module 404 And based on the steps described above in conjunction with Figure 6). The analyzed processed information corresponding to the first, second, and/or third plurality of images can be combined. In some embodiments, the processing unit 110 may perform a combination of monocular image analysis and stereo image analysis. For example, the processing unit 110 may perform monocular image analysis on the first plurality of images (for example, via the execution of the monocular image analysis module 402) and perform stereoscopic image analysis on the second and third plurality of images (for example, via the execution of the stereoscopic image analysis module). 404). The configuration of the image capture devices 122, 124, and 126 (including their respective locations and fields of view 202, 204, and 206) can affect the type of analysis performed on the first, second, and third plurality of images. The disclosed embodiments are not limited to specifically configured image capture devices 122, 124, and 126, or the types of analysis performed on the first, second, and third plurality of images.

[0201]

In some embodiments, the processing unit 110 may perform a test of the system 100 based on the images acquired and analyzed in steps 710 and 720.

Such a test may provide an indicator of the overall performance of the system 100 to image capture devices 122, 124, and 126 of certain configurations. For example, the processing unit 110 may determine the ratio of "wrong hits" (for example, the system 100 incorrectly determines that there is a vehicle or pedestrian) and the ratio of "missing hits."

[0202]

In step 730, the processing unit 110 may generate one or more navigation responses in the vehicle 200 based on information obtained from both of the first, second, and third plurality of images.

The selection of both of the first, second, and third plurality of images may depend on various factors, for example, the number, type, and size of objects detected in each of the plurality of images. The processing unit 110 may also make selections based on the following: image quality and resolution, the effective field of view reflected in the image, the number of captured frames, the extent to which one or more objects of interest actually appear in the frame (for example, the object appears The percentage of the frame, the proportion of objects appearing in each such frame, etc.), etc.

[0203]

In some embodiments, the processing unit 110 may select the information obtained from two of the first, second, and third images by determining the degree of consistency between the information obtained from one image source and the information obtained from other image sources. information.

For example, the processing unit 110 may combine the processed information obtained from each of the image capturing devices 122, 124, and 126 (whether through monocular analysis, stereo analysis, or any combination of the two) and determine whether to span from the image capturing devices 122, 124 Each captured image in 126 presents consistent visual indicators (eg, lane markings, detected vehicles and their locations and/or paths, detected traffic lights, etc.). The processing unit 110 may also exclude information that is inconsistent across the captured image (for example, a vehicle that changes lanes, a lane model of a vehicle indicating that it is too close to the vehicle 200, etc.). Thus, the processing unit 110 can select information obtained from two of the first, second, and third plurality of images based on the determination of the coincidence and inconsistency information.

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[0204]

For example, the navigation response may include turns, lane shifts, acceleration changes, and so on.

The processing unit 110 may generate one or more navigation responses based on the analysis performed in step 720 and the technique described above in conjunction with FIG. 4. The processing unit 110 may also use data obtained from the execution speed and acceleration module 406 to generate one or more navigation responses. In some embodiments, the processing unit 110 may generate one or more objects based on the relative position, relative velocity, and/or relative acceleration between the vehicle 200 and the detected object in any of the first, second, and third plurality of images. Navigation response. Multiple navigation responses can occur simultaneously, sequentially, or in any combination thereof.

[0205]

Smart lane offset

[0206]

The system 100 may provide driver assistance functionality to monitor and adjust the free space between the vehicle 200 and the travel boundary (eg, lane boundary) of the vehicle 200.

A lane may refer to a designated or expected path of travel of a vehicle and may have marked boundaries (e.g., lines on a road) or unmarked boundaries (e.g., road curbs, road barriers, guardrails, parked vehicles, etc.).

For example, by default, the system 100 may maximize or increase the free space between the vehicle 200 and the current lane boundary. Further, under certain conditions, the system 100 can cause the vehicle 200 to shift toward the side of the current travel lane without leaving the lane. For example, when the vehicle 200 is traveling around a curve, the system 100 can reduce the deviation toward the inside of the curve (for example, adjust the position of the vehicle 200 to be closer to the inside of the curve). As another example, in the case where an obstacle (such as a parked car, pedestrian, or cyclist) exists on one side of the lane, the system 100 may add an offset on the side of the vehicle 200 where the obstacle exists (for example, adjust the vehicle The position of 200 makes it farther away from obstacles).

[0207]

Figure 8A illustrates a vehicle 200 traveling on a road 800 in which the disclosed system and method for identifying lane constraints and operating the vehicle 200 within the lane constraints may be used.

As shown, the vehicle 200 may have a first vehicle side 802, and the first vehicle side 802 may be a first distance 805 from the first lane constraint 810. Similarly, the vehicle 200 may have a second vehicle side 812 opposite the first vehicle side 802, and the second vehicle side 812 may be a second distance 815 from the second lane constraint 820. In this way, the first lane constraint 810 and the second lane constraint 820 may define a lane in which the vehicle 200 can travel.

[0208]

The processing unit 110 may be configured to determine the first lane constraint 810 and the second lane constraint 820 based on a plurality of images acquired by the image capturing devices 122-126 that the processing unit 110 may receive via the data interface 128.

According to some embodiments, the first lane constraint 810 and/or the second lane constraint 820 may be identified by visible lane boundaries (such as dashed or solid lines marked on the road surface). Additionally or alternatively, the first lane constraint 810 and/or the second lane constraint 820 may include curbs or obstacles on the road surface. Additionally or alternatively, the first lane constraint 810 and/or the second lane constraint 820 may include markers (e.g., Bots point). According to some embodiments, the processing unit 110 may determine the first lane constraint 810 and/or the second lane constraint 820 by identifying the midpoint of the road surface width. According to some embodiments, if the processing unit 110 recognizes only the first lane constraint 810, the processing unit 110 may estimate the second lane constraint 820, such as based on the estimated lane width or road width. When, for example, the line specifying the lane of the road has not been painted or otherwise labeled, the processing unit 110 can recognize lane constraints in this manner.

[0209]

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Detecting the first lane constraint 810 and/or the second lane constraint 820 may include: the processing unit 110 determines its three-dimensional model in the camera coordinate system.

For example, the three-dimensional model of the first lane constraint 810 and/or the second lane constraint 820 may be described by a third polynomial. In addition to three-dimensional modeling of the first lane constraint 810 and/or the second lane constraint 820, the processing unit 110 may perform multi-frame estimation of host motion parameters (such as the speed, yaw and pitch rate, and acceleration of the vehicle 200). Optionally, the processing unit 110 may detect static and moving vehicles and their positions, headings, speeds and accelerations (all relative to the vehicle 200). The processing unit 110 may further determine a road elevation model to convert all the information acquired from the multiple images into a three-dimensional space.

[0210]

Generally, as a default condition, the vehicle 200 may travel relatively centered within the first lane constraint and the second lane constraint 810 and/or 820.

However, in some situations, environmental factors can make it undesirable or unfeasible, such as when objects or structures exist on one side of the road. Thus, there may be situations where the vehicle 200 may desirably or advantageously be closer to one lane constraint or the other. The processing unit 110 may also be configured to determine whether such a situation referred to as a lane shift condition exists based on multiple images.

[0211]

In order to determine whether the lane deviation condition exists, the processing unit 110 may be configured to determine that one or more objects 825 exist in the vicinity of the vehicle 200.

For example, the object 825 may include another vehicle traveling on the road 800, such as a car, truck, or motorcycle. For each object 825, the processing unit 110 may determine an offset contour. Offset contour may include determining whether the object 825 will be located within a predetermined range of the vehicle 200 in its current predicted position. If the processing unit 110 determines that the object 825 is located or will be located within the predetermined range of the vehicle 200, the processing unit 110 may determine whether there is enough in the first lane constraint 810 and the second lane constraint 820 in order for the vehicle 200 to bypass the object 825. Space. If there is not enough space, the processing unit 110 may perform a lane change. If there is enough space, the processing unit 110 may determine whether there is enough time to bypass the object 825 before the distance between the vehicle 200 and the object 825 approaches. If there is enough time, the processing unit 110 may initiate or activate the offset maneuver to bypass the object 825. The offset maneuver may be performed by the processing unit 110 so that the movement of the vehicle 200 is smooth and comfortable for the driver. For example, the offset slew rate may be approximately 0.15 m/sec to 0.75 m/sec. The offset maneuver may be performed such that the maximum amplitude of the offset maneuver will occur when the distance between the vehicle 200 and the object 825 is shortened. If there is not enough time, the processing unit 110 may initiate braking (e.g., by sending an electronic signal to the braking system 230), and then initiate the excursion maneuver.

[0212]

After setting each offset contour for each object 825, the processing unit may combine the offset contours so that the maximum lateral distance is maintained with each object 825 bypassed by the vehicle 200.

That is, the offset maneuver may be modified and/or performed such that the lateral distance between the vehicle 200 and each object 825 bypassed by the vehicle 200 is maximized.

[0213]

Additionally or alternatively, the object 825 may be parked or stationary vehicles, walls, or people (such as pedestrians), or bicycle traffic.

The processing unit 110 may determine that a lane offset condition exists based on certain characteristics of the object 825. For example, the processing unit 110 may determine that if the height of the object 825 exceeds a predetermined threshold, such as

10 cm from the road surface, the object 825 constitutes a lane offset condition. In this way, the processing unit 110 may be configured to filter out objects for which lane deviation conditions will not occur, such as small pieces of debris.

[0214]

Additionally or alternatively, the processing unit 110 may be configured to determine whether the lane offset condition exists on the first vehicle side 802 based on the position of the target object 830 on the first side 802 of the vehicle.

The target object 830 may include one or more objects constituting the lane deviation condition. Additionally or alternatively, the target object 830 may not constitute a lane departure condition. For example, the target object 830 may be a street sign or other object that is far enough away from the lane of travel or that does not occur frequently enough (not constituting a lane departure condition). The processing unit 110 may be configured to conclude that the lane deviation condition does not exist if such a target object 830 is detected.

[0215]

The processing unit 110 may be configured to cause the vehicle 200 to travel such that the first distance 805 and the second distance 810 are substantially different to avoid or keep further away from the object 825.

For example, if the lane offset condition exists on the first vehicle side 802, the processing unit 110 may be configured to cause the vehicle 200 to travel within the first lane constraint 810 and the second lane constraint 820, such that the first distance 805 is greater than the second distance 815 . This is illustrated in Figure 8A, for example. Alternatively, if the lane offset condition exists on the second vehicle side 812, the processing unit 110 may create or execute such an offset profile configured to cause the vehicle 200 to constrain 810 and the second lane in the first lane. Travel within the lane constraint 820 such that the first distance 805 is smaller than the second distance 815. This is illustrated in Figure 8B, for example.

[0216]

As another example, a parked vehicle may be located on one side of the vehicle 200, and pedestrians may be located on the other side of the vehicle 200.

In such a situation, the system 100 may determine that it is desirable to reduce the distance between the vehicle 200 and the parked vehicle in order to provide more space between the vehicle 200 and the pedestrian. Therefore, the processing unit 110 may cause the vehicle 200 to travel so that the distance between parked vehicles is reduced.

[0217]

The recognition of the first vehicle side 802 and the second vehicle side 812 needs not to be static, so that at different points in time, the processing unit 110 can recognize the first vehicle side 802 as the driver side or the passenger side of the vehicle 200.

For example, depending on which side of the vehicle 200 one or more objects 825 are present, the recognition of the first vehicle side 802 may be changed so that if there is a lane offset condition based on the object 825, the object 825 is present on the first vehicle side 802 on. In such a situation, the processing unit 110 may create or execute an offset profile that is configured to cause the vehicle 200 to travel within the first lane constraint 810 and the second lane constraint 820 such that it is greater than the second distance 815 The first distance 805 of is provided towards the object 825.

[0218]

According to some embodiments, when a lane offset condition exists on the first vehicle side 802, the processing unit 110 may create an offset profile configured to cause the vehicle 200 to constrain 810 and the second lane in the first lane Travel within the constraint 820 such that the first distance 805 is at least 1.25 times greater than the second distance 815.

Additionally or alternatively, when a lane offset condition exists on the first vehicle side 802, the processing unit 110 may create an offset profile configured to cause the vehicle 200 to constrain 810 and the second lane in the first lane. Traveling within the two-lane constraint 820 makes the first distance 805 greater than the second distance 815 by at least 2 times.

[0219]

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In some embodiments, as shown in FIG. 8C, the processing unit 110 may determine that the lane offset condition exists on both the first vehicle side 802 and the second vehicle side 812.

Then, the processing unit 110 may create such an offset profile for the offset condition that is configured to cause the vehicle 200 to travel within the first lane constraint 810 and the second lane constraint 820 such that the first distance 805 is substantially It is equal to the second distance 815.

[0220]

The processing unit 110 may be configured to prioritize the offset contours for the moving object 825 and the stationary object 825.

For example, the processing unit 110 may preferentially offset the contour to maintain a predetermined distance between the vehicle 200 and the moving object 825 and/or the static object 825. The processing unit 200 may prioritize these offset conditions (better than these offset conditions) based on certain lane characteristics (such as a curve). The last priority lane departure condition may include imitating the preceding vehicle.

[0221]

The processing unit 110 may condition the offset profile or offset into a desired look-ahead point, which may be located in the middle of the lane defined by the first lane constraint 810 and the second lane constraint 820.

The processing unit 110 may calculate and implement the yaw rate command based on the look-ahead point and the offset profile. The yaw rate command may be used to calculate the torque command based on the yaw rate command and the yaw rate of the vehicle 200 measured by using a gyroscope. The processing unit 110 may send a torque command to the steering system of the vehicle 200 (for example, the steering system 240).

[0222]

According to some embodiments, such as via the user interface 170, an input from the driver of the vehicle 200 may cancel the processing unit 110.

For example, a user input can cancel the control of the processing unit 110, causing the vehicle 200 to travel within the first lane constraint 810 and the second lane constraint 820, so that the first distance 805 is greater than the second distance 815.

[0223]

Additionally or alternatively, the processing unit 110 may be configured to determine whether the lane deviation condition is substantially non-existent based on a plurality of images captured by the image capturing device 122.

This may include situations in which one or more objects 825 below a certain size threshold are detected, and/or when no object 825 is detected, the detected one or more objects 825 are located at a predetermined distance from the lane constraint Outside. In such a situation, the processing unit 110 may be configured to cause the vehicle 200 to travel within the first lane constraint 810 and the second lane constraint 820 such that the first distance 805 is equal to or substantially equal to the second distance 815.

[0224]

As illustrated in FIG. 8D, the lane deviation condition may include a curved road.

The processing unit 110 may be configured to cause the vehicle 200 to travel within the first lane constraint 810 and the second lane constraint 820, such that the first distance 805 is toward the outside of the curve relative to the vehicle 200, and the second distance 815 is toward the curve relative to the vehicle 200. Inside. For example, the first distance 805 may be smaller than the second distance 815.

[0225]

FIG. 9 is an exemplary block diagram of the memory 140 and/or 150 consistent with the disclosed embodiments. The memory 140 and/or 150 may store instructions for performing one or more operations.

As illustrated in FIG. 9, the memory 140 may store one or more modules for performing the lane deviation condition detection and response described herein. For example, the memory 140 may store the lane restriction module 910 and the lane offset module 920. The application processor 180 and/or the image processor 190 can execute instructions stored in any of the modules 910 and 920 (included in the memory 140). Those skilled in the art will understand that the references to the processing unit 110 in the following discussion may refer to the application processor 180 and the image processor 190 individually or collectively. Therefore, the steps of any of the following processes may be executed by one or more processing devices.

[0226]

The lane restriction module 910 may store instructions, and when executed by the processing unit 110, the instructions may detect and define the first lane restriction 810 and the second lane restriction 820.

For example, the lane offset module 910 may process multiple images received from at least one image capture device 122-124 to detect the first lane constraint 810 and the second lane constraint 820. As discussed above, this may include identifying painted lane lines and/or measuring the midpoint of the road surface.

[0227]

The lane offset module 920 may store instructions. When executed by the processing unit 110, the instructions may detect the existence of lane offset conditions and/or identify whether the lane offset conditions exist on the first vehicle side 802 and/or the second vehicle side. 812 on.

For example, the lane offset module 920 may process multiple images to detect the presence of the object 825 on the first vehicle side 802 and/or the second vehicle side 812. The lane offset module 920 may process multiple images to detect a curve in the road on which the vehicle 200 is traveling. Additionally or alternatively, the lane offset module 920 may receive information from another module or other system that indicates the presence of an object 825 and/or a curved lane. The lane offset module 920 may perform control to change the position of the vehicle 200 relative to the first lane constraint 810 and/or the second lane constraint 820. For example, if the lane offset module 920 determines that the lane offset condition is only on the first vehicle side 802, the lane offset module 920 may cause the vehicle 200 to move closer to the second lane constraint 820. On the other hand, if the lane offset module 920 determines that the lane offset condition is only on the first vehicle side 812, the lane offset module 920 may cause the vehicle 200 to move closer to the first lane constraint 810.

[0228]

FIG. 10 illustrates a process 1000 for navigating the vehicle 200 consistent with the disclosed embodiment.

The process 1000 may identify lane constraints that define the lane of travel in which the vehicle travels. The process 1000 includes causing the vehicle 200 to travel closer to one or another lane constraint, such as the first lane constraint 810 or the second lane constraint 820 in response to detecting a lane offset condition. In this way, the process 1000 can be used to drive the vehicle 200 within lane constraints and to consider environmental factors that may be more desirable to displace the vehicle 200 within the first lane constraint 810 and the second lane constraint 820.

[0229]

At step 1010, the process 1000 may include using at least one image capture device 122, 124, and/or 126 to acquire multiple images of the area near the vehicle 200.

For example, the processing unit 110 may receive multiple images via the data interface 128. For example, the processing unit 110 may be configured to determine that one or more objects 825 exist on one side of the road. For example, the object 825 may be a parked or stationary vehicle, wall or person (such as pedestrian) or bicycle traffic. The processing unit 110 may determine whether the lane deviation condition exists based on certain characteristics of the object 825. For example, the processing unit 110 may determine that if the height of the object 825 exceeds a predetermined threshold, such as 10 cm from the road surface, the object 825 constitutes a lane offset condition. In this way, the processing unit 110 may be configured to filter out objects for which lane deviation conditions will not occur, such as small pieces of debris.

[0230]

Additionally or alternatively, the processing unit 110 may be configured to determine whether the lane offset condition exists on the first vehicle side 802 based on the position of the target object 830 on the first side 802 of the vehicle.

The target object 830 may be one or more objects constituting the lane deviation condition. Additionally or alternatively, the target object 830 may not constitute a lane departure condition. For example, the target object 830 may be a road obstacle or a street sign. The processing unit 110 may be configured to conclude that the lane offset condition does not exist if such a target object 830 is detected.

[0231]

In step 1020, the process 1000 may determine the first lane constraint on the first vehicle side 802 and the second lane constraint on the second vehicle side 812 based on the multiple images.

For example, the processing unit 110 may be configured to determine the first lane constraint 810 and the second lane constraint 820 based on a plurality of images received via the data interface 128.

[0232]

At step 1030, the process 1000 may determine whether a lane offset condition exists on the first vehicle side 802.

If the lane offset condition does exist on the first vehicle side 802, then at step 1040, the process 1000 may include: causing the vehicle 200 to travel within the first lane constraint 810 and the second lane constraint 820, so that the second distance 815 is less than the first A distance of 805. The processing unit 110 may be configured to cause the vehicle 200 to travel such that the first distance 805 and the second distance 810 are substantially different to avoid or keep further away from the object 825. For example, if the lane offset condition exists on the first vehicle side 802, the processing unit 110 may be configured to cause the vehicle 200 to travel within the first lane constraint 810 and the second lane constraint 820, such that the first distance 805 is greater than the second distance 815. This is illustrated in Figure 8A, for example. Alternatively, if the lane offset condition exists on the second vehicle side 812, the processing unit 110 may be configured to cause the vehicle 200 to travel within the first lane constraint 810 and the second lane constraint 820, so that the first distance 805 is less than the second The distance is 815. This is illustrated in Figure 8B, for example. For example, in order to navigate the vehicle 200 according to the process 1000, the processing unit 110 may send electronic signals to one or more of the throttle system 220, the braking system 230, and/or the steering system 240 of the vehicle 200.

[0233]

If the lane offset condition does not exist on the first vehicle side 802, then in step 1050, the method may include: determining whether the lane offset condition exists on the second vehicle side 812.

If the lane offset condition exists on the second vehicle side 812, the method may include causing the vehicle 200 to travel between the first lane constraint 810 and the second lane constraint 820 such that the first distance 805 is less than the second distance 815.

[0234]

Navigate the car to the default lane

[0235]

The system 100 may provide driver assistance functionality for monitoring the location of the vehicle 200 in the current travel lane and if the current travel lane is not the predetermined default travel lane, the vehicle 200 enters the predetermined default travel lane.

The predetermined default lane of travel may be defined by user input and/or as a result of processing images received from at least one image capture device 122-126.

[0236]

The system 100 may also provide the driver and passengers of the vehicle 200 and/or other drivers with a notification that the vehicle 200 is about to change lanes to a predetermined default lane of travel.

For example, the system 100 may activate a turn signal located at or near one of the bumper areas 210.

Additionally or alternatively, the system 100 may issue a voice notification, such as through a speaker 360. When the vehicle is traveling, the vehicle 200 may use the system 100 to select a specific lane as a predetermined default traveling lane. When the current lane in which the vehicle 200 travels (for example, the current travel lane) is different from the predetermined default travel lane, the system 100 may cause the vehicle 200 to make a lane change, for example, enter the predetermined default travel lane.

[0237]

FIG. 11 illustrates a vehicle 200 traveling in the current traveling lane 1110 of the road 800.

According to some embodiments, the vehicle 200 may have a predetermined default lane 1120 of travel. For example, the predetermined default travel lane 1120 may be the rightmost lane of the road 800. The navigation system 100 may be configured to determine whether the vehicle 200 is traveling in a predetermined default travel lane 1120, and if not, cause the vehicle 200 to change to the predetermined default travel lane 1120. For example, the processing unit 110 may be configured to compare the current travel lane 1110 with a predetermined default travel lane 1120 and cause the vehicle 200 to return to the predetermined default travel lane 1120.

[0238]

According to some embodiments, the processing unit 110 may detect the object 1130 in the predetermined default travel lane 1120 based on a plurality of images acquired by one or more of the image capturing devices 122-126.

The processing unit 110 may detect the position and speed of the vehicle 200 relative to the object 1130 by analyzing the image using the technique described above in conjunction with FIGS. 5A to 5D. According to some embodiments, the processing unit 110 may determine whether the vehicle 200 should overtake the object 1130. It may be desirable, for example, that the speed and/or acceleration of the vehicle 200 relative to the object 1130 exceed a certain threshold.

[0239]

FIG. 12A is an exemplary block diagram of the memory 140 consistent with the disclosed embodiments. The memory 140 may store instructions for performing one or more operations.

As illustrated in FIG. 12A, the memory 140 may store one or more modules for performing the detection and response of the default travel lane and the current travel lane described herein. For example, the memory 140 may store the current lane detection module 1210, the default lane detection module 1220, and the action module 1230.

[0240]

The current lane detection module 1210 can store instructions, and when executed by the processing unit 110, the instructions can detect and limit the current lane 1110 of travel.

For example, the processing unit 110 may execute the current lane detection module 1212 to process a plurality of images received from at least one image capturing device 122-124 and detect the current traveling lane 1110. This may include detecting the relative position of the vehicle 200 relative to the curb of the road 800, the midpoint of the road 800, and/or lane markers (such as painted lane lines). The processing unit 110 may detect the position of the vehicle 200 relative to the road 800 by analyzing the image using the technique described above in conjunction with FIGS. 5A to 5D.

[0241]

The default lane detection module 1220 may store instructions, and when executed by the processing unit 110, the instructions may identify a predetermined default lane 1120 and compare the default lane detection module 1220 with the current lane 1110 identified by the current lane detection module 1210.

The default lane detection module 1220 may identify the predetermined default lane of travel 1120 based on user input and/or multiple images received from at least one image capture device 122-124. For example, the user may select the default lane through a voice command received by the speaker 360 or by selecting a menu displayed on the touch screen 320.

[0242]

In some embodiments, the predetermined default travel lane 1120 may be the rightmost travel lane, or may be a lane with more desirable characteristics.

For example, the default lane detection module 1220 may include instructions for selecting a lane with less traffic, the lane of the vehicle closest to the speed of the vehicle 200, and/or the lane closest to an exit or the street where the vehicle 200 will turn. . In some embodiments, the predetermined default lane of travel 1120 may be determined based on data received from the position sensor 130 (such as a global positioning system).

[0243]

The action module 1230 may store an instruction, and when executed by the processing unit 110, the instruction may generate a response identifying the current travel lane 1110 and a predetermined default travel lane 1120.

For example, the processing unit 110 may execute the action module 1230 to cause the vehicle 200 to change lanes when the current travel lane 1110 is different from the predetermined default travel lane 1120. Additionally or alternatively, the action module 1230 may initiate a lane change notification, such as activating the turn signal 210 or generating a voice notification.

[0244]

The action module 1230 may include instructions that cause the processing unit 110 to determine whether the vehicle 200 should move out of the predetermined default lane 1120 of travel.

For example, the action module 1230 may determine that the object 1130 in the predetermined default travel lane 1120 should be bypassed by the vehicle 200.

[0245]

The action module 1230 may further include instructions that cause the processing unit 110 to determine whether it is safe to perform a lane change.

For example, before performing a lane change, the processing unit 110 may evaluate and determine one or more characteristics of the road 800 based on, for example, analysis of multiple images performed using the technique described above in conjunction with FIGS. 5A to 5D. If the analysis indicates that the lane change condition is unsafe, the processing unit 110 may determine that the vehicle 200 should remain in the current lane.

[0246]

The action module 1230 may include additional instructions for manipulating the vehicle 200 to maneuver out and return to the predetermined default travel lane 1120 (such as bypassing the object 1130).

When executing these instructions, the processing unit 110 may use the estimated motion of the vehicle 200 to estimate the location of the predetermined default lane 1120 of travel. This may be advantageous in situations where the predetermined default lane of travel 1120 cannot be kept as detected by the image capture devices 122-124.

[0247]

The processing unit 110 may be configured to execute an offset profile that offsets the vehicle 200 from a predetermined default travel lane 1120 by a full lane width, which may be estimated based on the distance between detected lane markers.

The offset maneuver defined by the offset profile may be performed by the processing unit 110 so that the movement of the vehicle 200 is smooth and comfortable for the driver. For example, the offset slew rate may be approximately 0.15 m/sec to 0.75 m/sec. During the offset maneuver, the processing unit 110 can execute an instruction from the action module 1230, and the instruction switches to follow the center of the current traveling lane 1110. These instructions may include a gradual transition

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from following the predicted lane of the belt offset to following the current lane 1110 of travel. The gradual transition can be done by defining the desired look-ahead point so that no more changes in time than the recommended slew rate (which can be about 0.25 m/s) are allowed.

[0248]

The instructions for making the vehicle 200 transition from the predetermined default lane of travel 1120 may be used to make the vehicle 200 transition back into the predetermined default lane of travel.

For example, the processing unit 110 may be configured to execute an offset profile that offsets the vehicle 200 from the current travel lane 1110 by a full lane width, which may be estimated based on the distance between detected lane markers. The offset maneuver defined by the offset profile may be performed by the processing unit 110 so that the movement of the vehicle 200 is smooth and comfortable for the driver. For example, the offset slew rate may be approximately 0.15 m/sec to 0.75 m/sec. During the shifting maneuver, the processing unit 110 can execute an instruction from the action module 1230, and the instruction switches to follow the center of the predetermined default travel lane 1120. These instructions may include a gradual transition from following the predicted lane of the belt offset to following the predetermined default lane of travel 1120. The gradual transition can be done by defining the desired look-ahead point so that no more changes in time than the recommended slew rate (which can be about 0.25 m/s) are allowed.

[0249]

In one or more steps of making the vehicle 200 transition between two lanes, the processing unit 110 may calculate and implement a yaw rate command based on the look-ahead point and the offset profile.

The yaw rate command may be used to calculate the torque command based on the yaw rate command and the yaw rate of the vehicle 200 measured using a gyroscope. The processing unit 110 may send a torque command to the steering system of the vehicle 200 (for example, the steering system 240).

[0250]

FIG. 12B illustrates a process 1250 for navigating the vehicle 200 to the default lane consistent with the disclosed embodiment.

According to some embodiments, the process 1250 may be implemented by one or more components of the navigation system 100 (such as at least one processing unit 110). The process 1250 may identify the current lane 1110 of the vehicle 200 and compare it with the predetermined default lane 1120 to determine whether the vehicle 200 is traveling within the predetermined default lane 1120. If the vehicle 200 does not travel in the predetermined default travel lane 1120, the processing unit 110 may cause the vehicle 200 to change lanes so as to navigate to the default travel lane 1120.

[0251]

In step 1260, one or more of the image capturing devices 122-124 may acquire multiple images of the area near the vehicle 200.

The processing unit 110 may receive multiple images via the data interface 128.

[0252]

In step 1270, the processing unit 110 may execute the current lane detection module 1210 to detect and define the current lane 1110 of travel.

For example, the processing unit 110 may process multiple images, for example, to detect the relative position of the vehicle 200 with respect to the curb of the road 100, the midpoint of the road 100, and/or the painted lane markers. The processing unit 110 may detect the position of the vehicle 200 relative to the road 800 by analyzing the image using the technique described above in conjunction with FIGS. 5A to 5D.

[0253]

In step 1280, the processing unit 110 may execute the default lane detection module 1220 to identify a predetermined default lane 1120 and compare the default lane detection module 1220 with the current lane 1110 identified by the current lane detection module 1210.

The default lane detection module 1220 may identify the predetermined default lane of travel 1120 based on user input and/or multiple images received from at least one image capture device 122-124.

[0254]

For example, as discussed above, the processing unit 110 may determine the predetermined default lane of travel 1120 based on any number of factors.

The predetermined default travel lane 1120 may be the rightmost lane among the plurality of travel lanes 1110 and 1120. Additionally or alternatively, the determination of the predetermined default lane of travel 1120 may be based on input received from the user via the user interface 170 by processing a plurality of images, and/or based on data received from the position sensor 130 (such as a global positioning system). The predetermined default travel lane 1120 may be determined once for each vehicle trip, or may be determined periodically. For example, the predetermined default lane of travel 1120 may be dynamically determined in response to the conditions of a given location.

[0255]

If the current lane 1110 is not the same as the predetermined default travel lane 1120, the processing unit 110 may execute the action module 1230 to cause the vehicle 100 to navigate to the default travel lane 1120.

For example, the processing unit 110 may send an electronic signal to one or more of the throttle system 220, the braking system 230, and/or the steering system 240 of the vehicle 200 to trigger a desired response. For example, the processing unit 110 may cause the steering system 240 to steer the steering wheel of the vehicle 200 to achieve a predetermined angle of rotation.

[0256]

Further, before performing the lane change, the processing unit 110 may determine whether the lane change is safe (for example, there are no vehicles or objects on the road).

As discussed above, the processing unit 110 may evaluate one or more characteristics of the road 800 based on, for example, analysis of multiple images performed using the techniques described above in conjunction with FIGS. 5A to 5D. If the lane change condition is unsafe, the processing unit 110 may determine that the vehicle 200 should remain in the current lane.

[0257]

In some implementations, the execution action module 1230 can initiate a lane change notification.

For example, the processing unit 110 may generate a signal to activate a turn signal and/or generate a voice notification via the speaker 360. Therefore, such notification may occur before the vehicle 200 changes lanes. In other embodiments, the execution action module 1230 may initiate a notification to the driver of the vehicle 200 that the vehicle 200 is not traveling in the default lane without causing the lane change to occur. Therefore, in such an embodiment, the driver of the vehicle 200 may determine whether to manually take an action and steer the vehicle 200 to change lanes.

[0258]

In some embodiments, the system 100 may notify the user of the vehicle 200 and/or other drivers in the vicinity of the vehicle 200 that if the vehicle 200 will move to a predetermined default lane of travel 1120, the vehicle 200 will change lanes.

For example, the processing unit 110 may activate the turn signal of the vehicle 200 before causing the vehicle 200 to change lanes. Additionally or alternatively, a voice notification notifying other drivers in the vicinity may be generated by the processing unit 110. The voice notification may be sent to a receiver included in other nearby vehicles via, for example, Bluetooth. Additionally or alternatively, the at least one processing unit 110 may cause a voice indicator to notify the driver of the vehicle 200 before causing the vehicle 200 to switch lanes. In this way, the driver of the vehicle 200 can expect that the control system 100 will be applied to the vehicle 200.

[0259]

Control the speed of turning vehicles

[0260]

The system 100 may provide driver assistance functionality for controlling the speed (ie, speed and/or direction) of the vehicle 200 in different scenarios, such as when making a turn (eg, passing a curve).

For example, the system 100 may be configured to use a combination of map, location, and/or visual data to control the speed of the vehicle 200 when turning.

In particular, the system 100 can control the speed of the vehicle 200 when approaching a curve (while navigating the curve) and/or when leaving the curve. The system 100 may consider different factors to control the speed, depending on the position of the vehicle 200 relative to the curve at a given time. For example, the system 100 may initially cause the vehicle 200 to decelerate in response to learning that the curve is a certain distance in front of the vehicle 200. However, while the vehicle 200 is turning through a curve, the system 100 may cause the vehicle 200 to accelerate and/or change direction based on the analysis of the characteristics of the curve.

[0261]

13A and 13B are schematic representations of bringing a vehicle (for example, the vehicle 200) close to and navigating a curve having one or more characteristics of the road 1300 consistent with the disclosed embodiment.

As illustrated in FIG. 13A, a visual indicator (such as a road sign 1302 located near the road 1300) may inform the vehicle 200 that the curve is ahead. In response to the warning provided by the road sign 1302, the driver of the vehicle 200 and/or the system 100 that provides driver assistance functionality for the vehicle 200 may adjust the speed of the vehicle 200 (for example, by decelerating and/or steering) to safely Navigate corners.

[0262]

When the vehicle 200 is approaching a curve, the system 100 may detect the lane width 1306 and the curve radius 1308 by using the image capturing device 122 and/or 124 (which may be a camera) of the vehicle 200.

Based on the curve radius 1308, the lane width 1306, and other characteristics associated with the curve detected using the image capture device 122 and/or 124, the system 100 may adjust the speed of the vehicle 200. Specifically, the system 100 may adjust the speed of the vehicle 200 when the vehicle 200 approaches a curve and/or the vehicle 200 navigates the curve. The system 100 may also adjust the speed of the vehicle 200 as it leaves the curve in response to, for example, a traffic light 1304 that appears after the curve. The following describes further details on adjusting the speed of the vehicle 200 and detecting the lane width 1306, the radius of curvature or the radius of a curve 1308, and the characteristics associated with the curve in conjunction with FIGS. 14 and 15.

[0263]

In some embodiments, the system 100 may identify the curve to be navigated based on map data and/or vehicle location information (eg, GPS data).

The system 100 may determine the initial target speed of the vehicle based on one or more characteristics of the curve reflected in the map data. The system 100 may adjust the speed of the vehicle to the initial target speed, and determine one or more observed characteristics of the curve based on one or more images acquired by one or more of the image capture devices 122-126. The system 100 may determine the updated target speed based on the observed one or more characteristics of the curve, and adjust the speed of the vehicle to the updated target speed.

[0264]

FIG. 14 is an exemplary block diagram of a memory consistent with the disclosed embodiments, the memory being configured to store instructions for performing one or more operations.

As indicated in FIG. 14, the memory 140 may store a curve recognition module 1402, a characteristic observation module 1404, and a speed module 1406. The disclosed embodiments are not limited to the memory 140 of any particular configuration. Further, the processing unit 110 can execute instructions stored in any of the modules 1402-1406 (included in the memory 140).

[0265]

In one embodiment, the curve recognition module 1402 may store software instructions (such as computer vision software), and when executed by the processing unit 110, the software instructions can analyze one or more sets of images and/or use maps and/or Or location data (for example, data stored in the map database 160) to detect a curve.

The image group may be acquired by one or more of the image capture devices 122, 124, and 126. Based on this analysis, the system 100 (eg, via the processing unit 110) may cause the speed of the vehicle 200 to change. For example, if the processing unit 110 detects that there is a curve within the minimum threshold distance in front of the vehicle 200, the processing unit 110 may cause the speed of the vehicle 200 to decrease by a predetermined amount and/or adjust the direction of the vehicle 200 by a specific angle.

[0266]

In one embodiment, the characteristic observation module 1404 may store software instructions (such as computer vision software). When executed by the processing unit 110, the software instructions observe the curve detected by the system 100 (for example, by executing the curve recognition module 1402). Dao-related characteristics.

The processing unit 110 may analyze one or more sets of images acquired by one or more of the image capture devices 122, 124, and 126 and/or use map and/or location data (for example, stored in the map database 160). Data) to observe the characteristics associated with the detected curve. The analysis can generate information associated with the curve, such as the radius of the curve 1308, the width of the lane 1306, the degree of curvature, the rate of change of curvature, the inclination of the curve, the length or arc length of the curve, and so on. These characteristics may include estimates (for example, curve characteristics calculated using pre-existing data and/or mathematical models based on such data) and actual values (for example, curve characteristics calculated by analyzing captured images of the curve) . Based on this analysis, the processing unit 110 may cause the speed of the vehicle 200 to change. For example, in view of the higher rate of curvature change associated with a curve 25 meters in front of the vehicle 200, the processing unit 110 may cause the speed of the vehicle 200 to decrease and/or adjust the direction of the vehicle 200 by a specific angle.

[0267]

In one embodiment, the speed module 1406 may store software instructions configured to analyze data from one or more computerized electrical devices that are configured to determine the target speed and cause the speed of the vehicle 200 to change is the target speed.

For example, the processing unit 110 may execute the speed module 1406 to calculate the target speed of the vehicle 200 based on the data obtained from executing the curve recognition module 1402 and the characteristic observation module 1404. For example, such data may include initial target position and initial speed, updated target position and update speed, final target position and final speed, and so on. In addition, the processing unit 110 may calculate the speed of the vehicle 200 based on input from other systems of the vehicle 200 (such as the throttle system 220, the braking system 230, and/or the steering system 240 of the vehicle 200). Based on the calculated target speed, the processing unit 110 may send electronic signals (for example, via a controller area network bus ("CAN bus")) to the throttle system 220, braking system 230, and/or steering system 240 of the vehicle 200 to The change in the speed and/or direction of the vehicle 200 is triggered by, for example, physically depressing the brake, releasing the accelerator of the vehicle 200, or turning the vehicle 200 in a specific direction (for example, at a specific angle). The increase in speed may be associated with a corresponding acceleration (for example, between 0.2 m/s2 and 3.0 m/s2). Conversely, the speed reduction can be associated with the corresponding deceleration. Additionally, acceleration or deceleration may be based on road type (eg, highway, city street, country road, etc.), the presence of any nearby speed constraints (eg, sharp curves, traffic lights), and road width or lane width 1306. For the purposes of this disclosure, deceleration may refer to acceleration having a negative value.

[0268]

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15 is a flowchart showing an exemplary process 1500 for controlling the vehicle speed based on the detected curve and the observed curve characteristics and/or map data about the curve, consistent with the disclosed embodiment.

In step 1510, the processing unit 110 may receive a plurality of images via the data interface 128 between the processing unit 110 and the image acquisition unit 120. For example, a camera (such as the image capturing device 122) included in the image acquisition unit 120 may capture a plurality of images and send the images to the processing unit 110 via a digital connection (eg, USB, wireless, Bluetooth, etc.). In some embodiments, the processing unit 110 may receive more than one multiple images via multiple data interfaces. For example, the processing unit 110 may receive multiple images from each of the image capture devices 122, 124, 126, and each of the image capture devices 122, 124, 126 may have an associated data interface for communicating with the processing unit 110 data. The disclosed embodiments are not limited to any specific data interface structure or protocol.

[0269]

In step 1520, the processing unit 110 may execute the curve recognition module 1502 to detect a curve located in front of the vehicle 200 based on, for example, map and/or location data (for example, data stored in the map database 160).

Such data can indicate the location of a curve that exists on a given road. The data may indicate the absolute position of a particular curve (for example, via GPS coordinates) or the relative position of the curve (for example, by describing the curve relative to the vehicle 200, road signs 1302, traffic lights 1304, and/or other descriptive landmarks) . In some embodiments, the processing unit 110 may execute the curve recognition module 1502 to detect a curve by analyzing a plurality of images. This analysis can be performed using the technique described above in conjunction with FIGS. 5A to 5D and FIG. 6.

[0270]

In step 1530, the processing unit 110 may execute the speed module 1406 to determine the initial target speed of the vehicle 200 based on, for example, data obtained from executing the curve recognition module 1402.

The initial target speed may reflect the speed and direction of the vehicle 200 to safely enter the upcoming curve, and may be determined using the technique described above in conjunction with FIG. 14. For example, the speed module 1406 may determine the initial target speed based on known or estimated characteristics associated with the upcoming curve, such as the curve radius 1308 and the inclination of the curve. The speed module 1406 may calculate the initial target speed according to mathematical models and/or formulas and based on various constraints. In some embodiments, for example, the speed module 1406 may be based on the presence of a traffic light (such as a traffic light 1304) before, during, or after a curve, weather conditions (e.g., light rain, heavy rain, strong wind, cloudy, etc.), road conditions (For example, asphalt roads, dirt roads, potholes, etc.), speed limit, nearby vehicles or pedestrians, etc. to determine the initial target speed. The initial target speed may also be based on the lateral acceleration limit associated with the vehicle 200. In some embodiments, the lateral acceleration limit may be in the range of 0.2 m/sec 2 to 3.0 m/sec 2 and may be adjusted depending on the curve characteristics, the width of the road, or the width of the lane 1306. Additionally, the initial target speed may be based on the focal range associated with one or more cameras (such as image capture devices 122 and 124).

[0271]

For example, the speed module 1406 may determine the initial target speed based on the radius of curvature of the road in front of the vehicle 200.

The speed module 1406 may determine the radius of curvature at various distances from the vehicle 200 and store the information in a vector R(1:n). In one embodiment, the speed module 1406 may determine the radius of curvature of the following locations: (1) the current position of the vehicle 200; (2) the distance from the vehicle 200 D end point, where D end point represents the recognition of the road characteristics before the vehicle 200 The distance that allows the system 100 to control the navigation response of the vehicle 200 so that the driver can feel comfortable; and (3) the incremental distance from the vehicle 200, such as every 1 meter, and so on. The value of the distance D end point may depend on the current speed Vego of the vehicle 200. For example, the greater the value of Vego (e.g., the faster the vehicle 200 travels), the greater the value of D end point (e.g., the longer the distance can be considered to provide enough time for the system 100 to provide a navigation response, such as based on approaching a sharp turn Or curve to reduce the speed of the vehicle 200 comfortably). In one embodiment, the D endpoint can be calculated according to the following formula: D endpoint=(Vego2/2)/(0.7/40*Vego+0.5). Thus, the vector D(1:n)=[1:1:n], where n=round down (D end point).

[0272]

In some embodiments, the speed module 1406 may determine the initial target speed based on the lateral acceleration constraint amax (eg, the maximum allowable lateral acceleration).

a can fall within the range of 1.5 m/s2 to 3.5 m/s2 at most. Based on a maximum and the radius of curvature vector R (discussed above), the speed module 1406 may limit the speed of the vehicle 200 (for example, at different points or distances from the current position of the vehicle 200) to the speed v limit, calculated as: v Limit (1:n)=(amax*R(1:n))1/2. In addition, the deceleration constraint derived from the determination of the v limit can be calculated as: dec limit=minimum{((vlimit(1:n) 2-Vego2)/2), maximum{dmin, D(1:n) -2*Vego}}, where d is at least equal to 40 meters. The smallest value of d may indicate a point at which the driver of the vehicle 200 feels comfortable to decelerate.

[0273]

In some embodiments, the speed module 1406 may determine the initial target speed based on the curvature slew rate constraint slew maximum (which may be based on the rate of curvature change).

The maximum slew can fall within the range of 0.5 m/s3 to 1.5 m/s3. The speed module 1406 can determine the v limit according to the following formula: v limit (1:n)=(slew max/abs{{1/R(1:n)}})1/3. Further, the speed module 1406 can determine the dec limit according to the following formula: dec limit=minimum{((vlimit(1:n)2-Vego2)/2), maximum{dminimum, D(1:n)-2* Vego}}, where d is at least equal to 40 meters.

[0274]

In some embodiments, the speed module 1406 may determine comfort constraints such that the driver of the vehicle 200 is comfortable while the vehicle 200 experiences various navigation responses, such as turning or navigation curves.

The speed module 1406 may determine the v limit according to the following formula: v limit (1:n)=4/500*R(1:n)+22.5. Further, the speed module 1406 can determine the dec limit according to the following formula: dec limit=minimum{((vlimit(1:n) 2-Vego2)/2), maximum{dminimum, D(1:n)-2* Vego}}, where d is at least equal to 40 meters.

[0275]

The speed module 1406 may merge the three constraints determined above, namely the lateral acceleration constraint, the curvature slew rate constraint, and the comfort constraint by using the minimum value of the dec limit calculated in association with each constraint.

After merging the constraints, the speed module 1406 can reach the initial target speed by determining the amount to adjust the speed of the vehicle 200 according to the following formula, denoted as v comfort: v comfort = v comfort (previous) + dec limit * Δt, where v comfort (Previous) represents the previous speed of the vehicle 200 (eg, the previously determined speed, the speed of the vehicle 200 before any adjustments are made by the speed module 1406, etc.), and Δt represents the time between the determination of v comfort and v comfort (previous) .

[0276]

In step 1540, the processing unit 110 may execute the speed module 1406 to adjust the speed of the vehicle 200 to the initial target speed determined in step 1530.

Based on the current speed of the vehicle 200 and the initial target speed determined in step 1530, the processing unit 110 may send electronic signals to the throttle system 220, the braking system 230, and/or the steering system 240 of the vehicle 200 to change the speed of the vehicle 200 To the initial target speed. Further, one or more actuators may control the throttle system 220, the braking system 230, and/or the steering system 240. For example, the processing unit 110 may send an electronic signal to cause the system 100 to physically depress the brake for a predetermined amount or partially release the accelerator of the vehicle 200. Further, the processing unit 110 may send an electronic signal to cause the system 100 to steer the vehicle 200 in a specific direction. In some embodiments, the magnitude of the acceleration (or deceleration) may be based on the difference between the current speed of the vehicle 200 and the initial target speed. When the difference is large (for example, the current speed is 10km/hr greater than the initial target speed), for example, the system 100 can maximize the deceleration and cause the vehicle 200 to achieve the initial target as safely as possible in the shortest amount of time. Speed mode brake to

change the current speed. Alternatively, the system 100 may apply the brakes in a manner that minimizes the deceleration and causes the vehicle 200 to gradually achieve the initial target speed. More generally, the system 100 can change the current speed to the initial target speed according to any particular braking profile (eg, a braking profile that requires a high braking level for the first two seconds and a low braking level for the following three seconds). The disclosed embodiments are not limited to any specific braking profile or braking method.

[0277]

In step 1550, the processing unit 110 may execute the characteristic observation module 1404 to determine one or more characteristics of the curve located in front of the vehicle 200 based on, for example, analyzing multiple images performed using the technique described above in conjunction with FIGS. 5A to 5D.

For example, the characteristics may include estimated and/or actual values associated with the radius of the curve 1308, the width of the road or lane 1306, the degree of curvature, the rate of change of curvature, the inclination of the turn, and the like. For example, the characteristics may also include information conveyed by one or more road signs, such as road signs 1302. In addition, the characteristic may include the length or arc length of the detected curve (which may be a function of the speed of the vehicle 200 when approaching the curve). The processing unit 110 may execute the characteristic observation module 1404 to calculate values associated with these characteristics (for example, curve radius 1308, degree of curvature, curvature change rate, curve arc length, etc.) based on mathematical models and/or formulas. . In some embodiments, the processing unit 110 may execute the characteristic observation module 1404 to construct a mathematical model that expresses the curvature of the curve as a function of distance (for example, distance traveled). Such models may be subject to constraints, such as maximum lateral acceleration constraints (for example, in the range of 1.5 m/sec2 to 3.0 m/sec2) and/or maximum lateral acceleration derived constraints (for example, at 0.8 m/sec2 To 1.2 m/s2). These constraints can result in the maximum speed of the vehicle 200 (as a function of distance traveled).

[0278]

In step 1560, the processing unit 110 may execute the speed module 1406 to calculate an updated target speed based on the characteristics determined in step 1550.

The updated target speed may reflect the updated speed and/or direction of the vehicle 200 to safely perform any combination of the following: (i) entering the upcoming curve; (ii) navigating through the curve; or (iii) leaving the curve. The updated target speed can be determined using the technique described above in conjunction with FIG. 14 and step 1530. For example, the speed module 1406 may determine the updated target speed based on characteristics associated with the curve and based on mathematical models and/or formulas.

[0279]

In step 1570, the processing unit 110 may execute the speed module 1406 to adjust the speed of the vehicle 200 to the updated target speed determined in step 1560.

This adjustment can be accomplished using the technique described above in connection with step 1540. For example, based on the current speed of the vehicle 200 and the updated target speed determined in step 1560, the processing unit 110 may send electronic signals to the throttle system 220, the braking system 230, and/or the steering system 240 of the vehicle 200 (for example, via CAN Bus) to change the speed of the vehicle 200 to the updated target speed. At this point, the current speed of the vehicle 200 is not necessarily the same as the initial target speed determined in step 1530. For example, the processing unit 110 may have determined the updated target speed in step 1560, and at the same time adjust the speed of the vehicle 200 to the initial target speed. This may really exist when the difference between the speed of the vehicle 200 and the initial target speed is large (for example, greater than 10 km/hr) and the associated acceleration is small.

[0280]

In some embodiments, the system 100 may routinely update to the target speed based on continued observation of the characteristics of the curve (for example, based on image data of the portion of the vehicle 200 that depicts the curve).

In addition, after the system 100 navigates the vehicle 200 through the curve, the system 100 may cause the vehicle 200 to accelerate to a new target speed, which is suitable for the section of the road without curve, which is determined by the system through analysis. 100 is determined based on the map data, location data and/or image data acquired.

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[0281]

Imitate the previous car

[0282]

The system 100 may provide driver assistance functionality for causing the vehicle 200 to imitate (or refuse to imitate) the preceding vehicle in different scenarios (such as when the current vehicle switches lanes, accelerates, or turns).

For example, the system 100 may be configured to detect the preceding vehicle by analyzing multiple images and determine one or more actions taken by the preceding vehicle.

In some scenarios, such as when the current vehicle turns at an intersection, the system 100 may be configured to cause the vehicle 200 to refuse to imitate the turn. In other scenarios, such as when the current vehicle turns at an intersection and does not change its course within the intersection, the system 100 may be configured to cause the vehicle 200 to imitate the turn. The system 100 may also be configured to cause the vehicle 200 to imitate one or more actions of the preceding vehicle based on the navigation history of the preceding vehicle.

[0283]

16A and 16B are schematic representations of the host vehicle 200a that imitates one or more actions of the preceding vehicle 200b on the road 1600a consistent with the disclosed embodiment.

As illustrated in FIGS. 16A and 16B, the host vehicle 200a may track the preceding vehicle 200b while traveling in the same lane of the road 1600a. The lane may have a left edge 1620, a right edge 1630, and a midpoint 1610, and w1 and w2 indicate the left half and right half of the lane, respectively. The host vehicle 200a and the preceding vehicle 200b may be positioned in the lane so that the vehicles are not centered on the midpoint 1610. As shown in FIG. 16A, for example, the host vehicle 200a may be centered to the right of the midpoint 1610 such that the distance c1 between the host vehicle 200a and the left edge 1620 is greater than the distance c2 between the host vehicle 200a and the right edge 1630. In contrast, the leading vehicle 200b can be centered on the left of the midpoint 1610, so that the distance c3 between the leading vehicle 200b and the left edge 1620 is smaller than the distance c4 between the leading vehicle 200b and the right edge 1630. The positions of the host vehicle 200a and the preceding vehicle 200b may have different configurations. For example, the host vehicle 200a and the preceding vehicle 200b may be positioned anywhere on the road 1600a. Further, although FIG. 16A depicts the front vehicle 200b having the camera system, the disclosed embodiments are not limited to the configuration in which the front vehicle 200b includes the camera system.

[0284]

The system 100 of the host vehicle 200a may cause the host vehicle 200a to imitate one or more actions of the preceding vehicle 200b.

As shown in FIG. 16B, for example, the host vehicle 200a may imitate the lane shift performed by the preceding vehicle 200b. After imitating the lane shift, the distance c1 may be equal to the distance c3, and the distance c2 may be equal to the distance c4. In some embodiments, the host vehicle 200a may mimic the lane shift performed by the preceding vehicle 200b, so that the distances c1 and c3 are not equal to the distances c2 and c4. For example, in the case where the host vehicle 200a imitates the left lane shift of the host vehicle 200b and (after the lane shift) is positioned to the left of the host vehicle 200a, c1 will be less than c3 and c2 will be greater than c4. Alternatively, in the case where the host vehicle 200a imitates the left lane displacement of the host vehicle 200b and is positioned to the right of the host vehicle 200a, c1 will be greater than c3 and c2 will be less than c4.

[0285]

16C and 16D are schematic representations of the host vehicle 200a that imitates one or more actions of the preceding vehicle 200b on the road 1600b consistent with the disclosed embodiment.

As illustrated in FIG. 16C, the host vehicle 200a may travel behind the preceding vehicle 200b, and the preceding vehicle 200b may turn left at the intersection. The system 100 of the host vehicle 200a may cause the host vehicle 200a to imitate a left turn of the preceding vehicle 200b, as shown in FIG. 16D. The system 100 may cause the host vehicle 200a to change lanes while

turning in the intersection, navigation history associated with the preceding vehicle 200b, the relative speed difference between the host vehicle 200a and the preceding vehicle 200b, etc., based on various factors. The vehicle 200a imitates a left turn. In addition, the host vehicle 200a may mimic the preceding vehicle 200b under various conditions, such as based on whether the preceding vehicle 200b travels along the same route or the same part of the route along which the host vehicle 200a travels. Further details on the scenario in which the system 100 can cause the host vehicle 200a to imitate one or more actions of the preceding vehicle 200b are described below in conjunction with FIGS. 17-22.

[0286]

In some embodiments, the system 100 may be configured to determine whether to mimic the specific movement of the preceding vehicle.

For example, the system 100 may determine that certain movements of the preceding vehicle do not need to be imitated because such movements do not affect the route of the preceding vehicle. For example, the system 100 may determine that small changes in movement (such as movement in a specific lane) need not be imitated. In other embodiments, the system 100 may implement a smooth operation to filter out a small amount of movement of the vehicle in front. Smooth operation may cause the host vehicle to perform more significant and/or important movements of the preceding vehicle (for example, changing lanes), while filtering out a smaller amount of movement that does not affect the overall route of the preceding vehicle.

[0287]

FIG. 17 is an exemplary block diagram of a memory consistent with the disclosed embodiments, the memory being configured to store instructions for performing one or more operations.

As shown in FIG. 17, the memory 140 can store a lane restriction module 1702, an action detection module 1704, and an action response module 1706. The disclosed embodiments are not limited to the memory 140 of any particular configuration. Further, the processing unit 110 can execute instructions stored in any of the modules 1702-1706 (included in the memory 140).

[0288]

In one embodiment, the lane restriction module 1702 may store software instructions (such as computer vision software) that, when executed by the processing unit 110, determine one or more restrictions associated with the lane of travel of the host vehicle 200a.

The lane constraints may include a midpoint 1610, a left edge 1620, and a right edge 1630 of the lane. The lane constraints may also include one or more lines or other symbols marked on the surface of the road 1600a or 1600b. The processing unit 110 may execute the lane restriction module 1702 to determine the restriction by, for example, analyzing one or more sets of images and/or using map and/or location data (e.g., data stored in the map database 160). The image group may be acquired by one or more of the image capture devices 122, 124, and 126. Based on this analysis, the system 100 (eg, via the processing unit 110) may cause the host vehicle 200a to travel within the lane defined by the left edge 1620 and the right edge 1630. In some embodiments, if one of the distances c1 or c2 is less than a predetermined threshold, the system 100 may cause the host vehicle 200a to move away from the left edge 1620 or the right edge 1630.

[0289]

In one embodiment, the action detection module 1704 may store software instructions (such as computer vision software) that, when executed by the processing unit 110, detect one or more actions taken by the preceding vehicle 200b traveling in front of the host vehicle 200a .

The preceding vehicle 200b may travel in the same or different lane as the host vehicle 200a. The processing unit 110 may execute the action detection module 1704 to detect one or more actions taken by the preceding vehicle 200b by, for example, analyzing one or more sets of images acquired by one or more of the image capturing devices 122, 124, and 126 . Based on this analysis, for example, the processing unit 110 may determine that the preceding vehicle 200b has changed lanes, has turned, accelerated, decelerated, applied brakes, and the like. As another example, the preceding vehicle 200b may perform a maneuver such that the first offset distance of the preceding vehicle 200b on the side adjacent to the first lane constraint is different from the second offset distance of the preceding vehicle 200b on the side adjacent to the second lane constraint. Offset distance. For example, the processing unit 110 may perform such analysis based on the technique described above in conjunction with FIGS. 5A to 5D.

[0290]

In one embodiment, the action response module 1706 may store software instructions (such as computer vision software) that, when executed by the processing unit 110, are based on the preceding vehicle 200b detected by the system 100 (for example, via the execution of the action detection module 1704). The one or more actions taken determine the one or more actions taken by the host vehicle 200a.

For example, the processing unit 110 may execute the action response module 1706 to determine whether to imitate one or more actions of the preceding vehicle 200b. The determination may be based on the nature of the actions of the preceding vehicle 200b (for example, turning, lane shifting, etc.), information associated with the host vehicle 200a (for example, the speed from the side of the road, distances c1 and c2, etc.), Road and environmental conditions (for example, potholes, heavy rain or wind, etc.), etc. In the case that the processing unit 110 determines to imitate one or more actions of the preceding vehicle 200b, the processing unit 110 may accomplish this by the following means: for example, to the throttle system 220, the braking system 230 and/or the steering system 240 of the host vehicle 200a. Electronic signals are sent (e.g., via a CAN bus) to trigger turns, lane shifts, speed changes and/or direction changes of host vehicle 200a. The processing unit 110 may use the techniques described above in conjunction with FIGS. 4 to 7 to cause the host vehicle 200a to imitate one or more actions. In order to imitate one or more actions, the system 100 may provide control signals to one or more of the throttle system 220, the braking system 230, and the steering system 240 (for example, by causing acceleration, turning, lane shift, etc.) Etc.) Navigation vehicle 200. Further, one or more actuators may control the throttle system 220, the braking system 230, and/or the steering system 240.

[0291]

FIG. 18 is a flowchart showing an exemplary process for causing the host vehicle 200a to imitate one or more actions of the preceding vehicle 200b consistent with the disclosed embodiment.

In step 1810, the processing unit 110 may receive a plurality of images via the data interface 128 between the processing unit 110 and the image acquisition unit 120. For example, a camera (such as the image capturing device 122) included in the image acquisition unit 120 may capture a plurality of images and send the images to the processing unit 110 via a digital connection (eg, USB, wireless, Bluetooth, etc.). In some embodiments, the processing unit 110 may receive more than one multiple images via multiple data interfaces. For example, the processing unit 110 may receive multiple images from each of the image capture devices 122, 124, 126, and each of the image capture devices 122, 124, 126 may have an associated data interface for communicating with the processing unit 110 data. The disclosed embodiments are not limited to any specific data interface structure or protocol.

[0292]

In steps 1820 and 1830, the processing unit 110 may execute the lane restriction module 1702 to determine constraints associated with the travel lane of the host vehicle 200a on each side of the host vehicle 200a.

The processing unit 110 may determine the constraint by analyzing the image received in step 1810. Thus, in step 1820, the processing unit 110 may determine the first lane constraint on the first side of the host vehicle 200a (for example, the distance between the left side of the host vehicle 200a and the left edge 1620 of the lane, c1), and In step 1830, the second lane constraint on the second side opposite to the first side is determined (e.g., the distance between the right side of the host vehicle 200a and the right edge 1620 of the lane, c2). In some embodiments, the processing unit 110 may use a map and/or position data indicating the position of the host vehicle 200a relative to the midpoint 1610, left edge 1620, and right edge 1630 of the lane (for example, stored in the map database 160). Data) to determine constraints. The processing unit 110 may determine the constraint based on analyzing both the image received in step 1810 and the map and/or location data; doing so may increase the confidence level associated with the constraint.

[0293]

In step 1840, the processing unit 110 may execute the lane restriction module 1702 to cause the host vehicle 200a to travel within the lane restriction determined in steps 1820 and 1830.

For example, the left side of the host vehicle 200a may be positioned to the left of the left edge 1620, or the right side of the host vehicle 200a may be positioned to the right of the right edge 1630. In such a scenario, the processing unit 110 may send

electronic signals (for example, via the CAN bus) to the throttle system 220, the braking system 230, and/or the steering system 240 of the host vehicle 200a to cause the host vehicle 200a to adjust its position and Travel within the lane constraints.

[0294]

In step 1850, the processing unit 110 may execute the motion detection module 1704 to locate the preceding vehicle 200b within the image received in step 1810 by analyzing the image.

The processing unit 110 may use the technique described above in conjunction with FIG. 5A and FIG. 5B to detect the presence of the vehicle in the image. For each detected vehicle, the processing unit 110 may construct a multi-frame model of the position, speed (for example, speed and direction), and acceleration of the detected vehicle relative to the host vehicle 200a. The processing unit 110 can construct such a model using the technique described above in conjunction with FIG. 5A and FIG. 5B. In addition, the processing unit 110 may determine the lane of travel associated with each detected vehicle, based on, for example, lanes or other road markings and the lane constraints determined in steps 1820 and 1830. The processing unit 110 may determine that the preceding vehicle 200b is the closest detected vehicle and is traveling in the same lane as the host vehicle 200a. In step 1860, the processing unit 110 can execute the action detection module 1704 to determine one or more actions taken by the preceding vehicle 200b in the image detected in step 1850. For example, the processing unit 110 may determine: the preceding vehicle 200b has changed lanes, has turned, accelerated, decelerated, and so on. In addition, the processing unit 110 may analyze the image to determine characteristics associated with the preceding vehicle 200b, such as its (e.g., relative to the host vehicle 200a) speed and position. These determinations can be based on the techniques described above in conjunction with FIGS. 5A and 5B. In some embodiments, the processing unit 110 may analyze the image to determine characteristics associated with the action performed by the preceding vehicle 200b. For example, in a situation where the preceding vehicle 200b is turning, the processing unit 110 may determine the position information of the preceding vehicle 200b just before starting the turn, the position information of the preceding vehicle 200b when the turn is completed, the turning radius, and the description of the position of the preceding vehicle 200b when the turn is completed. The velocity profile of the velocity change (for example, over a period of time).

[0295]

In step 1870, the processing unit 110 may execute the action response module 1706 to cause the host vehicle 200a to imitate one or more actions of the preceding vehicle 200b determined in step 1850.

For example, the processing unit 110 may send electronic signals (for example, via the CAN bus) to the throttle system 220, the braking system 230, and/or the steering system 240 of the host vehicle 200a to trigger the turning, lane shift, and speed of the host vehicle 200a. Change and/or change of direction. In addition, the processing unit 110 may construct a set of waypoints to guide the position and speed of the host vehicle 200a to change. The waypoints may be based on lane markings (e.g., midpoint 1610, left edge 1620, right edge 1630, etc.) represented by a polynomial (e.g., third polynomial) and target coordinates associated with the target vehicle (such as the preceding vehicle 200b) Wait). The processing unit 110 may adjust the coefficients of the polynomial so that the path points exceed the target coordinates. The processing unit 110 may also offset the waypoint (for example, with respect to the left edge 1620 and the right edge 1630) based on a predetermined offset amount. When the processing unit 110 adjusts the polynomial coefficients and offsets the path points, the processing unit 110 may also calculate local curvature information for each obtained section formed between the path points.

[0296]

In some embodiments, the processing unit 110 (eg, via the execution action response module 1706) may cause the host vehicle 200a to mimic the preceding vehicle 200b within a certain position, speed, and/or acceleration constraint associated with the two vehicles.

For example, the constraint may require a predetermined minimum distance (eg, a safety distance) between the host vehicle 200a and the preceding vehicle 200b or a predetermined maximum difference in speed and/or acceleration between the vehicles. Thus, if the action performed by imitating the preceding vehicle 200b would violate one or more constraints (for example, imitating acceleration would cause the host vehicle 200a to be too close to the preceding vehicle 200b), the processing unit 110 may cause the host vehicle 200a to refuse to imitate the preceding vehicle 200b. One or more actions. In addition, the processing unit 110 may cause the host vehicle 200a to follow the speed profile of the preceding vehicle 200b and maintain a predetermined distance or a safe distance from the preceding vehicle 200b even while mimicking the action performed by the preceding vehicle 200b (for example, lane shift). The processing unit 110 can accomplish this by causing the

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host vehicle 200a to: (i) continuously shorten the distance to the preceding vehicle 200b when the distance is greater than the predetermined minimum distance; (ii) continuously reduce the speed difference between the host vehicle 200a and the preceding vehicle 200b Gap; and (iii) matching the acceleration of the preceding vehicle 200b to a degree consistent with predetermined constraints. In order to control to what extent these actions should be performed, the processing unit 110 may associate each action with a weight in real time based on the current predicted distance from the preceding vehicle 200b. Thus, for example, when the distance to the preceding vehicle 200b decreases, a greater weight may be added to the deceleration instead of matching the acceleration of the preceding vehicle 200b.

[0297]

As another example, in a case where the host vehicle 200a approaches the preceding vehicle 200b at a speed greater than the speed of the preceding vehicle 200b, the processing unit 110 may cause the host vehicle 200a to gradually decelerate, so that when the distance between the two vehicles is equal to the predetermined safety distance ((Such as the minimum following distance), the speed of the two vehicles is the same.

In another example, when the preceding vehicle 200b suddenly appears in front of the host vehicle 200a, causing the distance between the two vehicles to be less than the minimum following distance, the processing unit 110 may cause the host vehicle 200a to gradually decelerate to avoid getting closer to the preceding vehicle. 200b, at the same time increase the distance between vehicles until the distance reaches the minimum following distance.

[0298]

19 is a flowchart showing an exemplary process 1900 for causing host vehicle 200a to refuse to imitate a turn of the preceding vehicle 200b, consistent with the disclosed embodiment.

In step 1910, as described above in conjunction with step 1810 of FIG. 18, the processing unit 110 may receive multiple images via the data interface 128 between the processing unit 110 and the image acquisition unit 120. In step 1920, as described above in conjunction with step 1850 of FIG. 18, the processing unit 110 may execute the motion detection module 1704 to locate the preceding vehicle 200b in the image received in step 1910 by analyzing the image. In step 1925, the processing unit 110 may execute the action detection module 1704 to use the technique described above in conjunction with step 1860 in FIG. 18 to determine whether the vehicle 200b in front is turning at the intersection. If it is determined that the preceding vehicle 200b is turning at the intersection (step 1925, yes), then in step 1930, the processing unit 110 may cause the host vehicle 200a to refuse to imitate the turn of the preceding vehicle 200b. Otherwise (step 1925, No), the process 1900 ends.

[0299]

20 is a flowchart showing an exemplary process 2000 for causing the host vehicle 200a to imitate or reject the turn of the preceding vehicle 200b consistent with the disclosed embodiment.

In step 2010, as described above in conjunction with step 1810 of FIG. 18, the processing unit 110 may receive multiple images via the data interface 128 between the processing unit 110 and the image acquisition unit 120. In step 2020, as described above in conjunction with step 1850 in FIG. 18, the processing unit 110 may execute the motion detection module 1704 to locate the vehicle 200b in front in the image received in step 2010 by analyzing the image. In step 2025, the processing unit 110 may execute the action detection module 1704 to use the technique described above in conjunction with step 1860 in FIG. 18 to determine whether the preceding vehicle 200b is turning at the intersection. If it is determined that the preceding vehicle 200b is turning at the intersection (step 2025, YES), then in step 2035, the processing unit 110 may execute the motion detection module 1704 to determine whether the preceding vehicle 200b is at step 1860 using the technique described above in conjunction with step 1860 of FIG. Change lanes within the intersection. Otherwise (step 2025, No), the process 2000 ends. If it is determined that the preceding vehicle 200b is changing lanes within the intersection (step 2035, YES), then in step 2050, the processing unit 110 may cause the host vehicle 200a to refuse to imitate the turn of the preceding vehicle 200b. Otherwise (step 2035, No), in step 2040, the processing unit 110 may cause the host vehicle 200a to imitate the turn of the preceding vehicle 200b.

[0300]

21 is a flowchart showing another exemplary process 2100 for causing the host vehicle 200a to imitate one or more actions of the first preceding vehicle consistent with the disclosed embodiment.

In step 2110, as described above in conjunction with step 1810 in FIG. 18, the processing unit 110 may receive multiple images via the data interface 128 between the processing unit 110 and the image acquisition unit 120. In steps 2120 and 2130, as described above in conjunction with step 1850 of FIG. 18, the processing unit 110 may execute the motion detection module 1704 to locate the first and second vehicles ahead in the image received in step 2110 by analyzing the image. In step 2135, the processing unit 110 can execute the motion detection module 1704 to determine whether the turning radius of the first preceding vehicle path is smaller than the second preceding vehicle path using the technique described above in conjunction with step 1860 in FIG. 18. If it is determined that the turning radius of the first preceding vehicle path is smaller than the second preceding vehicle path (step 2135, YES), then in step 2140, the processing unit 110 may cause the host vehicle 200a to imitate the turn of the first preceding vehicle. Otherwise (step 2135, No), the process 2100 ends.

[0301]

22 is a flowchart showing an exemplary process 2200 for causing the host vehicle 200a to imitate one or more actions of the preceding vehicle 200b based on the navigation history, consistent with the disclosed embodiment.

In step 2210, as described above in conjunction with step 1810 of FIG. 18, the processing unit 110 may receive multiple images via the data interface 128 located between the processing unit 110 and the image acquisition unit 120. In step 2220, as described above in conjunction with step 1850 in FIG. 18, the processing unit 110 may execute the motion detection module 1704 to locate the vehicle 200b in front within the image received in step 2210 by analyzing the image.

[0302]

In step 2230, the processing unit 110 may determine the position information of the preceding vehicle 200b by analyzing the image received in step 2210.

The position information of the preceding vehicle 200b may indicate the position of the preceding vehicle 200b relative to the host vehicle 200a. The processing unit 110 may analyze the image to obtain the position information of the preceding vehicle 200b and one or more actions taken by the preceding vehicle 200b by using the techniques described above in conjunction with FIGS. 5A to 5D.

[0303]

In step 2240, the processing unit 110 may compare the position information of the preceding vehicle 200b determined in step 2230 with predetermined map data (for example, data stored in the map database 160).

For example, by comparing the location information with predetermined map data, the processing unit 110 can obtain the location coordinates of the preceding vehicle 200b. In addition, the processing unit 110 may use predetermined map data as an indicator of the confidence level associated with the location information determined in step 2230.

[0304]

In step 2250, the processing unit 110 may create a navigation history associated with the preceding vehicle 200b by, for example, tracking actions taken by the preceding vehicle 200b.

The processing unit 110 may associate the action taken by the preceding vehicle 200b (for example, determined according to the analysis image in step 2230) with the predetermined map data in step 2240. Thus, the navigation history may indicate that the preceding vehicle 200b performing certain actions (for example, turning, lane shifting, etc.) is at a certain position coordinate.

[0305]

In step 2260, the processing unit 110 may execute the action response module 1706 to determine whether to cause the host vehicle 200a to imitate one or more of the preceding vehicle 200b based on the navigation history created in step 2250 and using the technique described above in conjunction with step 1870 of FIG. 18 Actions.

For example, even in the case where no turn is detected according to the analysis image (for example, in step 2230), when the navigation history indicates that the preceding vehicle 200b has successfully navigated at least one previous turn, the processing unit 110 (for example, via the action response module 1706) The host vehicle 200a may be caused to imitate the

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turn of the preceding vehicle 200b. More generally, in a case where the navigation history indicates that the preceding vehicle 200b has successfully performed such an action, the processing unit 110 may cause the host vehicle 200a to imitate the action taken by the preceding vehicle 200b.

[0306]

Navigate the vehicle to overtake another vehicle

[0307]

The system 100 may provide driver assistance functionality for monitoring the vicinity of the vehicle 200 and aborting the lane change if the lane change is deemed to cause a risk such as a collision with another vehicle (eg, a target vehicle).

For example, if it is determined that the target vehicle is located in a different lane from the vehicle 200, the system 100 may enable the vehicle 200 to complete the overtaking of the target vehicle.

If, before completing the overtaking, the system 100 determines that the target vehicle is entering the driving lane of the vehicle 200, the system 100 may cause the vehicle 200 to abort the overtaking. For example, aborting an overtaking may include causing the vehicle 200 to brake or causing the vehicle 200 to stop accelerating.

[0308]

As illustrated in FIG. 23, the vehicle 200 can travel on the road 2300.

The vehicle 200 may be equipped with the system 100 and may implement any of the disclosed embodiments to recognize lane constraints and operate the vehicle 200 within the lane constraints. The system 100 may also facilitate lane changes made by the vehicle 200. For example, the system 100 may determine whether the situation allows the vehicle 200 to change lanes safely, and if the situation changes during the lane change, cause the vehicle 200 to abort the lane change.

[0309]

As shown in FIG. 23 and as previously discussed with respect to FIGS. 8A to 8D, the vehicle 200 may include a first vehicle side 802, and the first vehicle side 802 may be a first distance 805 from the first lane constraint 2302.

Similarly, the vehicle 200 may include a second vehicle side 812 opposite the first vehicle side 802, and the second vehicle side 812 may be a second distance 815 from the second lane constraint 2304. In this way, the first lane constraint 810 and the second lane constraint 2304 may define the lane 2330 in which the vehicle 200 may travel.

[0310]

The system 100 may determine the first lane constraint 2302 and the second lane constraint 2304 based on multiple images acquired by one or more of the image capture devices 122-126.

According to some embodiments, the first lane constraint 2302 and/or the second lane constraint 2304 may be identified by visible lane boundaries (including lines marked on the road surface). Additionally or alternatively, the first lane constraint 2302 and/or the second lane constraint 2304 may include the curb of the road surface. According to some embodiments, the system 100 can determine the first lane constraint 2302 and/or the second lane constraint 2304 by identifying the midpoint of the road width 2320 (or any other suitable road feature that the vehicle 200 can use as a navigation reference). For example, the system 100 can identify lane constraints in this way when the lines specifying the lanes of the road are not painted or otherwise labeled.

[0311]

When overtaking the target vehicle 2310, the lane change of the vehicle 200 may be complicated due to the change of the trajectory of the target vehicle 2330.

Thus, the system 100 can identify the target vehicle 2310 based on analysis of multiple images acquired by one or more of the image capture devices 122-126. The system 100 may also identify the second lane 2340 in which the target vehicle 2310 travels. Further, the system 100 may determine whether the second lane 2340 is different from the lane 2330 in which the

vehicle 200 is traveling. If the second lane 2340 is different from the lane 2330, the system 100 may be configured to enable the vehicle 200 to pass the target vehicle 2310.

[0312]

The system 100 may also monitor the target vehicle 2310 based on multiple images.

For example, the system 100 may monitor the position of the target vehicle 2310, such as monitoring the position of the target vehicle 2310 relative to the vehicle 200, relative to the first lane constraint 2302 and/or the second lane constraint 2304, absolute position, or relative to another reference point. Location. Additionally or alternatively, monitoring the location of the target vehicle 2310 may include estimating the speed of the target vehicle 2310.

[0313]

If the system 100 determines that the target vehicle 2310 is entering the lane 2330 in which the vehicle 200 is traveling, the system 100 may cause the vehicle 200 to abort the overtaking of the target vehicle 2310.

For example, the system 100 may cause the vehicle 200 to stop accelerating or apply braking. Additionally or alternatively, the system 100 may issue a voice notification, such as informing the driver of the vehicle 200 to abort the lane change.

[0314]

FIG. 24A is an exemplary block diagram of the memory 140 consistent with the disclosed embodiments, and the memory 140 may store instructions for performing one or more operations.

As illustrated in FIG. 24A, the memory 140 may store one or more modules for identifying the target vehicle and the responses described herein. For example, the memory 140 may store the lane restriction module 2400, the target vehicle acquisition module 2410, and the action module 2415.

[0315]

In one embodiment, the lane restriction module 2400 may store instructions, and when executed by the processing unit 110, the instructions may detect and define the first lane restriction 2302 and the second lane restriction 2304.

For example, the processing unit 110 may execute the lane offset module 2400 to process a plurality of images received from at least one image capturing device 122-124 and detect the first lane constraint 2302 and the second lane constraint 2304. As discussed above, this may include identifying painted lane lines or markers and/or measuring the midpoint of the road surface. The processing unit 110 may perform this analysis based on the technique described above in conjunction with FIGS. 5A to 5D.

[0316]

In some embodiments, the target acquisition module 2410 may store instructions, and when executed by the processing unit 110, the instructions may detect the existence of the target vehicle 2310 and monitor the location of the target vehicle 2310.

For example, the target acquisition module 2410 may process multiple images to detect and monitor the target vehicle 2310. Additionally or alternatively, when the target acquisition module 2410 is executed, the processing unit 110 may receive information from another module or other system that indicates the existence and/or location of the target vehicle 2310. The processing unit 110 may perform this analysis based on the technique described above in conjunction with FIGS. 5A to 5D.

[0317]

The processing unit 110 may be configured to determine the existence of one or more objects (such as a target vehicle 2310 in the vicinity of the vehicle 200).

For example, the target vehicle 2310 may include another vehicle traveling near the vehicle 200, such as a car, a truck, or a motorcycle. For each target vehicle 2310, the processing unit 110 may determine an offset profile. The offset profile may include determining whether the target vehicle 2310 will be located within a predetermined range of the vehicle 200 in its current predicted position. If the processing unit 110 determines that the target vehicle 2310 is located or will be located within the predetermined range of the vehicle 200, the processing unit may determine whether there is any in the first lane constraint 810

and the second lane constraint 820 in order for the vehicle 200 to bypass the target vehicle 2310. enough space. If there is not enough space, the processing unit 110 may perform a lane change. If there is enough space, the processing unit 110 may determine whether there is enough time to bypass the target vehicle 2310 before the distance between the vehicle 200 and the target vehicle 2310 is shortened. If there is enough time, the processing unit 110 may initiate or activate an offset maneuver to bypass the target vehicle 2310. The offset maneuver may be performed by the processing unit 110 so that the movement of the vehicle 200 is smooth and comfortable for the driver. For example, the offset slew rate may be approximately 0.15 m/sec to 0.75 m/sec. The offset maneuver may be performed such that the maximum amplitude of the offset maneuver will occur when the distance between the vehicle 200 and the object 825 is shortened. If there is not enough time, the processing unit 110 may initiate braking and then initiate an offset maneuver.

[0318]

Further, the processing unit 110 may execute the action module 2415 to suspend the plan of the vehicle 200 to overtake the target vehicle 2310.

If the target vehicle 2310 is not in the lane 2330 of the vehicle 200, the instructions included in the action module 1230 may enable the vehicle 200 to pass the target vehicle 2330. However, if the execution target vehicle acquisition module 2410 indicates that the target vehicle 2310 is changing lanes and entering the lane 2330 of the vehicle 200, the processing unit 110 may execute the instruction included in the action module 2415 to stop the lane change of the vehicle 200. For example, the processing unit 110 may send an electronic signal to the throttle system 220, the braking system 230, and/or the steering system 240 of the vehicle 200 to stop the lane change. Additionally or alternatively, the processing unit may cause a voice notification to be issued.

[0319]

FIG. 24B illustrates a flowchart of an exemplary process 2420 for navigating a vehicle in an intruding vehicle consistent with the disclosed embodiment.

The process 2420 may identify the lane constraints that define the travel lane in which the vehicle (for example, vehicle 200) travels, identify and monitor the target vehicle (for example, vehicle 2310), and enable the vehicle to pass the target vehicle or if it is determined that the target vehicle is entering the travel of the vehicle The lane is suspended for overtaking.

[0320]

In step 2430, at least one of the image capturing devices 122, 124, and/or 126 may acquire multiple images of the area near the vehicle 200.

For example, a camera (such as the image capturing device 122) included in the image acquisition unit 120 may capture a plurality of images and send the images to the processing unit 110 via a digital connection (eg, USB, wireless, Bluetooth, etc.). In some embodiments, the processing unit 110 may receive more than one multiple images via multiple data interfaces. For example, the processing unit 110 may receive multiple images from each of the image capture devices 122, 124, 126, and each of the image capture devices 122, 124, 126 may have an associated data interface for communicating with the processing unit 110 data. The disclosed embodiments are not limited to any specific data interface structure or protocol.

[0321]

Next, in step 2440, the processing unit 110 may use the multiple images received via the data interface 128 to determine the first lane constraint on the first vehicle side 802 and the second lane constraint on the second vehicle side 812.

For example, as part of implementing step 2440, the processing unit 110 may execute instructions of the lane restriction module 910. Further, as a part of determining the first lane constraint and the second lane constraint, the processing unit 110 may use one or more of the processes discussed above in conjunction with FIGS. 5A to 5D.

[0322]

In step 2450, the processing unit 110 may obtain the target vehicle 2310.

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In order to obtain the target vehicle 2310, the processing unit 110 may execute the target vehicle obtaining module 2410. For example, the processing unit 110 may execute instructions to analyze the acquired image to identify the second lane 2340 traveled by the target vehicle 2310 and determine whether the target vehicle 2310 travels in the lane 2330 traveled by the vehicle 200. This determination may be based on the technique described above in conjunction with FIGS. 5A to 5D.

[0323]

In step 2455, the processing unit 110 may determine whether the second lane 2340 traveled by the target vehicle 2310 is different from the lane 2330 traveled by the vehicle 200.

[0324]

In step 2460, if the second lane 2340 is different from the lane 2330 in which the vehicle 200 travels, the processing unit 110 may enable the vehicle 200 to pass the target vehicle 2310.

In order to enable the vehicle 200 to overtake the target vehicle 2310, the processing unit may execute the action module 2415.

[0325]

Next, in step 2465, the processing unit 110 may execute the target acquisition module 2410 to monitor the target vehicle 2310.

This may include estimating the speed of the target vehicle 2310 and determining the location of the target vehicle 2310, such as relative to the vehicle 200.

[0326]

Step 2470 may include determining whether the target vehicle 2310 has entered the lane 2330.

If the processing unit 110 determines that the target vehicle 2310 has not entered the lane 2330, then in step 2480, the processing unit 110 may allow the vehicle 200 to complete the overtaking.

[0327]

In step 2490, if the processing unit 110 determines that the target vehicle 2310 has entered the lane 2330 (or is entering the lane 2330 or is otherwise on a trajectory that will bring the vehicle 2310 into the lane 2330), the processing unit 110 may execute the action module 2415 To stop the transcendence.

For example, this may include issuing a voice notification to the driver of the vehicle 200 via the speaker 360.

Additionally or alternatively, step 2490 may include executing instructions included in the action module 2415 to cause the processing unit 110 to send electronic signals to the throttle system 220, the braking system 230, and/or the steering system 240 of the vehicle 200, thereby suspending Lane change.

[0328]

Navigate the vehicle to avoid intrusion into traffic

[0329]

The system 100 may provide driver assistance functionality for monitoring the vicinity of the vehicle 200 and responding to the presence of another vehicle invading the vehicle 200.

Monitoring the vicinity of the vehicle 200 may include monitoring a collision threshold.

For example, the collision threshold may include the time to collision or the minimum predetermined distance between the vehicle 200 and other traffic. The system 100 may further cause the vehicle 200 to take an evasive action to avoid intruding into traffic. For example, the avoidance action may include braking, changing lanes, or otherwise changing the course of the vehicle 200.

[0330]

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As illustrated in FIG. 25, the vehicle 200 may travel on a road 2500.

The vehicle 200 may include a system 100 for detecting and responding to intrusive traffic. For example, the vehicle 200 may determine that another vehicle is entering the lane of travel of the vehicle 200, or otherwise determine that the other vehicle is crossing the collision threshold. The vehicle 200 may react to the intruding vehicle by, for example, changing the route, braking, or accelerating.

[0331]

As discussed with respect to FIGS. 8A to 8D and as shown in FIG. 25, the vehicle 200 may include a first vehicle side 802, and the first vehicle side 802 may be a first distance 805 from the first lane constraint 2502.

Similarly, the vehicle 200 may include a second vehicle side 812 opposite the first vehicle side 802, and the second vehicle side 812 may be a second distance 815 from the second lane constraint 2504. In this way, the first lane constraint 2502 and the second lane constraint 2504 may define the lane 2505 in which the vehicle 200 may travel.

[0332]

The system 100 may determine the first lane constraint 2502 and the second lane constraint 2504 based on multiple images acquired by one or more of the image capture devices 122-126.

According to some embodiments, the first lane constraint 2502 and/or the second lane constraint 2504 may be identified by visible lane boundaries, such as lines marked on the road surface. Additionally or alternatively, the first lane constraint 2502 and/or the second lane constraint 2504 may include the curb of the road surface. According to some embodiments, the system 100 may determine the first lane constraint 2502 and/or the second lane constraint 2502 by identifying the midpoint 2520 of the road width (or any other suitable road feature vehicle 200 may be used as a navigation reference). The system 100 can identify lane constraints in this way when, for example, the line specifying the lane of the road has not been painted or otherwise labeled.

[0333]

Detecting the first lane constraint 2502 and/or the second lane constraint 2504 may include the processing unit 110 determining their three-dimensional models in the camera coordinate system.

For example, the three-dimensional model of the first lane constraint 2502 and/or the second lane constraint 2504 can be described by a third polynomial. In addition to the three-dimensional modeling of the first lane constraint 2502 and/or the second lane constraint 2504, the processing unit 110 may estimate motion parameters, such as the speed, yaw and pitch rate, and acceleration of the vehicle 200. Optionally, the processing unit may detect static and moving vehicles and their position, heading, speed and acceleration (all relative to vehicle 200). The processing unit 110 may determine a road elevation model to convert information acquired from a plurality of images into a three-dimensional space.

[0334]

What the driver of the vehicle 200 cannot assume is that if it is safe to shift the traffic into the lane 2505 in which the vehicle 200 is traveling, other traffic traveling in adjacent or nearby adjacent lanes will only change lanes.

Thus, it may be desirable to consider and monitor traffic traveling in a nearby lane to detect lateral intrusion into the lane 2505 of the vehicle 200 so that the vehicle 200 can react to the lateral intrusion to avoid a collision. The system 100 may identify the intruding vehicle 2510 based on the multiple images and determine that the intruding vehicle 2510 is approaching the vehicle 200. The system 100 can then generate actions to consider the intrusion into the vehicle. For example, the system 100 may cause the vehicle 200 to maintain the current speed and travel within the first lane constraint 2502 and the second lane constraint 2504 such that the first distance 2530 on the first vehicle side 802 where the intruding vehicle 2510 approaches is greater than the second distance 2540 .

[0335]

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The processing unit 110 may be configured to determine the presence of one or more intruding vehicles 2510 in the vicinity of the vehicle 200.

For each intruding vehicle 2510, the processing unit 110 may determine an offset profile. The offset profile may include determining whether the invading vehicle 2510 will be located within a predetermined range of the vehicle 200 in its current predicted position. If the processing unit 110 determines that the intruding vehicle 2510 is located or will be located within the predetermined range of the vehicle 200, the processing unit may determine whether there are any within the first lane constraint 2502 and the second lane constraint 2504 in order for the vehicle 200 to bypass the intruding vehicle 2510 enough space. If there is not enough space, the processing unit 110 may perform a lane change. If there is enough space, the processing unit 110 may determine whether there is enough time to bypass the intruding vehicle 2510 before the distance between the vehicle 200 and the intruding vehicle 2510 is shortened.

[0336]

For example, if there is enough time, the processing unit 110 may initiate or activate an offset maneuver to bypass the invading vehicle 2510.

The offset maneuver may be performed by the processing unit 110 so that the movement of the vehicle 200 is smooth and comfortable for the driver. For example, the offset slew rate may be approximately 0.15 m/sec to 0.75 m/sec. The excursion maneuver may be performed such that the maximum amplitude of the excursion maneuver will occur when the distance between the vehicle 200 and the invading vehicle 2510 is shortened. If there is not enough time, the processing unit 110 may initiate braking (e.g., via sending an electronic signal to the braking system 230), and then initiate an offset maneuver (e.g., by sending an electronic signal to the throttle system 220 and/or the steering system 240). Signal).

[0337]

The system 100 may determine based on multiple images acquired by one or more of the image capture devices 122-126 that the intruding vehicle 2510 has crossed at least one collision threshold.

For example, the at least one collision threshold may include the minimum predetermined distance 2550 between the vehicle 200 and the invading vehicle 2510. For example, as illustrated in FIG. 25, the intruding vehicle 2510 is shown as exceeding the minimum predetermined distance 2550. Additionally or alternatively, the at least one collision threshold may include the time when the vehicle 200 and the invading vehicle 2510 are about to collide. The time-based collision threshold may be determined based on the following: the distance between the vehicle 200 and the intruding vehicle 2510, the speed of the vehicle 200 and/or the intruding vehicle 2510, the lateral speed of the vehicle 200 and/or the intruding vehicle 2510, and/or the vehicle 200 And/or the acceleration of the intruding vehicle 2510. The collision threshold based on the collision time can be set to allow the system 100 to have enough time to effectively perform the evasive action to avoid the collision.

[0338]

If the system 100 determines that at least one collision threshold has been crossed, the system 100 may cause the vehicle 200 to take an evasive action.

For example, this may include causing other subsystems of the vehicle 200 to operate. Thus, the system 100 may be operated to cause the speed of the vehicle 200 to increase by communicating with the throttle system 220, the braking system 230, and/or the steering system 240 to change the speed and/or direction of the vehicle 200.

[0339]

The evasive action may include causing the vehicle 200 to change lanes.

It may be desirable to respond in a situation where, for example, the vehicle 200 is traveling on a multi-lane highway, and the system 100 determines that changing lanes away from the invading vehicle 2510 will avoid a collision. The avoidance action may include causing the vehicle 200 to change its course. Additionally or alternatively, the avoidance action may include changing the route of the vehicle 200. For example, in order to take an evasive action, the processing unit 110 may send an electronic signal to the throttle system 220, the braking system 230, and/or the steering system 240.

[0340]

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The system 100 may also be configured to cause the vehicle 200 to take an action after the dodging action has been completed.

For example, the system 100 may cause the vehicle 200 to return to the midpoint 2520 of the lane 2505 in which the vehicle 200 travels. Additionally or alternatively, the system 100 may cause the vehicle 200 to return to a preset speed after braking in response to the intruding vehicle 2510.

[0341]

FIG. 26 is an exemplary block diagram of a memory 140 consistent with the disclosed embodiment, and the memory 140 may store instructions for detecting and responding to a lateral intrusion of a vehicle's traffic.

As illustrated in FIG. 26, the memory 140 may store a lane restriction module 2610, an intruding vehicle acquisition module 2620, and an action module 2630.

[0342]

In one embodiment, the lane restriction module 2610 may store instructions, and when executed by the processing unit 110, the instructions may detect and define the first lane restriction 2502 and the second lane restriction 2504.

For example, the processing unit 110 may execute the lane offset restriction module 2610 to process a plurality of images received from at least one image capturing device 122-126 and detect the first lane restriction 2502 and the second lane restriction 2504. As discussed above, this may include identifying painted lane lines and/or measuring the midpoint of the road surface. The processing unit 110 may perform this analysis based on the technique described above in conjunction with FIGS. 5A to 5D.

[0343]

In one embodiment, the intruding vehicle acquisition module 2620 may store an instruction, and when executed by the processing unit 110, the instruction may detect the existence of the intruding vehicle 2510 and monitor the intruding vehicle 2510.

For example, the intrusion vehicle acquisition module 2620 may include instructions for determining the relative location of the intrusion vehicle 2510 with respect to the vehicle 200. In some embodiments, this may include monitoring the speed of the intruding vehicle 200. According to some embodiments, the intruding vehicle acquisition module 2620 may determine whether the intruding vehicle 2510 has exceeded the collision threshold. For example, the collision threshold may be the minimum predetermined distance between the vehicle 200 and the invading vehicle 2510. If the intruding vehicle 2510 is closer to the vehicle 200 than the minimum predetermined distance, the processing unit 110 may determine that the intruding vehicle 2510 is indeed intruding and execute an instruction to avoid a collision with the intruding vehicle 2510.

[0344]

Additionally or alternatively, the collision threshold may include the collision time.

The time-based collision threshold may be determined based on the following: the distance between the vehicle 200 and the intruding vehicle 2510, the speed of the vehicle 200 and/or the intruding vehicle 2510, the lateral speed of the vehicle 200 and/or the intruding vehicle 2510, and/or the vehicle 200 And/or the acceleration of the intruding vehicle 2510. The collision threshold based on the collision time may be set to allow sufficient time for the processing unit 110 and the system 100 to effectively perform an avoidance action to avoid a collision.

[0345]

Further, the processing unit 110 may execute the action module 2630 to respond to the detection of the intruding vehicle 2510 and/or to cross the collision threshold.

For example, the action module 2630 may include instructions for causing the vehicle 200 to maintain the current speed and travel within the first lane constraint 2502 and the second lane constraint 2504 such that the first distance 2530 is greater than the second distance 2540. The first distance 2530 may be located on the same side of the vehicle 200 as the intruding vehicle 2510, so that the vehicle 200 is further away from the intruding vehicle 2510 while still within the first lane constraint 2502 and the second lane constraint 2504. If the processing unit 110 determines that the collision threshold has been crossed, the

processing unit 110 may execute the action module 2630 to cause the vehicle 200 to take an evasive action, such as changing a route, braking, and/or changing lanes. The action module 2630 may also include instructions that cause the vehicle 200 to resume its course after completing the evasive action. For example, after braking or returning to the center of the lane 2505, the processing unit 110 may cause the vehicle 200 to restore the preset speed.

[0346]

FIG. 27 illustrates a flowchart of an exemplary process 2720 of detecting and responding to lateral intrusion of traffic by a vehicle consistent with the disclosed embodiments.

The process 2720 may identify the lane constraints that define the lane in which the vehicle travels, determine whether the intruding vehicle 2510 is approaching, and cause the vehicle 200 to maintain the current speed and travel within the first lane constraint 2501 and the second lane constraint 2504, so that the intrusion of the vehicle 200 The first distance 2530 on the side where the vehicle 2510 approaches is greater than the second distance 2540.

[0347]

In step 2730, at least one image capturing device 122, 124, and/or 126 may acquire multiple images of the area near the vehicle 200.

For example, a camera (such as the image capturing device 122) included in the image acquisition unit 120 may capture a plurality of images and send the images to the processing unit 110 via a digital connection (eg, USB, wireless, Bluetooth, etc.). In some embodiments, the processing unit 110 may receive more than one multiple images via multiple data interfaces. For example, the processing unit 110 may receive multiple images from each of the image capture devices 122, 124, 126, and each of the image capture devices 122, 124, 126 may have an associated data interface for communicating with the processing unit 110 data. The disclosed embodiments are not limited to any specific data interface structure or protocol.

[0348]

Next, in step 2740, the processing unit 110 may use the multiple images received via the data interface 128 to determine the first lane constraint on the first vehicle side 802 and the second lane constraint on the second vehicle side 812.

For example, as part of implementing step 2740, the processing unit 110 may execute instructions of the lane restriction module 2610. Further, as a part of determining the first lane constraint and the second lane constraint, the processing unit 110 may use one or more of the processes discussed above in conjunction with FIGS. 5A to 5D.

[0349]

In step 2750, the processing unit 110 may determine whether the intruding vehicle 2510 is approaching.

To make this determination, the processing unit 110 may execute the intrusion vehicle acquisition module 2620. The intrusive vehicle acquisition module 2620 may include instructions for processing images to detect other traffic. This may include identifying vehicles within a specific range of vehicle 200, such as those vehicles that are adjacent to vehicle 200. These neighboring vehicles may be invading vehicles 2510.

[0350]

Once the intruding vehicle 2510 is identified, the processing unit can determine more information about the vehicle 2510.

For example, in step 2555, the processing unit 110 may determine whether the target vehicle 2330 has exceeded the collision threshold. For example, the collision threshold may be the minimum predetermined distance between the vehicle 200 and the invading vehicle 2510. If the intruding vehicle 2510 is closer to the vehicle 200 than the minimum predetermined distance, the processing unit 110 may determine that the intruding vehicle 2510 is indeed intruding and execute an instruction to avoid a collision with the intruding vehicle 2510.

[0351]

Additionally or alternatively, the collision threshold may be the collision time.

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The time-based collision threshold may be determined based on the following: the distance between the vehicle 200 and the intruding vehicle 2510, the speed of the vehicle 200 and/or the intruding vehicle 2510, the lateral speed of the vehicle 200 and/or the intruding vehicle 2510, and/or the vehicle 200 And/or the acceleration of the intruding vehicle 2510. The collision threshold based on the collision time may be set to allow sufficient time for the processing unit 110 and the system 100 to effectively perform an avoidance action to avoid a collision.

[0352]

In step 2760, the processing unit 110 may cause the vehicle 200 to maintain the current speed and travel within the first lane constraint 2502 and the second lane constraint 2504.

In order to cause the vehicle 200 to operate in this manner, the processing unit 110 may execute the action module 2630. Additionally or alternatively, step 2760 may include executing instructions on the action module 1230 to cause the processing unit 110 to send electronic signals to the accelerator 2610, brakes 2620, and/or steering system of the vehicle 200, so that the vehicle 200 maintains the current speed and is in the first position. The one-lane restriction 810 and the second-lane restriction 820 travel within.

[0353]

In step 2755, if the processing unit 110 determines that the collision threshold has been exceeded, the processing unit 110 may take an evasive action.

The evasive action may include causing the vehicle 200 to change lanes. A response may be expected, for example, that the vehicle 200 is traveling on a multi-lane highway, and the system 100 determines that changing lanes away from the invading vehicle 2510 will avoid a collision. The avoidance action may include causing the vehicle 200 to change its course. Additionally or alternatively, the avoidance action may include changing the route of the vehicle 200. For example, the processing unit 110 may take an evasive action by sending electronic signals to the throttle system 220, the braking system 230, and/or the steering system 240 of the vehicle 200. After completing the avoidance action, in step 2780, the processing unit 110 may control the vehicle 200 to resume its original navigation (for example, resume navigation to a desired location).

[0354]

Multi-threshold response zone for vehicle navigation

[0355]

The system 100 may provide driver assistance functionality for generating vehicle 200 responses, such as braking, accelerating, switching lanes, turning, and/or other navigation responses.

For example, if the system 100 detects that there is another vehicle in front of the vehicle 200 that is traveling at a slower speed than the vehicle 200, the system 100 may cause the vehicle 200 to reduce its speed by braking.

The system 100 may apply a braking profile that takes into account the immediacy of the risk (for example, the risk of collision) to provide the driver with a natural driving feeling.

[0356]

For example, the system 100 may generate a variety of different responses depending on the situation of the collision with another vehicle and the deterministic risk.

If the target vehicle is far ahead and the deterministic risk of collision is low, the system 100 may take no action in response to the speed or direction change of the target vehicle ahead. When the target vehicle may be closer or when the risk of collision rises above a predetermined level, the system 100 may generate a response, such as braking, and so on. When the risk of collision is even higher (for example, the system 100 determines that the collision is imminent without evasive action), the system 100 may cause the vehicle 100 to take an evasive action, such as maximum or near maximum braking, change of direction, and so on.

[0357]

28A and 28B are schematic representations of the host vehicle 200a on the road 2800 consistent with the disclosed embodiment.

In some examples, road 2800 may be divided into two lanes, lane 2810 and lane 2820. The target object, such as the target vehicle 200b, may travel in front of the host vehicle 200a in the same lane (for example, the lane 2820 shown in FIGS. 28A and 28B) or in a different lane. As shown in the example depicted in FIG. 28A, the host vehicle 200a and the target vehicle 200b may be separated by a distance d1. In a given time after the scene is depicted in FIG. 28A, as shown in FIG. 28B, the host vehicle 200a and the target vehicle 200b can be separated by a distance d2, where d2 is less than d1. For example, the host vehicle 200a can travel at a speed greater than that of the target vehicle 200b, causing the distance between the vehicles to decrease from d1 to d2.

[0358]

As another example, the host vehicle 200a and the target vehicle 200b can travel at the same speed until the target vehicle 200b reduces its speed through braking, or the host vehicle 200a increases its speed through acceleration, causing the distance between the vehicles to decrease from d1 to d2 .

As another example, the target vehicle 200b may intrude from one side of the host vehicle 200a. In some situations, if the target vehicle 200b is in front of the host vehicle 200a or far enough away from the host vehicle 200a (eg, five meters or more, 10 meters or more, etc.) and moves toward the host vehicle 200a, the system 100 may not take any action. However, if the target vehicle 200b continues to move closer to the host vehicle 200a, the system 100 may cause the host vehicle 200a to brake, change speed, and/or change lanes. For example, if the target vehicle 200b is within a predetermined threshold (e.g., within five meters), the host vehicle 200a may take action. There may be different scenarios involving the relative speed and position of the host vehicle 200a and the target vehicle 200b, and the disclosed embodiments are not limited to any specific scenario.

[0359]

In some embodiments, the multi-threshold response zone can provide the user with a natural-feeling driving experience.

For example, as discussed above, if the risk of collision is low, the system 100 may ignore the movement of the target vehicle 200b. As a result, when there is no risk of collision (for example, when the target vehicle 200b is 100 meters before, the host vehicle 200a will not need to imitate every movement of the target vehicle 200b), the host vehicle 200a may not respond to the movement of the target vehicle 200b or action. However, if the target vehicle 200b is close to the host vehicle 200a and/or if the system 100 determines that the risk of collision is high, a responsive maneuver can be taken to make the user feel safer by increasing the space between the host vehicle 200a and the target vehicle 200b. If the system 100 determines that an impact may be imminent, the system 100 can take a more aggressive action without surprising the user, as this action may be necessary to avoid the impact.

[0360]

Therefore, in some embodiments, the system 100 may associate different reaction zones with different degrees of response actions.

For example, in some embodiments, when the target vehicle 200b is within the first threshold (e.g., when the target vehicle 200b is far away from the host vehicle 200a), the system 100 may take no action; when the target vehicle 200b is within the second threshold (e.g., , When the target vehicle 200b is closer to the host vehicle 200a), the system 100 can take a moderate action; and when the target vehicle 200 is within the third threshold (for example, when the target vehicle 200b is close enough to the host vehicle 200a, there is a risk of collision), the system 100 can take more radical actions. In the first reaction zone associated with the first threshold, when the estimated distance from the target associated with the target vehicle 200b is more than twice the predetermined safe distance, the system 100 may take no action. In some embodiments, the first reaction zone may be applied in the case where the estimated distance from the target associated with the target vehicle 200b falls within the range of 1.5 times to 2.5 times the predetermined safety distance.

[0361]

The estimated distance to the target may be the current distance between the host vehicle 200a and the target vehicle 200b plus the predicted time of the distance (for example, in the range of 0.1 second to 1.0 second, depending on factors associated with the system 100, such as speed Track the expected changes after the control loop, actuators, and vehicle dynamics.

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The expected distance change can be calculated as: (v target-v main) * t prediction + ((a target-a main) * t prediction 1/2), where v target and v main correspond to target vehicle 200b and host vehicle 200a respectively The speeds of a target and a main correspond to the accelerations of the target vehicle 200b and the host vehicle 200a, respectively, and the t prediction corresponds to the predicted time. The selection of the predicted time that approximates the overall reaction time of the system 100 may take into consideration the fact that the desired navigation response of the host vehicle 200a may not be implemented immediately, so as to provide the driver and/or passengers of the host vehicle 200a with a smooth and natural driving experience.

[0362]

The predetermined safety distance can be defined as: maximum {d static, d dynamic}.

Dstatic, which may fall within a range of 2 to 10 meters, may indicate a desired safety distance between the host vehicle 200a and another vehicle (such as the target vehicle 200b) when the vehicle is stopped and/or is moving at a low speed. d dynamic can represent the expected safety distance when the vehicle is moving at a speed greater than low speed, and can be calculated as: t safety * minimum (v target, v main), where v target and v main correspond to target vehicle 200b and host vehicle 200a, respectively speed. t safety may fall within the range of 0.5 seconds to 2.5 seconds, and may be adjusted by the driver of the host vehicle 200a via the user interface 170 according to the driver's preference. Thus, the driver can control the distance maintained by the system 100 between the host vehicle 200a and other vehicles.

[0363]

In the second reaction zone associated with the second threshold, the system 100 may place the target vehicle 200b in the safe zone and apply different weights to different maneuvers performed by the target vehicle 200b.

For example, when the target vehicle 200b can approach the lower boundary of the safe zone, for example, the estimated distance from the target associated with the target vehicle 200b can be close to the predetermined safe distance (discussed above in conjunction with the first reaction zone), and the system 100 can decelerate to maneuver. Assign more weight (e.g., imitate more) and assign a smaller weight to maneuver acceleration (e.g., imitate less). In some embodiments, the lower boundary may fall within the range of 0.5 times to 1.5 times the predetermined safety distance (depending on the driver's preference). Conversely, when the target vehicle 200b approaches the upper boundary of the safety zone, for example, the estimated distance from the target associated with the target vehicle 200b may be close to twice the predetermined safety distance, and the system 100 may assign a smaller weight to the maneuvering deceleration (for example, , imitate less) and assign more weight to maneuver acceleration (for example, imitate more). In some embodiments, the lower boundary may fall within the range of 1.5 times to 2.5 times the predetermined safety distance (depending on the driver's preference).

[0364]

In the third reaction zone associated with the third threshold, when the estimated distance from the target associated with the target vehicle 200b is less than a predetermined safe distance, the system 100 may place the target vehicle 200b in the danger zone.

In this scenario, the system 100 may cause the host vehicle 200a to imitate (eg, immediately imitate) any deceleration maneuvers performed by the target vehicle 200b (while ignoring any acceleration maneuvers). In some embodiments, in the case where the estimated distance from the target associated with the target vehicle 200b falls within the range of 0.5 to 1.5 times the predetermined safety distance (depending on the driver's preference), the first reaction zone may be applied .

[0365]

In some embodiments, the system 100 may generate a response of the host vehicle 200a, such as braking.

As indicated in FIG. 28B, for example, the distance between the host vehicle 200a and the target vehicle 200b may be reduced from d1 to d2. Depending on the distance d2 and extending to the time before the collision, the system 100 may cause the host vehicle 200a to reduce its speed to avoid a collision with the target vehicle 200b. Additionally, based on, for example, the time before the collision, the system 100 may apply one or more braking profiles when the host vehicle 200a is caused to reduce its speed. Thus, if the time (and/or distance d2) before the collision exceeds the first predetermined threshold, the system 100 may cause the host vehicle 200a to brake, change lanes, and/or change speed in a gradual manner, and if the time before the

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collision When the time (and/or the distance d2) is lower than the second predetermined threshold, the system 100 may cause the host vehicle 200a to brake, change lanes, and/or change speed in a faster manner.

[0366]

Figure 29 is an exemplary block diagram of a memory consistent with the disclosed embodiments, the memory being configured to store instructions for performing one or more operations.

As shown in FIG. 29, the memory 140 can store a target monitoring module 2902, an interception time module 2904, and an action response module 2906. The disclosed embodiments are not limited to the memory 140 of any particular configuration. Further, the processing unit 110 can execute instructions stored in any of the modules 2902-2906 (included in the memory 140).

[0367]

In one embodiment, the target monitoring module 2902 may store software instructions (such as computer vision software) that, when executed by the processing unit 110, identify and monitor targets appearing in multiple images representing the environment near the host vehicle 200 Object (such as target vehicle 200b).

For the purpose of the present disclosure, the target object may also be referred to as the target vehicle 200b, but the target object may be pedestrians, road hazards (eg, large debris), and so on. The multiple images may be acquired by one or more of the image capture devices 122, 124, and 126. The processing unit 110 may execute the target monitoring module 2902 to identify and monitor the target vehicle 200b by, for example, analyzing multiple images using the technology described above in conjunction with FIGS. 5A to 5D. Thus, the target monitoring module 2902 can track different variables, such as the motion (e.g., direction and trajectory), speed and acceleration associated with the target vehicle 200b, and the distance between the host vehicle 200a and the target vehicle 200b. Such information can be tracked continuously or at predetermined intervals.

[0368]

In one embodiment, the interception time module 2904 may store software instructions that, when executed by the processing unit 110, determine an indicator of the interception time between the host vehicle 200a and the target vehicle 200b.

The interception time may refer to the amount of time before the host vehicle 200a comes into contact (eg, collides) with the target vehicle 200b. The processing unit 110 may execute the interception time module 2904 to determine an indicator of the interception time based on analyzing images acquired by one or more of the image capturing devices 122, 124, and 126. For example, the intercept time module 2904 may use a series of time-based observations (such as Kalman filter or linear quadratic estimation (LQE)) of the position, velocity, and/or acceleration of the target vehicle 200b (relative to the host vehicle 200a), for example. Make sure. The Kalman filter may be based on a measurement result of the scale of the target vehicle 200b, where the measurement result of the scale is proportional to the interception time.

[0369]

In one embodiment, the action response module 2906 may store software instructions (such as computer vision software) that, when executed by the processing unit 110, generate one or more responses in the host vehicle 200a.

The response may be based on the identification and monitoring of the target vehicle 200b (e.g., performed via the execution target monitoring module 2902) and/or an indicator of the interception time between the host vehicle 200a and the target vehicle 200b (e.g., via the execution interception time module 2904 confirmed). The processing unit 110 may generate one or more responses in the host vehicle 200a by sending electronic signals to the throttle system 220, the braking system 230, and/or the steering system 240 of the host vehicle 200a, for example (for example, via the CAN bus) to Braking, accelerating, or triggering a turn, lane shift, and/or direction change of the host vehicle 200a. The processing unit 110 may use the extended Kalman filter to estimate data associated with the target vehicle 200b and the host vehicle 200a, such as speed, acceleration, turning rate, pitch angle, pitch rate, and the position of the target vehicle 200b relative to the host vehicle 200a And heading, size of target vehicle 200b, road geometry, etc. For example, the processing unit 110 may receive measurement results from components on the host vehicle 200a (such as an odometer, an inertial measurement unit (IMU), an image processor 190, etc.). Thus, the processing unit 110 can use the state formulas, rigid constraints, and motion assumptions derived from the kinematic formulas of motion to calculate data associated with the target vehicle 200b and/or the host vehicle 200a, where the input of the formula may include the input from the host vehicle 200a The measurement results of the components on the. The processing unit 110

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may also use the techniques described above in conjunction with FIGS. 4 to 7 to generate one or more responses of the host vehicle 200a.

[0370]

FIG. 30 is a flowchart illustrating an exemplary process 3000 for generating a response of the host vehicle consistent with the disclosed embodiment.

In step 3010, the processing unit 110 may receive a plurality of images via the data interface 128 located between the processing unit 110 and the image acquisition unit 120. For example, one or more cameras included in the image acquisition unit 120 can capture multiple images of the area in front of the host vehicle 200a (for example, or the side or back of the vehicle) and connect via data (for example, digital, wired, USB , Wireless, Bluetooth, etc.) send the image to the processing unit 110.

[0371]

In step 3020, the processing unit 110 may execute the target monitoring module 2902 to identify target objects (such as the target vehicle 200b) in a plurality of images.

For example, the target monitoring module 2902 may use the technique described above in conjunction with FIG. 5A and FIG. 5B to detect the presence of a vehicle in the image. Based on image data, location data (for example, GPS location information), map data, the yaw rate of the host vehicle 200a, lane or other road markings, speed data, and/or data from sensors included in the host vehicle 200a, multiple vehicles (And/or the object) may be detected in the same lane as the host vehicle 200a or a different lane, and the distance from the host vehicle 200a is variable. In the scenario of detecting multiple vehicles, the target monitoring module 2902 may determine the target vehicle 200b as the vehicle traveling in the same lane as the host vehicle 200a and/or the vehicle closest to the host vehicle 200a.

[0372]

In step 3030, the processing unit 110 can execute the target monitoring module 2902 to monitor the target vehicle 200b identified in step 3020.

For example, the target monitoring module 2902 may track information associated with the target vehicle 200b, such as movement (e.g., direction of travel and trajectory), speed and acceleration, and the distance between the host vehicle 200a and the target vehicle 200b. The target monitoring module 2902 can use the technique described above in conjunction with FIGS. 5A to 5D to track such information continuously or at predetermined intervals by analyzing multiple images. In step 3040, the processing unit 110 may execute the interception time module 2904 to determine an indicator of the interception time between the host vehicle 200a and the target vehicle 200b. The interception time module 2904 may make the determination by tracking the position, speed, and/or acceleration of the target vehicle 200b (relative to the host vehicle 200a) over one or more time periods. The interception time module 2904 may use the techniques described above in conjunction with FIGS. 5A and 5B to track such information.

[0373]

In step 3050, the processing unit 110 may execute the action response module 2906 to generate one or more responses of the host vehicle 200a.

For example, the processing unit 110 may (for example, via the CAN bus) send electronic signals to the throttle system 220, the braking system 230, and/or the steering system 240 of the host vehicle 200a to brake, accelerate or trigger the host vehicle 200a to turn, Lane shift and/or direction change. Further, one or more actuators may control the throttle system 220, the braking system 230, and/or the steering system 240. For example, the processing unit 110 may send an electronic signal to cause the system 100 to physically depress the brake for a predetermined amount or partially release the accelerator of the vehicle 200. Further, the processing unit 110 may send an electronic signal that causes the vehicle 200 of the system 100 to turn in a specific direction. Such a response may be based on the monitoring of the target vehicle 200b (performed at step 3030) and/or an indicator of the interception time between the host vehicle 200a and the target vehicle 200b (determined at step 3040). In some embodiments, the interception time may be compared with one or more predetermined thresholds (e.g., first and second interception thresholds). For example, if the indicator of interception time indicates that the target object is within a certain interception threshold (for example, within a second interception threshold), the response may include an emergency avoidance action. Emergency avoidance actions may include lane changes and/or emergency braking.

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[0374]

The threshold can be expressed as a unit of time.

Thus, for example, if the indicator of the interception time indicates that the target vehicle 200b is outside the first threshold (for example, the time before the collision between the host vehicle 200a and the target vehicle 200b exceeds the first threshold), the action response module 2906 The response may be generated in the host vehicle 200a based on the average motion profile associated with the target vehicle 200b. The average motion profile associated with the target vehicle 200b may represent the average position and/or average speed of the target vehicle 200b with respect to a certain threshold. In some embodiments, if the target vehicle 200b is a certain distance and/or is traveling at a certain speed, the system 100 may take no action. For example, if the target vehicle 200b is in front of the host vehicle 200a or is far enough away from the host vehicle 200a (eg, five meters, 10 meters, etc.), the system 100 may take no action unless the target vehicle 200b is closer to the host vehicle 200.

[0375]

If the indicator of the interception time indicates that the target vehicle 200b is between the first threshold and the second threshold (for example, the time before the collision between the host vehicle 200a and the target vehicle 200b falls between the first threshold and the second threshold) , The action response module 2906 may generate the response of the host vehicle 200a based on the actual motion associated with the target vehicle 200b.

The actual movement may represent the position and/or speed of the target vehicle 200b (for example, not averaged or delayed), if the interception time indicator indicates that the target vehicle 200b is within the second threshold (for example, between the host vehicle 200a and the target vehicle 200b) The time before the collision is lower than the second threshold), the action response module 2906 may generate an emergency action (such as lane change or emergency braking) of the host vehicle 200a.

[0376]

FIG. 31 is a flowchart showing an exemplary process 3100 for refusing to generate a response in the host vehicle consistent with the disclosed embodiment.

In step 3110, as described above in conjunction with step 3010 of FIG. 30, the processing unit 110 may receive multiple images via the data interface 128 located between the processing unit 110 and the image acquisition unit 120.

[0377]

In step 3120, as described above in connection with step 3020 of FIG. 30, the processing unit 110 may execute the target monitoring module 2902 to locate the target object (for example, the target vehicle 200b) in the image received in step 3010 by analyzing the image.

In step 3125, the processing unit 110 may execute the target monitoring module 2902 to determine whether the target object (for example, the target vehicle 200b) is traveling in a lane different from the host vehicle 200a using the technique described above in conjunction with the step 3030 of FIG. 30. If it is determined that the target vehicle 200b is traveling in a lane different from the host vehicle 200a (step 3125, YES), then in step 3130, the processing unit 110 may refuse to generate a response in the host vehicle 200a. Alternatively, if the system 100 determines that the target vehicle 200b does not pose an imminent risk of collision (for example, the target vehicle 200b is on a non-intersecting trajectory with the host vehicle 200a or the potential time to collide exceeds the threshold, so that the target object is at the current time It does not constitute an imminent risk), in step 3130, the processing unit 110 may refuse to generate a response in the host vehicle 200a. Otherwise (step 3125, No), the process 3100 can end without a response.

[0378]

Use a multi-section braking profile to stop autonomously driving vehicles

[0379]

The system 100 may provide driver assistance functionality for monitoring and responding to environmental conditions to control the braking of the vehicle 200.

For example, the system 100 may detect an object that triggers the stop of the vehicle 200 based on multiple images.

For example, the object may include another vehicle, a traffic light, and/or a traffic sign near the vehicle 200. The system 100 may use the braking profile to slow down and/or stop the vehicle 200. According to some embodiments, the braking profile may include multiple sections that perform deceleration at different stages. For example, the braking profile may cause the system 100 to stop the vehicle 200 at a reduced deceleration.

[0380]

By providing a braking profile that includes multiple segments, the system 100 can cause the vehicle 200 to operate in a manner that feels natural to the driver and/or passengers.

For example, when the driver stops the vehicle at a traffic light, the brake is usually not applied at a constant speed from the moment of application until the moment the vehicle stops. Operating the brake in this way results in a sudden stop at termination. Conversely, the driver can first apply the brake gently, then increase the pressure, and then when the vehicle reaches its target stop, the driver can reduce the braking level until it reaches zero (or near zero) when the vehicle stops. Operating the vehicle in this way can provide a natural stopping process, that is, the driver can first cause a gradual deceleration, so the vehicle will not experience a sudden initial deceleration and then terminate, so that the vehicle will not stop suddenly.

[0381]

The system 100 may provide autonomous vehicle navigation that may implement braking according to a method that feels natural to the driver and/or passengers of the vehicle 200.

For example, in some embodiments, the system 100 may cause one or more of the image capture devices 122-126 to acquire multiple images of the area near the vehicle 200. The processing device 110 may receive a plurality of images via the data interface 128, and identify triggers (for example, objects, traffic lights, and/or traffic signs) for stopping the vehicle 200 based on the analysis of the plurality of images. Based on the identified trigger, the system 100 can cause the vehicle 200 to stop according to the braking profile. In some embodiments, as determined based on an analysis of a plurality of images, the braking profile may include a plurality of segments (for example, including: a first segment associated with a first deceleration rate; including a first segment associated with a first deceleration rate; The second section of the second deceleration rate; and the third section where the braking level is reduced when approaching the target stopping point).

[0382]

FIG. 32A illustrates a vehicle 200 traveling on a road 3210 including an object 3220.

The system 100 may identify a trigger (e.g., object 3220) to stop the vehicle 200 relative to the detection of the trigger. For example, the system 100 may first decelerate the vehicle 200 after the trigger is detected, and stop the vehicle 200 before reaching the object 3220.

[0383]

The processing unit 110 may be configured to determine a trigger for stopping the vehicle 200 based on a plurality of images acquired by one or more of the image capturing devices 122-126.

The processing unit 110 may receive images from the image capture devices 122-126 via the data interface 128. According to some embodiments, the trigger may include an object 3220. For example, the object 3220 may be another vehicle on the road 2810. According to some embodiments, if the object 3220 is in a certain nearby area of the vehicle 200, the processing unit 110 may identify the trigger. For example, the recognition trigger may depend on the relative distance between the object 3220 and the vehicle 200. Further, this identification optionally considers the relative speed and/or relative acceleration between the object 3220 and the vehicle 200.

[0384]

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Additionally or alternatively, the trigger may include a traffic sign, such as the traffic sign 3240 shown in FIG. 32A.

For example, the traffic sign 3240 may be a stop sign and/or a speed limit sign. According to some embodiments, the processing unit 110 may process multiple images to determine the content of the traffic sign 3240 as part of determining whether the trigger exists. For example, if the vehicle 200 exceeds the speed limit, the processing unit 110 may determine the existence of the trigger based on the speed limit specified by the traffic sign 3240. As another example, if the yellow light is on and/or the red light is on, the processing unit 110 may determine the existence of the trigger based on the traffic light 2830.

[0385]

Based on the multiple images, the processing unit 110 may determine the target stopping location 3250, and once the braking profile is executed, the vehicle 200 will stop at the target stopping location 3250.

Reaching the target stopping point 3250 may be accompanied by the release of the brake pressure of the vehicle 200. The target stop location 3250 may be based on the location of the traffic light 3230 and/or the traffic sign 3240 such that the vehicle 200 conforms to the traffic light 3230 and/or the traffic sign 3240. Alternatively, the target stop location 3250 may be based on the object 3220 such that the vehicle 200 stops before reaching the object 3220. Therefore, the target stop location 3250 may be based on the location of the object 3220 to avoid a collision between the vehicle 200 and the object 3220. In some embodiments, the update of the target stop location 3250 may be based on new information obtained from multiple images, such as newly identified targets, new visible obstacles, new visible signs, and so on.

[0386]

Figure 32B illustrates an exemplary braking profile consistent with the disclosed embodiment.

In the example shown in Figure 32B, the braking profile includes four sections. However, the number of sections is exemplary, and a braking profile consistent with the disclosed embodiments may include any suitable number of sections (eg, 2, 3, 4, 5, 6, etc. Section).

[0387]

In section 1, the system 100 may prepare for possible braking scenarios.

For example, in this area, the system 100 may receive information (e.g., map data and/or image data) about an upcoming intersection (e.g., an intersection with traffic lights). The system 100 may gradually reduce the speed of the vehicle 200 (for example, depending on the characteristics of the intersection, the speed of the vehicle 200 may be gradually reduced to about 70-50 km/hr). The system 100 can generate speed adjustments, for example, about an average deceleration of about 0.2-0.4 m/s2 (approximately 0.5 m/s2 at the maximum) about 100-200 meters before the hub. By reducing the speed of the vehicle 200 in section 1, the system 100 can provide the driver and/or passengers of the vehicle 200 with the confidence that the system 100 knows the approach to the intersection.

[0388]

In section 2, the system 100 can apply strong braking.

In this section, the system 100 may receive information based on the analysis of the image data, for example, a traffic light turns red and/or there is a stopped vehicle at an intersection in the travel line of the vehicle 200. The system 100 can cause the vehicle 200 to experience a significant speed reduction in this zone, while the distance from the stop line or stopped vehicle is still large. Doing so can provide a comfortable feeling for the driver and/or passengers of the vehicle 200, and the system 100 will have enough space to complete the braking maneuver. The zone may be about 30-100 meters away from the stop line, and the average deceleration may be about 1.5-2.5 m/s2 (the maximum is about 3.5 m/s2).

[0389]

In section 3, the system 100 can make moderate braking adjustments.

For example, in this section, the system 100 may adjust the speed of the vehicle 200 according to the remaining distance from the stop line or the stopped vehicle and based on the current speed and deceleration of the vehicle 200. By making this adjustment, the system 100 can provide the driver and/or passenger of the vehicle 200 with an indication that the system 100 is

releasing most of the braking power while the speed is still decreasing, but slower than before. The zone can be about 5-30 meters away from the stop line or stop the vehicle, and the average deceleration can be about 0.5-1.5 m/s2 (the maximum is about 2 m/s2).

[0390]

In section 4, the system 100 can make small braking adjustments.

In this section, the system 100 can shorten the remaining distance from the stop line or the stopped vehicle at a very low speed gradually becoming zero. In this zone, the driver and/or passenger may feel the vehicle 200 slowly sliding into place (e.g., at a stop line or behind another vehicle). This zone may constitute about the last 5-7 meters from the stop line or stopped vehicle, and the average deceleration may be about 0.3-0.5 m/s2 (the maximum is about 1 m/s2).

[0391]

FIG. 33 is an exemplary block diagram of the memory 140 and/or 150 consistent with the disclosed embodiments. The memory 140 and/or 150 may store instructions for performing one or more operations.

As illustrated in FIG. 33, the memory 140 may store one or more modules for performing trigger detection and response described herein. For example, the memory 140 may store the trigger recognition module 3300 and the action response module 3310.

[0392]

The trigger recognition module 3300 may store an instruction, and when executed by the processing unit 110, the instruction may detect the existence of a trigger for stopping the vehicle 200.

For example, the trigger recognition module 3300 may process a plurality of images received from at least one image capture device 122-124 to detect the presence of a trigger. As discussed above, this may include identifying objects 3220, traffic lights 3230, and/or traffic signs 3240.

[0393]

The action response module 3310 may store an instruction, and when executed by the processing unit 110, the instruction may respond to the existence of a trigger.

For example, the action response module 3310 may perform control to decelerate and/or stop the vehicle 200. For example, the action response module 3310 may perform a braking profile to slow down and/or stop the vehicle 200. The action response module 3310 may determine to execute one of a plurality of braking profiles based on the number of braking profiles and based on, for example, environmental factors, the type of trigger being detected, and the speed of the vehicle 200. In order to navigate the vehicle 200 to a stop based on the detected trigger, the processing unit 110 may send an electronic signal to one or more of the throttle system 220, the braking system 230, and/or the steering system 240 of the vehicle 200. Further, one or more actuators may control the throttle system 220, the braking system 230, and/or the steering system 240. For example, the processing unit 110 may send an electronic signal to cause the system 100 to physically depress the brake for a predetermined amount.

[0394]

FIG. 34 illustrates a process 3400 for navigating the vehicle 200 consistent with the disclosed embodiment.

The process 3000 may identify a trigger for stopping the vehicle 200 (eg, an object, vehicle, traffic light, traffic sign, etc.) and execute a braking profile in response to the detection of the trigger. The process 3400 may detect various types of triggers to determine which of the multiple braking profiles to perform.

[0395]

The braking profile may be based on the type of the detected trigger and/or other environmental conditions related to the detected trigger (eg, distance from the object).

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For example, in some embodiments, the braking profile may include multiple sections (e.g., three sections). In the three-section braking profile, the first section of the braking profile may be associated with a first deceleration rate, the second section of the braking profile may include a second deceleration rate that is less than the first deceleration rate, and the braking profile The third section of may include causing the braking level to decrease when approaching the target stopping location, which is determined based on an analysis of multiple images acquired by one or more of the image capture devices 122-126. For example, in some embodiments, the first section may cause the vehicle 200 to gradually increase deceleration, the second section may cause the vehicle 200 to decelerate at a constant speed, and the third section may cause the vehicle 200 to gradually reduce its deceleration rate to zero. (Or near zero).

[0396]

In step 3410, the process 3400 may use at least one of the image capture devices 122-126 to acquire multiple images of the area near the vehicle 200.

For example, the processing unit 110 may receive multiple images via the data interface 128. The processing unit 110 may be configured to determine the presence of one or more objects and/or signs located on or near the road 3210 based on the acquired image. For example, the processing unit 110 may be configured to determine the existence of the object 3220, the traffic light 3230, and/or the traffic sign 3240. The processing unit 110 may be further configured to read the content of the traffic sign 3240. For example, the processing unit 110 may be configured to distinguish between a speed limit sign and a stop sign. Further, the processing unit 110 may be configured to process the image based on the traffic sign 3240 to determine the speed limit.

[0397]

At step 3420, the process 300 may include a trigger for stopping the vehicle 200.

For example, the processing unit 110 may identify the trigger based on the existence of the object 3220 in the area near the vehicle 200. Additionally or alternatively, the processing unit 110 may identify the trigger based on the current signal state of the traffic light 3230. According to some embodiments, if it is not a green light, the processing unit 110 may determine that the traffic light 3230 constitutes a trigger. According to some embodiments, for example, if the traffic sign 3240 is a stop sign, the processing unit 110 may determine that the traffic sign 3240 constitutes a trigger. In some embodiments, if the traffic sign 3240 is a speed limit sign and the vehicle 200 exceeds the speed limit, the traffic sign 3240 may constitute a trigger. Further in some embodiments, the processing unit 110 may cause the system 100 to provide a voice notification, recognize a trigger, and/or indicate that the vehicle 200 is braking or is about to start braking.

[0398]

After the processing unit 110 recognizes the trigger, in step 3430, the processing unit 110 may cause the vehicle 200 to decelerate and/or stop according to the braking profile.

In some embodiments, the braking profile may include a certain number of profile sections. The different contour sections of the braking contour can be defined by the time period and/or the vehicle speed. For example, the processing unit 110 may perform the control of the vehicle 200 according to the first contour section lasting a predetermined period of time or until the speed of the vehicle 200 reaches the target value. The target value may be a predetermined speed, or may be a percentage of the speed at which the vehicle 200 has traveled in the past before the braking profile was performed. In order to implement the braking profile, the processing unit 110 may send an electronic signal to one or more of the throttle system 220, the braking system 230, and/or the steering system 240 of the vehicle 200. Further, one or more actuators may control the throttle system 220, the braking system 230, and/or the steering system 240.

[0399]

As discussed above, according to some embodiments, the profile section of the braking profile may correspond to the deceleration rate.

For example, the braking profile may include multiple sections, and the first section may be associated with a first deceleration rate. The braking profile may further include a second section associated with a second deceleration rate. The second deceleration rate may be less than the first deceleration rate.

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[0400]

Further, as discussed above, according to some embodiments, the braking profile may include a third profile section, where a reduction in the braking level is a potential factor for the vehicle 200 to generate triggers (e.g., object 3220, traffic light 3230, traffic Flag 3240) as a function of the distance between.

For example, the braking profile may include reducing the braking level as the vehicle 200 approaches the target stopping location 3250. Further, reaching the target stopping point 3250 may be accompanied by the release of the brake pressure of the vehicle 200.

[0401]

For illustration purposes, the foregoing description has been presented.

It is not exhaustive and not limited to the specific forms or implementations disclosed. Considering the practice of the specification and disclosed embodiments, modifications and rewriting will be obvious to those skilled in the art. In addition, although various aspects of the disclosed embodiments are described as being stored in a memory, those skilled in the art will understand that these aspects may also be stored on other types of computer-readable media such as secondary storage devices, such as hard disks. Or CD ROM, or other forms of RAM or ROM, USB media, DVD, Blu-ray or other optical drive media.

[0402]

Computer programs based on written descriptions and published methods are within the skills of experienced developers.

Various programs or program modules can be created using any technology known to those skilled in the art or can be designed in combination with existing software. For example, program segments or program modules can be designed or used. Net Framework,. Net Compact Framework (and related languages such as Visual Basic, C, etc.), Java, C++, Objective-C, HTML, HTML/AJAX combination, XML or HTML including Java applets.

[0403]

Moreover, although illustrative embodiments have been described herein, the scope of any and all embodiments having equivalent elements, modifications, omissions, combinations (for example, aspects across various embodiments), adaptations, and/or changes will be based on the present disclosure Known by those skilled in the art.

The limitations in the claims should be interpreted broadly based on the language used in the claims, and are not limited to the examples described in this specification or during the prosecution of this application. Examples should be interpreted as non-exclusive. In addition, the steps in the disclosed method can be modified in any way, including reordering the steps and/or inserting or deleting steps. Therefore, it is expected that the specification and examples are considered to be illustrative only, and the true scope and spirit are indicated by the following claims and their full equivalents.

[0404]

Cross-references to related applications

[0405]

This application claims the following priority: U.S. Provisional Patent Application No. 61/911,490 filed on December 4, 2013; U.S. Provisional Patent Application No. 61/993,084 filed on May 14, 2014; Filed on May 14, 2014 United States Provisional Patent Application No. 61/993,111; United States Provisional Patent Application 62/015,524 filed on June 23, 2014; United States Provisional Patent Application 62/022,221 filed on July 9, 2014; United States filed on August 21, 2014 Provisional Patent Application No. 62/040,224; and U.S. Provisional Patent Application 62/040,269 filed on August 21, 2014.

The entire contents of all aforementioned applications are incorporated herein by reference.

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CLAIMS CN111027420A

1.

A computing platform for vehicles, the computing platform includes:

Memory; and

At least one processor, the at least one processor is configured to:

Reading a plurality of images of the forward field of view from the vehicle, the plurality of images corresponding to image data acquired by one or more cameras;

The first lane marking located on the first side of the lane and the second lane marking located on the second side of the lane are determined from the plurality of images. The vehicle can navigate through the lane, and the second side is connected to the lane. The first side is opposite;

Enabling the vehicle to autonomously navigate relatively centered between the first lane marking and the second lane marking;

Determining from the plurality of images whether an object is located on the first side or the second side of the lane and whether the object exceeds the first lane marking or exceeds the second lane marking; and

The vehicle is allowed to autonomously navigate to travel through a driving path offset from the center of the lane.

2.

The computing platform of claim 1, wherein the object is a vehicle.

3.

The computing platform of claim 1, wherein the object is a wall.

4.

The computing platform of claim 1, wherein the at least one processor:

The vehicle is allowed to autonomously navigate to return after the vehicle passes the object so as to be relatively centered between the first lane marking and the second lane marking.

5.

At least one non-transitory computer-readable medium, the non-transitory computer-readable medium comprising instructions that, when executed by a computing platform for a vehicle, cause the computing platform to:

Reading a plurality of images of the forward field of view from the vehicle, the plurality of images corresponding to image data acquired by one or more cameras;

The first lane marking located on the first side of the lane and the second lane marking located on the second side of the lane are determined from the plurality of images. The vehicle can navigate through the lane, and the second side is connected to the lane. The first side is opposite;

Enabling the vehicle to autonomously navigate relatively centered between the first lane marking and the second lane marking;

Determining from the plurality of images whether an object is located on the first side or the second side of the lane and whether the object exceeds the first lane marking or exceeds the second lane marking; and

The vehicle is allowed to autonomously navigate to travel through a driving path offset from the center of the lane.

6.

The at least one non-transitory computer readable medium of claim 5, wherein the object is a vehicle.

7.

The at least one non-transitory computer readable medium of claim 5, wherein the object is a wall.

8.

The at least one non-transitory computer-readable medium of claim 5, wherein the at least one non-transitory computer-readable medium includes instructions that, when executed by the computing platform, cause the computing platform to:

The vehicle is allowed to autonomously navigate to return after the vehicle passes the object so as to be relatively centered between the first lane marking and the second lane marking.

9.

A device including:

A component for reading a plurality of images of the forward field of view from the vehicle, the plurality of images corresponding to image data acquired by one or more cameras;

A means for determining from the plurality of images a first lane marking located on the first side of the lane and a second lane marking located on the second side of the lane, the vehicle can navigate through the lane, the first Two sides are opposite to the first side;

A component used to enable the vehicle to autonomously navigate relatively centrally between the first lane marking and the second lane marking;

Used for determining from the plurality of images whether the object is located on the first side or the second side of the lane and whether the object exceeds the first lane marking or the second lane marking Parts; and

A component for enabling the vehicle to autonomously navigate to travel through a driving path offset from the center of the lane.

10.

The device according to claim 9, wherein the object is a vehicle.

11.

The device according to claim 9, wherein the object is a wall.

12.

The device according to claim 9, said device comprising means for enabling said vehicle to autonomously navigate to return after said vehicle has passed said object so as to be between said first lane marking and said second lane marking Relatively centered parts.

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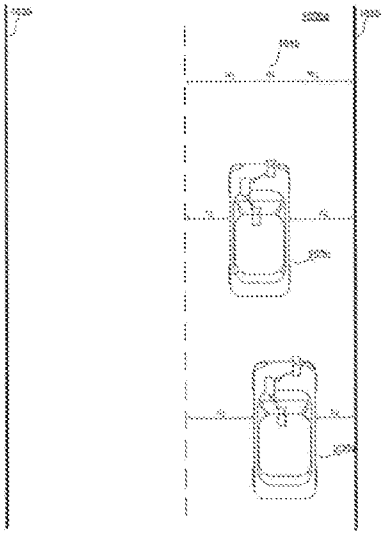
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(54)发明名称

用于模仿前车的系统和方法

(57)摘要

本发明涉及用于模仿前车的系统和方法。系统和方法使用相机来提供自主导航特征。在一个实施中，提供了一种用于主车辆的驾驶员辅助导航系统。所述系统可包括：至少一个图像捕获装置，所述至少一个图像捕获装置被构造成获取主车辆的附近区域的多个图像；数据接口；以及至少一个处理装置。所述至少一个处理装置可构造成：在所述多个图像中定位前车；基于所述多个图像来确定所述前车采取的至少一个动作；以及致使所述主车辆模仿所述前车的所述至少一个动作。



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1.一种用于车辆的计算平台，所述计算平台包括：

存储器；以及

至少一个处理器，所述至少一个处理器被构造成：

从所述车辆读取朝前视野的多个图像，所述多个图像对应于由一个或多个相机获取的图像数据；

从所述多个图像确定位于车道的第一侧的第一车道标记和位于所述车道的第二侧的第二车道标记，所述车辆能够导航通过所述车道，所述第二侧与所述第一侧相对；

使所述车辆在所述第一车道标记与所述第二车道标记之间相对居中地自主导航；

从所述多个图像确定对象位于所述车道的所述第一侧还是位于所述车道的所述第二侧以及所述对象超过所述第一车道标记还是超过所述第二车道标记；以及

使所述车辆自主地导航以行进经过从所述车道的中央偏移的驱动路径。

2.根据权利要求1所述的计算平台，其中，所述对象是车辆。

3.根据权利要求1所述的计算平台，其中，所述对象是墙。

4.根据权利要求1所述的计算平台，其中，所述至少一个处理器：

使所述车辆自主地导航以在所述车辆经过所述对象之后返回从而在所述第一车道标记与所述第二车道标记之间相对地居中。

5.至少一个非临时性计算机可读介质，所述非临时性计算机可读介质包括指令，所述指令在由用于车辆的计算平台执行时致使所述计算平台：

从所述车辆读取朝前视野的多个图像，所述多个图像对应于由一个或多个相机获取的图像数据；

从所述多个图像确定位于车道的第一侧的第一车道标记和位于所述车道的第二侧的第二车道标记，所述车辆能够导航通过所述车道，所述第二侧与所述第一侧相对；

使所述车辆在所述第一车道标记与所述第二车道标记之间相对居中地自主导航；

从所述多个图像确定对象位于所述车道的所述第一侧还是位于所述车道的所述第二侧以及所述对象超过所述第一车道标记还是超过所述第二车道标记；以及

使所述车辆自主地导航以行进经过从所述车道的中央偏移的驱动路径。

6.根据权利要求5所述的至少一个非临时性计算机可读介质，其中，所述对象是车辆。

7.根据权利要求5所述的至少一个非临时性计算机可读介质，其中，所述对象是墙。

8.根据权利要求5所述的至少一个非临时性计算机可读介质，其中，所述至少一个非临时性计算机可读介质包括指令，所述指令在由所述计算平台执行时致使所述计算平台：

使所述车辆自主地导航以在所述车辆经过所述对象之后返回从而在所述第一车道标记与所述第二车道标记之间相对地居中。

9.一种设备，该设备包括：

用于从车辆读取朝前视野的多个图像的部件，所述多个图像对应于由一个或多个相机获取的图像数据；

用于从所述多个图像确定位于车道的第一侧的第一车道标记和位于所述车道的第二侧的第二车道标记的部件，所述车辆能够导航通过所述车道，所述第二侧与所述第一侧相对；

用于使所述车辆在所述第一车道标记与所述第二车道标记之间相对居中地自主导航

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的部件；

用于从所述多个图像确定对象位于所述车道的所述第一侧还是位于所述车道的所述第二侧以及所述对象超过所述第一车道标记还是超过所述第二车道标记的部件；以及

用于使所述车辆自主地导航以行进经过从所述车道的中央偏移的驱动路径的部件。

10.根据权利要求9所述的设备，其中，所述对象是车辆。

11.根据权利要求9所述的设备，其中，所述对象是墙。

12.根据权利要求9所述的设备，所述设备包括用于使所述车辆自主地导航以在所述车辆经过所述对象之后返回从而在所述第一车道标记与所述第二车道标记之间相对地居中的部件。

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用于模仿前车的系统和方法

[0001] 本申请是申请日为2014年12月4日，申请号为201480074153.9(PCT/IB2014/003151)，发明名称为“用于模仿前车的系统和方法”的专利申请的分案申请。

技术领域

[0002] 所述本公开总体涉及自主车辆导航，更具体地，涉及使用相机提供自主车辆导航特征的系统和方法。

背景技术

[0003] 随着技术的不断进步，能够在道路上导航的完全自主车辆的目标是即将达到。首先，自主车辆能够识别其环境并且在无操作人员输入的情况下导航。自主车辆还可考虑各种因素并且基于这些因素做出适当的决定，以安全而准确地到达预期目的地。例如，当车辆惯常地在道路上行进时会遇到诸如其它车辆和行人的各种对象。自主驱动系统可在车辆环境中辨识这些对象，并且采取适当的而及时的动作来避免碰撞。另外，自主驱动系统可识别其它指示器，诸如交通信号、交通标志和车道标记，所述其它指示器规范车辆移动(例如，当车辆必须停止以及可行驶时，车辆不能超过的速度，车辆必须定位在道路上，等等)。自主驱动系统可能需要确定车辆何时应该变道、路口转弯、改变道路，等等。根据这些示例显而易见的是，许多因素可能需要解决，以便提供能够安全而准确地导航的自主车辆。

发明内容

[0004] 与本公开相一致的实施方式提供用于自主车辆导航的系统和方法。公开的实施方式可使用相机来提供自主车辆导航特征。例如，与公开的实施方式相一致，公开的系统可包括一个、两个或更多个相机，用于监测车辆环境并且基于对由所述相机中的一个或多个捕获的图像的分析来产生导航响应。

[0005] 与公开的实施方式相一致，提供了一种用于车辆的驾驶员辅助导航系统。所述系统可包括：至少一个图像捕获装置，所述至少一个图像捕获装置被构造成获取车辆附近区域的多个图像；数据接口；以及至少一个处理装置。所述至少一个处理装置可构造成：经由所述数据接口接收所述多个图像；根据所述多个图像确定在所述车辆的第一侧上的第一车道约束；根据所述多个图像确定与在所述车辆的所述第一侧相反的所述车辆的第二侧上的第二车道约束，其中所述第一车道约束和第二车道约束限定所述车辆行进的车道，并且其中第一距离对应于所述车辆的所述第一侧与所述第一车道约束之间的距离，并且第二距离对应于所述车辆的所述第二侧与所述第二车道约束之间的距离；基于所述多个图像来确定车道偏移条件是否存在于所述车辆的所述第一侧上；如果车道偏移条件存在于所述车辆的所述第一侧上，则致使所述车辆在所述第一车道约束和第二车道约束内行进，使得所述第一距离大于所述第二距离；基于所述多个图像来确定车道偏移条件是否存在于所述车辆的所述第二侧上；并且如果车道偏移条件存在于所述车辆的所述第二侧上，则致使所述车辆在所述第一车道约束和第二车道约束内行进，使得所述第一距离小于所述第二距离。

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[0006] 与公开的实施方式相一致，所述至少一个处理装置可进一步构造成如果基于所述多个图像确定车道偏移条件存在于所述车辆的所述第一侧和第二侧两者上，则致使所述第一距离与所述第二距离大致相同。所述至少一个处理装置可构造成基于所述多个图像来确定车道偏移条件是否基本上不存在，并且如果所述车道偏移条件基本上不存在，则致使所述车辆在所述第一车道约束和第二车道约束内行进，使得所述第一距离基本上等于所述第二距离。如果所述驾驶员辅助导航系统确定车道偏移条件存在，则所述至少一个处理装置可构造成致使所述第一距离比所述第二距离大至少1.25倍。替代地，所述至少一个处理装置可进一步构造成致使所述第一距离比所述第二距离大至少2倍。如果所述驾驶员辅助导航系统确定所述车道偏移条件包括弯路，则所述至少一个处理装置可构造成致使所述车辆在所述第一车道约束和第二车道约束内行进，使得所述第一距离朝向弯道的相对于所述车辆的外侧，并且所述第二距离朝向所述弯道的相对于所述车辆的内侧。如果所述驾驶员辅助导航系统确定所述车道偏移条件包括在所述车道的一侧上存在一个或多个对象，则所述至少一个处理装置可构造成致使所述车辆在所述第一车道约束和第二车道约束内行进，使得朝向所述一个或多个对象提供大于所述第二距离的所述第一距离。所述一个或多个对象可包括停放的车、墙和/或行人，并且可具有距路面大于10cm的高度。所述第一车道约束和第二车道约束中的至少一个可包括标记在路面上的线、路面的路边或者路面宽度的确定的中点。确定车道偏移条件是否存在于所述车辆的所述第一侧可基于目标对象在所述车辆的所述第一侧上的位置来执行。致使所述车辆在所述第一车道约束和第二车道约束内行进使得所述第一距离大于所述第二距离可基于所述车辆的驾驶员的输入而撤销。

[0007] 与另一公开的实施方式相一致，一种车辆可包括：第一车辆侧；与所述第一车辆侧相反的第二车辆侧；至少一个图像捕获装置，所述至少一个图像捕获装置被构造成获取车辆附近区域的多个图像；数据接口；以及至少一个处理装置。所述至少一个处理装置可构造成：经由所述数据接口接收所述多个图像；根据所述多个图像确定在所述第一车辆侧上的第一车道约束；根据所述多个图像确定在所述第二车辆侧上的第二车道约束，其中所述第一车道约束和第二车道约束限定所述车辆行进的车道，并且其中第一距离对应于所述第一车辆侧与所述第一车道约束之间的距离，并且第二距离对应于所述第二车辆侧与所述第二车道约束之间的距离；基于所述多个图像来确定车道偏移条件是否存在于所述第一车辆侧上；如果车道偏移条件存在于所述第一车辆侧上，则致使所述车辆在所述第一车道约束和第二车道约束内行进，使得所述第一距离大于所述第二距离；基于所述多个图像来确定车道偏移条件是否存在于所述第二车辆侧上；并且如果车道偏移条件存在于所述第二车辆侧上，则致使所述车辆在所述第一车道约束和第二车道约束内行进，使得所述第一距离小于所述第二距离。

[0008] 与公开的实施方式相一致，所述至少一个处理装置可进一步构造成如果基于所述多个图像确定车道偏移条件存在于所述第一车辆侧和第二车辆侧两者上，则致使所述第一距离与所述第二距离大致相同。所述至少一个处理装置可构造成基于所述多个图像来确定车道偏移条件是否基本上不存在，并且如果所述车道偏移条件基本上不存在，则致使所述车辆在所述第一车道约束和第二车道约束内行进，使得所述第一距离基本上等于所述第二距离。所述车道偏移条件可包括弯路，并且所述至少一个处理装置可构造成致使所述车辆在所述第一车道约束和第二车道约束内行进，使得所述第一距离朝向弯道的相对于所述车

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辆的外侧，并且所述第二距离朝向所述弯道的相对于所述车辆的内侧。所述车道偏移条件可包括在所述车道的一侧上存在一个或多个对象，并且所述至少一个处理装置可构造成致使所述车辆在所述第一车道约束和第二车道约束内行进，使得朝向所述一个或多个对象提供大于所述第二距离的所述第一距离。所述第一车道约束和第二车道约束中的至少一个可包括路面的路边和/或路面宽度的确定的中点。确定车道偏移条件是否存在于所述车辆的第一侧可基于目标对象在所述车辆的第一侧上的位置来执行。致使所述车辆在所述第一车道约束和第二车道约束内行进使得所述第一距离大于所述第二距离可基于所述车辆的驾驶员的输入而撤销。

[0009] 与另一公开的实施方式相一致，提供了一种用于导航车辆的方法。所述方法可包括：使用至少一个图像捕获装置来获取车辆附近区域的多个图像；根据所述多个图像确定所述车辆的第一侧上的第一车道约束；根据所述多个图像确定与所述车辆的所述第一侧相反的所述车辆的第二侧上的第二车道约束，其中所述第一车道约束和第二车道约束限定所述车辆行进的车道，并且其中第一距离对应于所述车辆的所述第一侧与所述第一车道约束之间的距离，并且第二距离对应于所述车辆的所述第二侧与所述第二车道约束之间的距离；基于所述多个图像来确定车道偏移条件是否存在于所述车辆的所述第一侧上；如果车道偏移条件存在于所述车辆的所述第一侧上，则致使所述车辆在所述第一车道约束和第二车道约束内行进，使得所述第一距离大于所述第二距离；基于所述多个图像来确定车道偏移条件是否存在于所述车辆的所述第二侧上；以及如果车道偏移条件存在于所述车辆的所述第二侧上，则致使所述车辆在所述第一车道约束和第二车道约束内行进，使得所述第一距离小于所述第二距离。

[0010] 与公开的实施方式相一致，提供了一种用于车辆的驾驶员辅助导航系统。所述系统可包括：至少一个图像捕获装置，所述至少一个图像捕获装置被构造成获取车辆附近区域的多个图像；数据接口；以及至少一个处理装置。所述至少一个处理装置可构造成：经由所述数据接口接收所述多个图像；根据所述多个图像确定多个可用行进车道之中的当前行进车道；以及如果所述当前行进车道与预定的默认行进车道不相同则致使所述车辆变道。

[0011] 与公开的实施方式相一致，所述预定的默认行进车道可以是所述多个可用行进车道之中的最右车道。所述至少一个处理装置可构造成在致使所述车辆变道之前激活转向信号。所述至少一个处理装置可构造成在致使所述车辆变道之前产生语音通知。所述至少一个处理装置可构造成在致使所述车辆变道之前产生语音指示。可基于所述车辆附近区域的所述多个图像、基于从全球定位系统接收的数据和/或基于从用户接收的输入来确定所述预定的默认行进车道。

[0012] 与另一公开的实施方式相一致，一种车辆可包括：主体；至少一个图像捕获装置，所述至少一个图像捕获装置被构造成获取车辆附近区域的多个图像；数据接口；以及至少一个处理装置。所述至少一个处理装置可构造成：经由所述数据接口接收所述多个图像；根据所述多个图像确定多个可用行进车道之中的当前行进车道；以及如果所述当前行进车道与预定的默认行进车道不相同则致使所述车辆变道。

[0013] 与公开的实施方式相一致，所述预定的默认行进车道可以是所述多个可用行进车道之中的最右车道。所述至少一个处理装置可构造成在致使所述车辆变道之前激活转向信号。所述至少一个处理装置可构造成在致使所述车辆变道之前产生语音通知。所述至少一

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个处理装置可构造成在致使所述车辆变道之前产生语音指示。可基于所述车辆附近区域的所述多个图像、基于从全球定位系统接收的数据和/或基于从用户接收的输入来确定所述预定的默认行进车道。

[0014] 与另一公开的实施方式相一致，提供了一种用于导航车辆的方法。所述方法可包括：使用至少一个图像捕获装置来获取车辆附近区域的多个图像；根据所述多个图像确定多个可用行进车道之中的当前行进车道；以及如果所述当前行进车道与预定的默认行进车道不相同则致使所述车辆变道。

[0015] 与公开的实施方式相一致，所述预定的默认行进车道可以是所述多个可用行进车道之中的最右车道。可在致使所述车辆变道之前激活转向信号。可基于所述车辆附近区域的所述多个图像来确定所述预定的默认行进车道。

[0016] 与公开的实施方式相一致，提供了一种用于车辆的驾驶员辅助导航系统。所述系统可包括：至少一个图像捕获装置，所述至少一个图像捕获装置被构造成获取车辆附近区域的多个图像；数据接口；以及至少一个处理装置。所述至少一个处理装置可构造成：经由所述数据接口接收所述多个图像；基于地图数据和车辆位置信息来辨识待导航的弯道；基于反映在所述地图数据中的弯道的至少一个特性来确定所述车辆的初始目标速度；将所述车辆的速度调整至所述初始目标速度；基于所述多个图像来确定弯道的观察到的一个或多个特性；基于所述弯道的观察到的一个或多个特性来确定更新的目标速度；以及将所述车辆的速度调整至所述更新的目标速度。

[0017] 与公开的实施方式相一致，所述弯道的至少一个特性可包括根据所述地图数据确定的所述弯道的预期曲率半径。所述初始目标速度可基于所述弯道的所述预期曲率半径和侧向加速极限来确定。所述侧向加速极限可介于约0.2米/秒^{2}到3.0米/秒^{2}之间。替代地，所述侧向加速极限可介于约1.5米/秒^{2}到3.0米/秒^{2}之间。所述侧向加速极限可基于由所述多个图像确定的道路宽度来调整。所述弯道的观察到的一个或多个特性可包括通过分析所述多个图像确定的所述弯道的实际曲率半径。所述更新的目标速度可基于所述弯道的所述实际曲率半径和侧向加速极限来确定。所述弯道的观察到的一个或多个特性可包括通过分析所述多个图像确定的所述弯道的实际曲率半径的变化率。所述弯道的观察到的一个或多个特性可包括通过分析所述多个图像确定的与所述弯道关联的转弯倾斜度。所述弯道的观察到的一个或多个特性可包括通过分析所述多个图像确定的与由一个或多个道路标志传达的所述弯道相关的信息。所述初始目标速度还可基于所述至少一个图像捕获装置的焦距范围。所述初始目标速度还可基于确定交通灯是否沿着所述弯道定位。所述初始目标速度还可基于确定交通灯是否位于所述弯道之后的预定距离内。

[0018] 与另一公开的实施方式相一致，一种车辆可包括：主体；至少一个图像捕获装置，所述至少一个图像捕获装置被构造成获取车辆附近区域的多个图像；数据接口；以及至少一个处理装置。所述至少一个处理装置可构造成：经由所述数据接口接收所述多个图像；基于地图数据和车辆位置信息来辨识待导航的弯道；基于反映在所述地图数据中的弯道的至少一个特性来确定所述车辆的初始目标速度；将所述车辆的速度调整至所述初始目标速度；基于所述多个图像来确定弯道的观察到的一个或多个特性；基于所述弯道的观察到的一个或多个特性来确定更新的目标速度；以及将所述车辆的速度调整至所述更新的目标速度。

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[0019] 与公开的实施方式相一致，所述弯道的至少一个特性可包括根据所述地图数据确定的所述弯道的预期曲率半径。所述初始目标速度可基于所述弯道的所述预期曲率半径和侧向加速极限来确定。所述侧向加速极限可基于由所述多个图像确定的道路宽度来调整。所述弯道的观察到的一个或多个特性可包括通过分析所述多个图像确定的所述弯道的实际曲率半径。所述更新的目标速度可基于所述弯道的所述实际曲率半径和侧向加速极限来确定。所述弯道的观察到的一个或多个特性可包括通过分析所述多个图像确定的所述弯道的实际曲率半径的变化率。所述弯道的观察到的一个或多个特性可包括通过分析所述多个图像确定的与所述弯道关联的转弯倾斜度。所述弯道的观察到的一个或多个特性可包括通过分析所述多个图像确定的与由一个或多个道路标志传达的所述弯道相关的信息。所述初始目标速度还可基于所述至少一个图像捕获装置的焦距范围。所述初始目标速度还可基于确定交通灯是否沿着所述弯道定位。所述初始目标速度还可基于确定交通灯是否位于所述弯道之后的预定距离内。

[0020] 与另一公开的实施方式相一致，提供了一种用于导航车辆的方法。所述方法可包括：使用至少一个图像捕获装置来获取车辆附近区域的多个图像；基于地图数据和车辆位置信息来辨识待导航的弯道；基于反映在所述地图数据中的弯道的至少一个特性来确定所述车辆的初始目标速度；将所述车辆的速度调整至所述初始目标速度；基于所述多个图像来确定弯道的观察到的一个或多个特性；基于所述弯道的观察到的一个或多个特性来确定更新的目标速度；以及将所述车辆的速度调整至所述更新的目标速度。

[0021] 与公开的实施方式相一致，提供了一种用于主车辆的驾驶员辅助导航系统。所述系统可包括：至少一个图像捕获装置，所述至少一个图像捕获装置被构造成获取主车辆附近区域的多个图像；数据接口；以及至少一个处理装置。所述至少一个处理装置可构造成：经由所述数据接口接收所述多个图像；根据所述多个图像中的至少一些图像来确定所述主车辆的第一侧上的第一车道约束；根据所述多个图像中的至少一些图像来确定与所述主车辆的所述第一侧相反的所述主车辆的第二侧上的第二车道约束，其中所述第一车道约束和第二车道约束限定所述主车辆行进的车道；致使所述主车辆在所述第一车道约束和第二车道约束内行进；在所述多个图像中定位前车；基于所述多个图像来确定所述前车采取的至少一个动作；以及致使所述主车辆模仿所述前车的所述至少一个动作。

[0022] 与公开的实施方式相一致，所述第一车道约束和第二车道约束中的至少一个可包括标记在路面上的线。所述第一车道约束和第二车道约束中的至少一个可包括路面的路边。所述第一车道约束和第二车道约束中的至少一个可包括路面宽度的确定的中点。所述前车采取的所述至少一个动作可包括转弯，并且所述至少一个处理装置可致使所述主车辆执行开始于所述前车启动其转弯的地点处的类似转弯。所述前车采取的所述至少一个动作可包括加速。所述前车采取的所述至少一个动作可包括制动。所述前车采取的所述至少一个动作可包括在所述前车的邻近所述第一车道约束的那一侧提供第一偏移距离，所述第一偏移距离不同于所述前车的邻近所述第二车道约束的那一侧的第二偏移距离。所述至少一个处理装置可进一步构造成基于所述多个图像或者基于地图数据和位置信息来确定所述前车是否在路口处转弯，并且如果确定所述前车是在路口处转弯，则拒绝模仿所述前车的所述转弯。所述至少一个处理装置可构造成基于所述多个图像或者基于地图数据和位置信息来确定所述前车是否在路口处转弯、确定所述前车是否在所述路口内变道，如果确定所

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述前车是在路口处转弯并且在所述路口内不变道则模仿所述前车的所述转弯，并且如果确定所述前车是在路口处转弯但在所述路口内变道则拒绝模仿所述前车的所述转弯。所述至少一个处理装置可构造成：基于所述多个图像来获取第一前车，基于所述多个图像来获取第二前车，并且如果基于所述多个图像确定所述第一前车继续行进的路径的转弯半径小于所述第二前车跟随的路径，则致使所述主车辆模仿所述第一前车。所述至少一个处理装置可构造成：确定所述前车的位置信息并且将所述位置信息与预定地图数据比较，通过跟踪所述前车相对于所述预定地图数据的移动为所述前车创建导航历史，并且基于所述前车的所述导航历史来确定是否致使所述主车辆模仿所述前车的所述至少一个动作。所述至少一个处理装置可构造成：当所述导航历史指示所述前车已成功导航至少一个前转弯时，甚至在基于所述多个图像未检测到转弯的情况下，致使所述主车辆模仿所述前车的转弯。

[0023] 与另一公开的实施方式相一致，一种主车辆可包括：主体；至少一个图像捕获装置，所述至少一个图像捕获装置被构造成获取主车辆附近区域的多个图像；数据接口；以及至少一个处理装置。所述至少一个处理装置可构造成：经由所述数据接口接收所述多个图像；根据所述多个图像中的至少一些图像来确定在所述主车辆的第一侧上的第一车道约束；根据所述多个图像中的至少一些图像来确定在与所述主车辆的所述第一侧相反的所述主车辆的第二侧上的第二车道约束，其中所述第一车道约束和第二车道约束限定所述主车辆行进的车道；致使所述主车辆在所述第一车道约束和第二车道约束内行进；在所述多个图像中定位前车；基于所述多个图像来确定所述前车采取的至少一个动作；以及致使所述主车辆模仿所述前车的所述至少一个动作。

[0024] 与公开的实施方式相一致，所述第一车道约束和第二车道约束中的至少一个可包括标记在路面上的线。所述第一车道约束和第二车道约束中的至少一个可包括路面的路边。所述第一车道约束和第二车道约束中的至少一个可包括路面宽度的确定的中点。所述前车采取的所述至少一个动作可包括转弯，并且所述至少一个处理装置可致使所述主车辆执行开始于所述前车启动其转弯的地点处的类似转弯。所述前车采取的所述至少一个动作可包括加速。所述前车采取的所述至少一个动作可包括制动。所述前车采取的所述至少一个动作可包括在所述前车的邻近所述第一车道约束的那一侧提供第一偏移距离，所述第一偏移距离不同于所述前车的邻近所述第二车道约束的那一侧的第二偏移距离。所述至少一个处理装置可进一步构造成基于所述多个图像或者基于地图数据和位置信息来确定所述前车是否在路口处转弯，并且如果确定所述前车是在路口处转弯，则拒绝模仿所述前车的所述转弯。所述至少一个处理装置可构造成基于所述多个图像或者基于地图数据和位置信息来确定所述前车是否在路口处转弯、确定所述前车是否在所述路口内变道，如果确定所述前车是在路口处转弯并且在所述路口内不变道则模仿所述前车的所述转弯，并且如果确定所述前车是在路口处转弯但在所述路口内变道则拒绝模仿所述前车的所述转弯。所述至少一个处理装置可构造成：基于所述多个图像来获取第一前车，基于所述多个图像来获取第二前车，并且如果基于所述多个图像确定所述第一前车继续行进的路径的转弯半径小于所述第二前车跟随的路径，则致使所述主车辆模仿所述第一前车。所述至少一个处理装置可构造成：确定所述前车的位置信息并且将所述位置信息与预定地图数据比较，通过跟踪所述前车相对于所述预定地图数据的移动为所述前车创建导航历史，并且基于所述前车的所述导航历史来确定是否致使所述主车辆模仿所述前车的所述至少一个动作。所述至少一

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个处理装置可构造成：当所述导航历史指示所述前车已成功导航至少一个前转弯时，甚至在基于所述多个图像未检测到转弯的情况下，致使所述主车辆模仿所述前车的转弯。

[0025] 与另一公开的实施方式相一致，提供了一种用于导航主车辆的方法。所述方法可包括：使用至少一个图像捕获装置来获取主车辆附近区域的多个图像；根据所述多个图像中的至少一些图像来确定在所述主车辆的第一侧上的第一车道约束；根据所述多个图像中的至少一些图像来确定在与所述主车辆的所述第一侧相反的所述主车辆的第二侧上的第二车道约束，其中所述第一车道约束和第二车道约束限定所述主车辆行进的车道；致使所述主车辆在所述第一车道约束和第二车道约束内行进；在所述多个图像中定位前车；基于所述多个图像来确定所述前车采取的至少一个动作；以及致使所述主车辆模仿所述前车的所述至少一个动作。

[0026] 与公开的实施方式相一致，提供了一种用于用户车辆的驾驶员辅助导航系统。所述系统可包括：至少一个图像捕获装置，所述至少一个图像捕获装置被构造成获取用户车辆附近区域的多个图像；数据接口；以及至少一个处理装置。所述至少一个处理装置可构造成：经由所述数据接口接收所述多个图像；根据所述多个图像确定在所述用户车辆的第一侧上的第一车道约束；根据所述多个图像确定在与所述用户车辆的所述第一侧相反的所述用户车辆的第二侧上的第二车道约束，其中所述第一车道约束和第二车道约束限定所述用户车辆行进的车道；基于所述多个图像来获取目标车辆；如果确定所述目标车辆行进的车道不同于所述用户车辆行进的车道则使所述用户车辆能够超越所述目标车辆；基于所述多个图像来监测所述目标车辆的位置；以及如果确定所述目标车辆正进入所述用户车辆行进的车道，则致使所述用户车辆在完成所述超越之前中止所述超越。

[0027] 与公开的实施方式相一致，致使所述用户车辆中止所述超越的步骤可包括致使施加所述用户车辆中的制动器。致使所述用户车辆中止所述超越的步骤可包括产生语音通知。致使所述用户车辆中止所述超越的步骤可包括致使所述用户车辆停止加速。监测所述目标车辆的位置的步骤可包括估算所述目标车辆的速度。所述第一车道约束和第二车道约束中的至少一个可包括标记在路面上的线、路面的路边和/或路面宽度的确定的中点。

[0028] 与另一公开的实施方式相一致，一种用户车辆可包括：至少一个图像捕获装置，所述至少一个图像捕获装置被构造成获取用户车辆附近区域的多个图像；数据接口；以及至少一个处理装置。所述至少一个处理装置可构造成：经由所述数据接口接收所述多个图像；根据所述多个图像确定在所述用户车辆的第一侧上的第一车道约束；根据所述多个图像确定在与所述用户车辆的所述第一侧相对的所述用户车辆的第二侧上的第二车道约束，其中所述第一车道约束和第二车道约束限定所述用户车辆行进的车道；基于所述多个图像来获取目标车辆；如果确定所述目标车辆行进的车道不同于所述用户车辆行进的车道则使所述用户车辆能够超越所述目标车辆；基于所述多个图像来监测所述目标车辆的位置；以及如果确定所述目标车辆正进入所述用户车辆行进的车道，则致使所述用户车辆在完成所述超越之前中止所述超越。

[0029] 与公开的实施方式相一致，致使所述用户车辆中止所述超越可包括致使施加所述用户车辆中的制动器。致使所述用户车辆中止所述超越可包括产生语音通知。致使所述用户车辆中止所述超越可包括致使所述用户车辆停止加速。监测所述目标车辆的位置可包括估算所述目标车辆的速度。所述第一车道约束和第二车道约束中的至少一个可包括标记在

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路面上的线、路面的路边和/或路面宽度的确定的中点。

[0030] 与另一公开的实施方式相一致，提供了一种用于导航用户车辆的方法。所述方法可包括：使用至少一个图像捕获装置来获取用户车辆附近区域的多个图像；根据所述多个图像确定在所述用户车辆的第一侧上的第一车道约束；根据所述多个图像确定与在所述用户车辆的所述第一侧相反的所述用户车辆的第二侧上的第二车道约束，其中所述第一车道约束和第二车道约束限定所述用户车辆行进的车道；基于所述多个图像来获取目标车辆；如果确定所述目标车辆行进的车道不同于所述用户车辆行进的车道则使所述用户车辆能够超越所述目标车辆；基于所述多个图像来监测所述目标车辆的位置；以及如果确定所述目标车辆正进入所述用户车辆行进的车道，则致使所述用户车辆在完成所述超越之前中止所述超越。

[0031] 与公开的实施方式相一致，致使所述用户车辆中止所述超越的步骤可包括致使施加所述用户车辆中的制动器。致使所述用户车辆中止所述超越的步骤可包括致使所述用户车辆停止加速。所述第一车道约束和第二车道约束中的至少一个可包括标记在路面上的线、路面的路边和/或路面宽度的确定的中点。

[0032] 与公开的实施方式相一致，提供了一种用于用户车辆的驾驶员辅助导航系统。所述系统可包括：至少一个图像捕获装置，所述至少一个图像捕获装置被构造成获取用户车辆附近区域的多个图像；数据接口；以及至少一个处理装置。所述至少一个处理装置可构造成：经由所述数据接口接收所述多个图像；根据所述多个图像确定在所述用户车辆的第一侧上的第一车道约束；根据所述多个图像确定在与所述用户车辆的所述第一侧相反的所述用户车辆的第二侧上的第二车道约束，其中所述第一车道约束和第二车道约束限定所述用户车辆行进的车道；基于所述多个图像来确定是否有侵入车辆从所述用户车辆的一侧接近；以及致使所述用户车辆维持当前速度并且在所述第一车道约束和第二车道约束内行进，使得在所述用户车辆的所述侵入车辆正接近的那一侧的第一距离大于第二距离。

[0033] 与公开的实施方式相一致，所述至少一个处理装置可进一步构造成如果对所述多个图像的分析指示所述侵入车辆已越过至少一个碰撞阈值则致使所述用户车辆采取躲避动作。所述躲避动作可包括变道、变动路线和/或制动。所述至少一个碰撞阈值可包括在所述用户车辆与所述侵入车辆之间维持的最小预定距离。所述至少一个碰撞阈值可包括将要碰撞的时间。所述至少一个处理装置可构造成在完成所述躲避动作之后致使所述用户车辆返回到所述用户车辆最初行进的车道的中央。所述至少一个图像捕获装置可具有至少140度的视场。所述至少一个处理装置可构造成在响应于侵入车辆进行制动之后致使所述用户车辆恢复预设速度。所述至少一个处理装置可构造成致使所述用户车辆返回到所述第一车道约束和第二车道约束内的车道地点，使得在响应于侵入车辆而变动路线之后，所述用户车辆与所述第一车道约束之间的所述第一距离基本上等于所述用户车辆与所述第二车道约束之间的所述第二距离。

[0034] 与另一公开的实施方式相一致，一种用户车辆可包括：至少一个图像捕获装置，所述至少一个图像捕获装置被构造成获取用户车辆附近区域的多个图像；数据接口；以及至少一个处理装置。所述至少一个处理装置可构造成：经由所述数据接口接收所述多个图像；根据所述多个图像确定在所述用户车辆的第一侧上的第一车道约束；根据所述多个图像确定在与所述用户车辆的所述第一侧相反的所述用户车辆的第二侧上的第二车道约束，其中

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所述第一车道约束和第二车道约束限定所述用户车辆行进的车道;基于所述多个图像来确定是否有侵入车辆从所述用户车辆的一侧接近;以及致使所述用户车辆维持当前速度并且在所述第一车道约束和第二车道约束内行进,使得在所述用户车辆的所述侵入车辆正接近的那一侧的第一距离大于第二距离。

[0035] 与公开的实施方式相一致,所述至少一个处理装置可进一步构造成如果所述对多个图像的分析指示所述侵入车辆已越过至少一个碰撞阈值则致使所述用户车辆采取躲避动作。所述躲避动作可包括变道、变动路线和/或制动。所述至少一个碰撞阈值可包括在所述用户车辆与所述侵入车辆之间维持的最小预定距离。所述至少一个碰撞阈值可包括将要碰撞的时间。所述至少一个处理装置可构造成在完成所述躲避动作之后致使所述用户车辆返回到所述用户车辆最初行进的车道的中央。所述至少一个图像捕获装置可具有至少140度的视场。所述至少一个处理装置可构造成在响应于侵入车辆进行制动之后致使所述用户车辆恢复预设速度。所述至少一个处理装置可构造成致使所述用户车辆返回到所述第一车道约束和第二车道约束内的车道地点,使得在响应于侵入车辆而变动路线之后,所述用户车辆与所述第一车道约束之间的所述第一距离基本上等于所述用户车辆与所述第二车道约束之间的所述第二距离。

[0036] 与另一公开的实施方式相一致,提供了一种用于导航用户车辆的方法。所述方法可包括:使用至少一个图像捕获装置来获取用户车辆附近区域的多个图像;根据所述多个图像确定在所述用户车辆的第一侧上的第一车道约束;根据所述多个图像确定在与所述用户车辆的所述第一侧相反的所述用户车辆的第二侧上的第二车道约束,其中所述第一车道约束和第二车道约束限定所述用户车辆行进的车道;基于所述多个图像来确定是否有侵入车辆从所述用户车辆的一侧接近;以及致使所述用户车辆维持当前速度并且在所述第一车道约束和第二车道约束内行进,使得在所述用户车辆的所述侵入车辆正接近的那一侧的第一距离大于第二距离。

[0037] 与公开的实施方式相一致,提供了一种用于主车辆的驾驶员辅助导航系统。所述系统可包括:至少一个图像捕获装置,所述至少一个图像捕获装置被构造成获取主车辆附近区域的多个图像;数据接口;以及至少一个处理装置。所述至少一个处理装置可构造成:经由所述数据接口接收所述多个图像;识别所述多个图像内的目标对象;经由所述多个图像监测所述目标对象的运动以及所述主车辆与所述目标对象之间的距离;基于监测的运动以及所述主车辆与所述目标对象之间的距离来确定所述主车辆与所述目标对象之间的拦截时间的指示器;以及基于所述拦截时间与多个预定拦截阈值的比较来产生所述主车辆的响应。

[0038] 与公开的实施方式相一致,所述目标对象可以是在与所述主车辆不同的车道中行进的目标车辆。所述拦截时间可基于由所述多个图像确定的被跟踪对象的速度的指示器。所述拦截时间可基于由所述多个图像确定的所述被跟踪对象的加速度的指示器。所述至少一个处理装置可进一步构造成确定所述目标对象是否在与所述主车辆相同的车道中行进,并且如果确定所述目标对象是在与所述主车辆不同的车道中行进则放弃所述主车辆的所述响应。确定所述目标对象是否在与所述主车辆相同的车道中行进可基于所述多个图像。确定所述目标对象是否在与所述主车辆相同的车道中行进可基于所述主车辆的预定地图数据或偏航率中的至少一者。如果拦截时间的所述指示器指示所述目标对象在相对于所述

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车辆的第一拦截阈值的外侧，则所述响应可基于与所述目标对象关联的平均运动轮廓。如果拦截时间的所述指示器指示所述目标对象在相对于所述车辆的所述第一拦截阈值与第二拦截阈值之间，则所述响应可基于所述目标对象的实际运动。如果拦截时间的所述指示器指示所述目标对象在所述第二拦截阈值内，则所述响应可包括紧急避让动作。所述紧急避让动作可包括变道和/或紧急制动。

[0039] 与另一公开的实施方式相一致，一种主车辆可包括：主体；至少一个图像捕获装置，所述至少一个图像捕获装置被构造成获取主车辆附近区域的多个图像；数据接口；以及至少一个处理装置。所述至少一个处理装置可构造成：经由所述数据接口接收所述多个图像；识别所述多个图像内的目标对象；经由所述多个图像监测所述目标对象的运动以及所述主车辆与所述目标对象之间的距离；基于监测的运动以及所述主车辆与所述目标对象之间的距离来确定所述主车辆与所述目标对象之间的拦截时间的指示器；以及基于所述拦截时间与多个预定拦截阈值的比较来产生所述主车辆的响应。

[0040] 与公开的实施方式相一致，所述目标对象可以是在与所述主车辆不同的车道中行进的目标车辆。所述拦截时间可基于由所述多个图像确定的被跟踪对象的速度的指示器。所述拦截时间可基于由所述多个图像确定的所述被跟踪对象的加速度的指示器。所述至少一个处理装置可进一步构造成确定所述目标对象是否在与所述主车辆相同的车道中行进，并且如果确定所述目标对象是在与所述主车辆不同的车道中行进则放弃所述主车辆的所述响应。确定所述目标对象是否在与所述主车辆相同的车道中行进可基于所述多个图像。确定所述目标对象是否在与所述主车辆相同的车道中行进可基于所述主车辆的预定地图数据或偏航率中的至少一者。如果拦截时间的所述指示器指示所述目标对象在相对于所述车辆的第一拦截阈值的外侧，则所述响应可基于与所述目标对象关联的平均运动轮廓。如果拦截时间的所述指示器指示所述目标对象在相对于所述车辆的所述第一拦截阈值与第二拦截阈值之间，则所述响应可基于所述目标对象的实际运动。如果拦截时间的所述指示器指示所述目标对象在所述第二拦截阈值内，则所述响应可包括紧急避让动作。所述紧急避让动作可包括变道和/或紧急制动。

[0041] 与另一公开的实施方式相一致，一种用于导航主车辆的方法可包括：经由至少一个图像捕获装置获取主车辆附近区域的多个图像；识别所述多个图像内的目标对象；基于所述多个图像来监测所述目标对象的运动以及所述主车辆与所述目标对象之间的距离；基于监测的运动以及所述主车辆与所述目标对象之间的距离来确定所述主车辆与所述目标对象之间的拦截时间的指示器；以及基于所述拦截时间与多个预定拦截阈值的比较来产生所述主车辆的响应。

[0042] 与公开的实施方式相一致，提供了一种用于车辆的驾驶员辅助导航系统。所述系统可包括：至少一个图像捕获装置，所述至少一个图像捕获装置被构造成获取车辆附近区域的多个图像；数据接口；以及至少一个处理装置。所述至少一个处理装置可构造成：经由所述数据接口接收所述多个图像；基于所述多个图像的分析来识别用于停止所述车辆的触发器；以及基于识别的所述触发器，根据制动轮廓来致使所述车辆停止，如基于对所述多个图像的分析确定的，所述制动轮廓包括与第一减速率关联的第一区段、具有小于所述第一减速率的第二减速率的第二区段以及在接近目标停止地点时使制动水平降低的第三区段。

[0043] 与公开的实施方式相一致，到达所述目标停止地点可伴随着制动压力的释放。所

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述触发器可包括对象。所述对象可包括所述车辆前方的另一车辆。所述触发器可包括交通灯信号、停止标志和/或限速标志。所述至少一个处理装置可进一步构造成提供识别所述触发器的语音通知。所述至少一个处理装置可构造成产生指示所述车辆正制动的语音通知。

[0044] 与另一公开的实施方式相一致，一种车辆可包括：主体；至少一个图像捕获装置，所述至少一个图像捕获装置被构造成获取车辆附近区域的多个图像；数据接口；以及至少一个处理装置。所述至少一个处理装置可构造成：经由所述数据接口接收所述多个图像；基于对所述多个图像的分析来识别用于停止所述车辆的触发器；以及基于识别的所述触发器，根据制动轮廓来致使所述车辆停止，如基于所述多个图像的分析确定的，所述制动轮廓包括与第一减速率关联的第一区段、具有小于所述第一减速率的第二减速率的第二区段以及在接近目标停止地点时使制动水平降低的第三区段。

[0045] 与公开的实施方式相一致，到达所述目标停止地点可伴随着制动压力的释放。所述触发器可包括对象。所述对象可包括所述车辆前方的另一车辆。所述触发器可包括交通灯信号、停止标志和/或限速标志。所述至少一个处理装置可进一步构造成提供识别所述触发器的语音通知。所述至少一个处理装置可构造成产生指示所述车辆正制动的语音通知。

[0046] 与另一公开的实施方式相一致，提供了一种用于导航车辆的方法。所述方法可包括：经由至少一个图像捕获装置获取车辆附近区域的多个图像；基于对所述多个图像的分析来识别用于停止所述车辆的触发器；以及基于识别的所述触发器，根据制动轮廓来致使所述车辆停止，如基于所述多个图像的分析确定的，所述制动轮廓包括与第一减速率关联的第一区段、具有小于所述第一减速率的第二减速率的第二区段以及在接近目标停止地点时使制动水平降低的第三区段。

[0047] 与其它公开的实施方式相一致，非临时性计算机可读的存储介质可存储程序指令，该程序指令由至少一个处理装置执行并且执行本文中描述的任何方法。

[0048] 前面的总体描述和以下详细描述仅是示例性和说明性的并不限制权利要求书。

附图说明

[0049] 并入本公开并构成本公开一部分的附图图示了各种公开的实施方式。在图中：

[0050] 图1是与公开的实施方式相一致的示例性系统的概略表示。

[0051] 图2A是包括与公开的实施方式相一致的系统的示例性车辆的概略侧视图表示。

[0052] 图2B是与公开的实施方式相一致的图2A所示车辆和系统的概略顶视图表示。

[0053] 图2C是包括与公开的实施方式相一致的系统的车辆的另一实施方式的概略顶视图表示。

[0054] 图2D是包括与公开的实施方式相一致的系统的车辆的又一实施方式的概略顶视图表示。

[0055] 图2E是包括与公开的实施方式相一致的系统的车辆的又一实施方式的概略顶视图表示。

[0056] 图2F是与公开的实施方式相一致的示例性车辆控制系统的概略表示。

[0057] 图3A是与公开的实施方式相一致的车辆的内部的概略表示，包括用于车辆成像系统的后视镜和用户接口。

[0058] 图3B是与公开的实施方式相一致的构造成定位在后视镜后面并且抵着车辆挡风

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玻璃的相机安装件的示例的图示。

[0059] 图3C是与公开的实施方式相一致的图3B所示的视角不同的相机安装件的图示。

[0060] 图3D是与公开的实施方式相一致的构造成定位在后视镜后面并且抵着车辆挡风玻璃的相机安装件的示例的图示。

[0061] 图4是与公开的实施方式相一致的构造成存储用于执行一个或多个操作的指令的存储器的示例性框图。

[0062] 图5A是示出与公开的实施方式相一致的用于基于单眼图像分析来产生一个或多个导航响应的示例性过程的流程图。

[0063] 图5B是示出与公开的实施方式相一致的用于检测一组图像中的一个或多个车辆和/或行人的示例性过程的流程图。

[0064] 图5C是示出与公开的实施方式相一致的用于检测一组图像中的路标和/或车道几何信息的示例性过程的流程图。

[0065] 图5D是示出与公开的实施方式相一致的用于检测一组图像中的交通灯的示例性过程的流程图。

[0066] 图5E是示出与公开的实施方式相一致的用于基于车辆路径来产生一个或多个导航响应的示例性过程的流程图。

[0067] 图5F是示出与公开的实施方式相一致的用于确定前车是否变道的示例性过程的流程图。

[0068] 图6是示出与公开的实施方式相一致的用于基于立体图像分析来产生一个或多个导航响应的示例性过程的流程图。

[0069] 图7是示出与公开的实施方式相一致的用于基于三组图像分析来产生一个或多个导航响应的示例性过程的流程图。

[0070] 图8A是与公开的实施方式相一致的在第一车道约束和第二车道约束内行进的示例性车辆的概略表示，其中车道偏移条件存在于第一车辆侧。

[0071] 图8B是与公开的实施方式相一致的在第一车道约束和第二车道约束内行进的示例性车辆的概略表示，其中车道偏移条件存在于第二车辆侧。

[0072] 图8C是与公开的实施方式相一致的在弯路上的第一车道约束和第二车道约束内行进的示例性车辆的概略表示。

[0073] 图8D是与公开的实施方式相一致的在第一车道约束和第二车道约束内行进的示例性车辆的概略表示，其中车道偏移条件存在于第一车辆侧和第二车辆侧两者上。

[0074] 图9是与公开的实施方式相一致的示例性导航系统的存储器的概略表示。

[0075] 图10是与公开的实施方式相一致的用于导航车辆的示例性方法的流程图。

[0076] 图11是与公开的实施方式相一致的在默认车道内行进包括导航系统的示例性车辆的概略表示。

[0077] 图12A是与公开的实施方式相一致的示例性导航系统的存储器的概略表示。

[0078] 图12B是与公开的实施方式相一致的用于导航车辆的示例性过程的流程图。

[0079] 图13A和图13B是与公开的实施方式相一致的接近以及导航具有一个或多个特性的弯道的示例性车辆的概略表示。

[0080] 图14是与公开的实施方式相一致的构造成存储用于执行一个或多个操作的指令

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的存储器的示例性框图。

[0081] 图15是示出与公开的实施方式相一致的用于基于被检测弯道和观察的弯道特性来控制车辆速度的示例性过程的流程图。

[0082] 图16A至图16D是与公开的实施方式相一致的模仿前车一个或多个动作的主车辆的概略表示。

[0083] 图17是与公开的实施方式相一致的构造成存储用于执行一个或多个操作的指令的存储器的示例性框图。

[0084] 图18是示出与公开的实施方式相一致的用于致使主车辆模仿前车一个或多个动作的示例性过程的流程图。

[0085] 图19是示出与公开的实施方式相一致的用于致使主车辆拒绝模仿前车转弯的示例性过程的流程图。

[0086] 图20是示出与公开的实施方式相一致的用于致使主车辆模仿或拒绝前车转弯的示例性过程的流程图。

[0087] 图21是示出与公开的实施方式相一致的用于致使主车辆模仿前车一个或多个动作的另一示例性过程的流程图。

[0088] 图22是示出与公开的实施方式相一致的用于基于导航历史来致使主车辆模仿前车一个或多个动作的示例性过程的流程图。

[0089] 图23是与公开的实施方式相一致的在另一车辆行进所沿着的道路上的第一车道约束和第二车道约束内行进的示例性车辆的概略表示。

[0090] 图24A是与公开的实施方式相一致的存储用于在侵入车辆之中导航车辆的指令的存储器的概略表示。

[0091] 图24B是与公开的实施方式相一致的用于在侵入车辆之中导航车辆的示例性过程的流程图。

[0092] 图25是与公开的实施方式相一致的在另一车辆行进所沿着的道路上的第一车道约束和第二车道约束内行进的示例性车辆的概略表示。

[0093] 图26是与公开的实施方式相一致的存储用于检测以及响应于车辆交通侧向侵入的指令的存储器的概略表示。

[0094] 图27是与公开的实施方式相一致的用于检测以及响应于车辆交通侧向侵入的示例性过程的流程图。

[0095] 图28A和图28B是与公开的实施方式相一致的产生主车辆响应的概略表示。

[0096] 图29是与公开的实施方式相一致的构造成存储用于执行一个或多个操作的指令的存储器的示例性框图。

[0097] 图30是示出与公开的实施方式相一致的用于产生主车辆响应的示例性过程的流程图。

[0098] 图31是示出与公开的实施方式相一致的用于拒绝产生主车辆响应的示例性过程的流程图。

[0099] 图32A是与公开的实施方式相一致的使对象存在于车辆附近的示例性车辆的概略表示。

[0100] 图32B图示了与公开的实施方式相一致的示例性制动轮廓。

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[0101] 图33是与公开的实施方式相一致的示例性导航系统的存储器的概略表示。

[0102] 图34是与公开的实施方式相一致的用于在导航车辆的同时实施制动轮廓的示例性方法的流程图。

具体实施方式

[0103] 以下详细描述参照附图。在可能的情况下，相同的附图标记在图中和以下描述中用来指相同或类似的部分。虽然本文中描述了若干说明性实施方式，但是可以进行修改、改写及其它实施。例如，对图中图示的部件可做出替换、添加或修改，并且本文中描述的说明性方法可通过将步骤替换、重新排序、移除或添加至公开的方法进行修改。因此，以下详细描述并不限于公开的实施方式和示例。相反，适当范围由所附权利要求限定。

[0104] 公开的实施方式提供使用相机来提供自主导航特征的系统和方法。在各种实施方式中，所述系统可包括监测车辆的环境的一个、两个或更多个相机。在一个实施方式中，所述系统可监测并调整车辆与车道边界之间的自由空间，车辆在所述车道内行进。在另一实施方式中，所述系统可选择特定车道作为车辆在行进同时使用的默认车道。在另一实施方式中，所述系统可控制车辆在不同场景(诸如转弯时)中的速度。在又一实施方式中，所述系统可模仿前车的动作。在又一实施方式中，所述系统可监测目标车辆并且在某些条件下(例如，如果目标车辆行进的车道不同于所述车辆行进的车道)使所述车辆能够超越目标车辆。在再一实施方式中，所述系统可响应于侧向侵入车辆(诸如试图进入所述车辆行进的车道中的车辆)来产生自然感觉。

[0105] 图1是与示例性公开的实施方式相一致的系统100的框图表示。取决于特定实施的要求，系统100可包括各种部件。在一些实施方式中，系统100可包括处理单元110、图像获取单元120、位置传感器130、一个或多个存储器单元140、150、地图数据库160和用户接口170。处理单元110可包括一个或多个处理装置。在一些实施方式中，处理单元110可包括应用处理器180、图像处理器190或任何其它合适的处理装置。类似地，取决于特定应用的要求，图像获取单元120可包括任何数目的图像获取装置和部件。在一些实施方式中，图像获取单元120可包括一个或多个图像捕获装置(例如，相机)，诸如图像捕获装置122、图像捕获装置124和图像捕获装置126。系统100可还包括数据接口128，该数据接口128将处理装置110和图像获取装置120通信连接。例如，数据接口128可包括用于将由图像获取装置120获取的图像数据发送到处理单元110的任何一个或多个有线和/或无线链路。

[0106] 应用处理器180和图像处理器190两者均可包括各种类型的处理装置。例如，应用处理器180和图像处理器190中的任一者或两者可包括微处理器、预处理器(诸如图像预处理器)、图形处理器、中央处理单元(CPU)、支持电路、数字信号处理器、集成电路、存储器或适于运行应用程序以及图像处理和分析的任何其它类型的装置。在一些实施方式中，应用处理器180和/或图像处理器190可包括任何类型的单核或多核处理器、移动装置微控制器、中央处理单元，等等。可使用各种处理装置，包括例如可购自诸如Intel®、AMD®等等制造商的处理器，并且可包括各种结构(例如，x86处理器、ARM®，等等)。

[0107] 在一些实施方式中，应用处理器180和/或图像处理器190可包括任何可购自Mobileye®的EyeQ系列处理器芯片。这些处理器设计各包括具有本地存储器和指令集的多处理单元。这样的处理器可包括用于接收来自多个图像传感器的图像数据的视频输入，并

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且还可包括视频输出功能。在一个示例中，EyeQ2®使用在332Mhz下操作的90纳米微米技术。EyeQ2®结构组成如下：两个浮点、超线程32位RISC CPU(MIPS32® 34K®核)、五个视觉计算引擎(VCE)、三个矢量微码处理器(VMP®)、Denali 64位移动DDR控制器、128位内部超音速互连、双16位视频输入控制器和18位视频输出控制器、16通道DMA以及若干外设。MIPS34K CPU管理五个VCE、三个VMP™和DMA、第二MIPS34K CPU和多通道DMA以及其它外设。五个VCE、三个VMP®和MIPS34K CPU可以执行多功能捆绑应用程序所需要的密集的视觉计算。在另一示例中，为第三代处理器并且比EyeQ2®强大六倍的EyeQ3®可在公开的实施方式中使用。

[0108] 虽然图1描绘了包括在处理单元110中的两个分离处理装置，但是可使用或多或少的处理装置。例如，在一些实施方式中，单个处理装置可用于完成应用处理器180和图像处理器190的任务。在其它实施方式中，这些任务可由多于两个处理装置执行。

[0109] 处理单元110可包括各种类型的装置。例如，处理单元110可包括各种装置，诸如控制器、图像预处理器、中央处理单元(CPU)、支持电路、数字信号处理器、集成电路、存储器或任何其它类型的用于图像处理和分析的装置。图像预处理器可包括用于捕获、数字化并处理来自图像传感器的图像的视频处理器。CPU可包括任何数目的微控制器或微处理器。支持电路可以是本领域普遍公知的任何数目的电路，包括高速缓存、电源、时钟和输入输出电路。存储器可存储软件，该软件当由处理器执行时会控制系统的操作。存储器可包括数据库和图像处理软件。存储器可包括任何数目的随机存取存储器、只读存储器、闪速存储器、盘驱动器、光学存储介质、磁带存储介质、可去除存储介质及其它类型的存储介质。在一个实例中，存储器可从处理单元110分离。在另一实例中，存储器可集成到处理单元110中。

[0110] 每个存储器140、150可包括软件指令，该软件指令当由处理器(例如，应用处理器180和/或图像处理器190)执行时可控制系统100的各方面的操作。这些存储器单元可包括各种数据库和图像处理软件。存储器单元可包括随机存取存储器、只读存储器、闪速存储器、盘驱动器、光学存储介质、磁带存储介质、可去除存储介质和/或任何其它类型的存储介质。在一些实施方式中，存储器单元140、150可从应用处理器180和/或图像处理器190分离。在其它实施方式中，这些存储器单元可集成到应用处理器180和/或图像处理器190中。

[0111] 位置传感器130可包括适于确定与系统100的至少一个部件关联的地点的任何类型的装置。在一些实施方式中，位置传感器130可包括GPS接收器。这样的接收器可以通过处理全球定位系统卫星传播的信号来确定用户位置和速度。来自位置传感器130的位置信息可供应用处理器180和/或图像处理器190使用。

[0112] 用户接口170可包括适于向来自系统100的一个或多个用户的输入提供信息或者用于接收所述输入的任何装置。在一些实施方式中，用户接口170可包括用户输入装置，包括例如触摸屏、麦克风、键盘、指针装置、跟踪轮、相机、旋钮、按钮，等等。在这样的输入装置的情况下，用户能够通过以下手段向系统100提供信息输入或命令：键入指令或信息、提供语音命令、使用按钮、指针或眼跟踪功能在屏幕上选择菜单选项或者用于将信息与系统100通信的任何其它合适的技术。

[0113] 用户接口170可配备有一个或多个处理装置，该一个或多个处理装置被构造成向用户提供信息或从用户接收信息并且处理该信息以供例如应用处理器180使用。在一些实施方式中，这样的处理装置可执行指令以辨识并跟踪眼移动、接收并解译语音命令、辨识并

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解译在触摸屏上做出的触摸和/或手势、响应于键盘输入或菜单选择，等等。在一些实施方式中，用户接口170可包括显示器、扬声器、触觉装置和/或用于向用户提供输出信息的任何其它装置。

[0114] 地图数据库160可包括用于存储对系统100有用的地图数据的任何类型的数据库。在一些实施方式中，地图数据库160可包括各种条目的在参考坐标系中与位置相关的数据，所述条目包括道路、水特征、地理特征、企业、关注点、餐厅、加油站，等等。地图数据库160不仅可存储这样的条目的地点，而且可存储与这些条目相关的描述词(包括例如，与任何存储特征关联的名称)。在一些实施方式中，地图数据库160可与系统100的其它部件物理定位。替代地或另外，地图数据库160或其一部分可相对于系统100的其它部件(例如，处理单元110)远程定位。在这样的实施方式中，来自地图数据库160的信息可通过网络的有线或无线数据连接(例如，通过蜂窝网络和/或因特网，等等)下载。

[0115] 图像捕获装置122、124和126可各包括适于从环境中捕获至少一个图像的任何类型的装置。而且，任何数目的图像捕获装置可用于获取图像以输入到图像处理器。一些实施方式可仅包括单个图像捕获装置，而其它实施方式可包括两个、三个或者甚至四个以上图像捕获装置。图像捕获装置122、124和126将在下面参照图2B至图2E进一步描述。

[0116] 系统100或其各种部件可整合到各种不同的平台中。在一些实施方式中，系统100可包括在如图2A所示的车辆200上。例如，如上面相对于图1描述的，车辆200可配备有处理单元110和系统100的任何其它部件。而在一些实施方式中，车辆200可仅配备有单个图像捕获装置(例如，相机)，在诸如结合图2B至图2E讨论的其它实施方式中，可使用多个图像捕获装置。例如，如图2A所示的车辆200的图像捕获装置122和124中的任一者可以是ADAS(先进驾驶员辅助系统)成像组的一部分。

[0117] 包括在车辆200上作为图像获取单元120的一部分的图像捕获装置可定位在任何合适的地点处。在一些实施方式中，如图2A至图2E和图3A至图3C所示，图像捕获装置122可位于后视镜附近。该位置可提供视线(类似于车辆200的驾驶员的视线)，可帮助确定对驾驶员而言什么是可见的，什么是不可见的。图像捕获装置122可定位在后视镜附近的任何地点处，但将图像捕获装置122放置在镜子的在驾驶员的那一侧上可进一步帮助获得表示驾驶员视场和/或视线的图像。

[0118] 针对图像获取单元120的图像捕获装置，还可使用其它地点。例如，图像捕获装置124可位于车辆200的保险杠之上或之中。这样的地点可尤其适合具有宽视场的图像捕获装置。位于保险杠上的图像捕获装置的视线可以不同于驾驶员的视线，因此，保险杠图像捕获装置和驾驶员可能并不总是看到相同的对象。图像捕获装置(例如，图像捕获装置122、124和126)也可位于其它地点中。例如，图像捕获装置可位于车辆200的一个或两个侧视镜之上或之中、车辆200的车顶上、车辆200的发动机罩上、车辆200的行李箱上、车辆200的侧面，安装在车辆200的任何窗口上、定位在车辆200的任何窗口的后面或前面，以及安装在车辆200的正面和/或背面的光图之中或附近，等等。

[0119] 除了图像捕获装置，车辆200可包括系统100的各种其它部件。例如，处理单元110可包括在车辆200上，与车辆的发动机控制单元(ECU)或者集成或者分离。车辆200还可配备有诸如GPS接收器的位置传感器130，并且还可包括地图数据库160以及存储器单元140和150。

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[0120] 图2A是与公开的实施方式相一致的示例性车辆成像系统的概略侧视图表示。图2B是图2A所示的实施方式的概略顶视图图示。如图2B中图示的，公开的实施方式可包括车辆200，车辆200在其主体中包括系统100，系统100具有定位在后视镜附近和/或车辆200的驾驶员附近的第一图像捕获装置122、定位在车辆200的保险杠区域(例如，保险杠区域210中的一个)之上或之中的第二图像捕获装置124，以及处理单元110。

[0121] 如图2C中图示的，图像捕获装置122和124两者均可定位在后视镜附近和/或车辆200的驾驶员附近。另外，虽然在图2B和图2C中示出了两个图像捕获装置122和124，但是应该理解的是，其它实施方式可包括多于两个图像捕获装置。例如，在图2D和图2E示出的实施方式中，第一图像捕获装置122，第二图像捕获装置124和第三图像捕获装置126被包括在车辆200的系统100中。

[0122] 如图2D中图示的，图像捕获装置122可定位在后视镜附近和/或车辆200的驾驶员附近，并且图像捕获装置124和126可定位在车辆200的保险杠区域(例如，保险杠区域210中的一个)之上或之中。并且如图2E所示，图像捕获装置122、124和126可定位在后视镜附近和/或车辆200的驾驶员座椅附近。公开的实施方式并不限于任何特定数目和构造的图像捕获装置，并且图像捕获装置可定位在车辆200内和/或上的任何适当的地点中。

[0123] 应理解的是，公开的实施方式并不限于车辆并且可以应用在其它背景中。还应理解的是，公开的实施方式并不限于特定类型的车辆200并且可应用于所有类型的车辆，包括汽车、卡车、拖车和其它类型的车辆。

[0124] 第一图像捕获装置122可包括任何合适类型的图像捕获装置。图像捕获装置122可包括光轴。在一个实例中，图像捕获装置122可包括具有全局快门的Aptina M9V024WVGA传感器。在其它实施方式中，图像捕获装置122可提供1280x960像素的分辨率并且可包括卷帘快门。图像捕获装置122可包括各种光学元件。在一些实施方式中，例如，可包括一个或多个透镜，为图像捕获装置提供期望的焦距和视场。在一些实施方式中，图像捕获装置122可与6mm透镜或12mm透镜关联。在一些实施方式中，如图2D中图示的，图像捕获装置122可构造成捕获具有期望视场(FOV)202的图像。例如，图像捕获装置122可构造成具有常规的FOV，诸如在40度到56度的范围内，包括46度FOV、50度FOV、52度FOV以上。替代地，图像捕获装置122可构造成具有23度到40度范围内的窄FOV，诸如28度FOV或36度FOV。另外，图像捕获装置122可构造成具有100度到180度范围内的宽FOV。在一些实施方式中，图像捕获装置122可包括宽角度的保险杠相机或者具有直到180度FOV。

[0125] 第一图像捕获装置122可相对于与车辆200关联的场景获取多个第一图像。多个第一图像中的每个均可被获取，作为可使用卷帘快门捕获的一系列图像扫描线。每个扫描线均可包括多个像素。

[0126] 第一图像捕获装置122可具有与获取第一系列图像扫描线中的每个关联的扫描速率。扫描速率可指这样的速率，即在所述速率下，图像传感器可以获取与包括在特定扫描线中的每个像素关联的图像数据。

[0127] 例如，图像捕获装置122、124和126可包含任何合适类型和数目的图像传感器，包括CCD传感器或CMOS传感器。在一个实施方式中，CMOS图像传感器可连同卷帘快门一起采用，使得一行中的每个像素一次读取一个，并且该行的扫描在一行接一行的基础上进行，直到整个图像帧已被捕获。在一些实施方式中，该行可相对于帧从上到下依次捕获。

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[0128] 使用卷帘快门可导致不同行中的像素在不同的时间被曝光并被捕获，这可致使被捕获的图像帧的歪斜和其它图像伪影。另一方面，当图像捕获装置122被构造成用全局或同步快门操作时，所有像素都可曝光持续相同的时间量并且在共同的曝光周期中。结果是，从采用全局快门的系统中收集的帧的图像数据表示整个FOV(诸如FOV 202)在特定时间的快照。对比之下，在卷帘快门应用中，帧中的每行均被曝光，并且数据在不同的时间被捕获。由此，移动的对象可能在具有卷帘快门的图像捕获装置中呈现失真。该现象将在下面更详细地描述。

[0129] 第二图像捕获装置124和第三图像捕获装置126可以是任何类型的图像捕获装置。如同第一图像捕获装置122，图像捕获装置124和126中的每个均可包括光轴。在一个实施方式中，图像捕获装置124和126中的每个均可包括具有全局快门的Aptina M9V024 WVGA传感器。替代地，图像捕获装置124和126中的每个均可包括卷帘快门。如同图像捕获装置122，图像捕获装置124和126可构造成包括各种透镜和光学元件。在一些实施方式中，与图像捕获装置124和126关联的透镜可提供等于或窄于与图像捕获装置122关联的FOV(诸如FOV 202)的FOV(诸如FOV 204和206)。例如，图像捕获装置124和126可具有40度、30度、26度、23度、20度或以下的FOV。

[0130] 图像捕获装置124和126可相对于与车辆200的关联的场景获取多个第二图像和第三图像。多个第二图像和第三图像中的每个均可获取为可使用卷帘快门捕获的第二系列和第三系列的图像扫描线。每个扫描线或行均可具有多个像素。图像捕获装置124和126可具有与获取包括在第二系列和第三系列中的每个图像扫描线关联的第二扫描速率和第三扫描速率。

[0131] 每个图像捕获装置122、124和126均可相对于车辆200定位在任何合适的位置和取向。可选择图像捕获装置122、124和126的相对定位以帮助将从图像捕获装置获取的信息融合到一起。例如，在一些实施方式中，与图像捕获装置124关联的FOV(诸如FOV 204)可与关联图像捕获装置122的FOV(诸如FOV 202)和关联图像捕获装置126的FOV(诸如FOV 206)部分地或完全地地重叠。

[0132] 图像捕获装置122、124和126可位于车辆200上任何合适的相对高度处。在一个实例中，在图像捕获装置122、124和126之间可能存在高度差，这可提供足够的视差信息来实现立体分析。例如，如图2A所示，两个图像捕获装置122和124处于不同的高度处。例如，在图像捕获装置122、124和126之间还可能存在侧向位移差，为处理单元110的立体分析给出额外视差信息。侧向位移差可记作d_x，如图2C和图2D所示。在一些实施方式中，前后位移(例如，范围位移)可能存在于图像捕获装置122、124和126之间。例如，图像捕获装置122可位于图像捕获装置124和/或图像捕获装置126后面的0.5米到2米以上。这种类型的位移可使图像捕获装置之一能够覆盖其它图像捕获装置的潜在盲点。

[0133] 图像捕获装置122可具有任何合适的分辨率功能(例如，与图像传感器关联的像素数目)，并且与图像捕获装置122关联的图像传感器的分辨率可大于、小于或等于与图像捕获装置124和126关联的图像传感器的分辨率。在一些实施方式中，与图像捕获装置122和/或图像捕获装置124和126关联的图像传感器可具有640 x 480、1024 x 768、1280 x 960的分辨率或具有任何其它合适的分辨率。

[0134] 帧速率(例如，在移动到捕获与下一个图像帧关联的像素数据之前图像捕获装置

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获取一个图像帧的一组像素数据的速率)可以是可控的。与图像捕获装置122关联的帧速率可大于、小于或等于与图像捕获装置124和126关联的帧速率。与图像捕获装置122、124和126关联的帧速率可取决于可能影响帧速率的计时的各种因素。例如,图像捕获装置122、124和126中的一个或多个可包括在获取与图像捕获装置122、124和/或126中的图像传感器的一个或多个像素关联的图像数据之前或之后强加的可选像素延迟周期。一般,对应于每个像素的图像数据可根据装置的时钟速率获取(例如,每个时钟周期一个像素)。另外,在包括卷帘快门的实施方式中,图像捕获装置122、124和126中的一个或多个可包括在获取与图像捕获装置122、124和/或126中的图像传感器的一行像素关联的图像数据之前或之后强加的可选水平消隐周期。进一步,图像捕获装置122、124和/或126中的一个或多个可包括在获取与图像捕获装置122、124和126的图像帧关联的图像数据之前或之后强加的可选垂直消隐周期。

[0135] 这些计时控制可使与图像捕获装置122、124和126关联的帧速率同步,甚至当每个图像捕获装置的线扫描速率不同时亦如此。另外,如将在下面更详细地讨论的,在其它因素(例如,图像传感器分辨率、最大线扫描速率,等等)之中,这些可选计时控制可使图像捕获装置122的FOV与图像捕获装置124和126的一个或多个FOV重叠的区域的图像捕获同步,甚至当图像捕获装置122的视场不同于图像捕获装置124和126的FOV时亦如此。

[0136] 图像捕获装置122、124和126的帧速率计时可取决于关联的图像传感器的分辨率。例如,假设两个装置有类似的线扫描速率,如果一个装置包括分辨率为640 x 480的图像传感器并且另一装置包括分辨率为1280 x 960的图像传感器,则将需要更多时间来获取来自具有更高分辨率的传感器的图像数据的帧。

[0137] 可影响图像捕获装置122、124和126的图像数据获取的计时的另一因素是最大线扫描速率。例如,获取包括在图像捕获装置122、124和126中的图像传感器的一行图像数据将需要一些最小时间量。假设没有添加像素延迟周期,则获取一行图像数据的该最小时间量将与特定装置的最大线扫描速率相关。提供较高最大线扫描速率的装置潜在地提供比具有较小最大线扫描速率的装置更大的帧速率。在一些实施方式中,图像捕获装置124和126中的一个或多个的最大线扫描速率可大于与图像捕获装置122关联的最大线扫描速率。在一些实施方式中,图像捕获装置124和/或126的最大线扫描速率可以是图像捕获装置122的最大线扫描速率的1.25倍、1.5倍、1.75倍或2倍以上。

[0138] 在另一实施方式中,图像捕获装置122、124和126可具有相同的最大线扫描速率,但图像捕获装置122可在小于或等于其最大扫描速率的扫描速率下操作。所述系统可构造成使得图像捕获装置124和126中的一个或多个在等于图像捕获装置122的线扫描速率的线扫描速率下操作。在其它实例中,所述系统可构造成使得图像捕获装置124和/或图像捕获装置126的线扫描速率可以是图像捕获装置122的线扫描速率的1.25倍、1.5倍、1.75倍或2倍以上。

[0139] 在一些实施方式中,图像捕获装置122、124和126可以是非对称的。即,它们可包括具有不同视场(FOV)和焦距的相机。例如,图像捕获装置122、124和126的视场可包括相对于车辆200的环境的任何期望区域。在一些实施方式中,图像捕获装置122、124和126中的一个或多个可构造成获取来自车辆200前方、车辆200后方、车辆200侧方或它们的组合的环境的图像数据。

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[0140] 进一步，与每个图像捕获装置122、124和/或126关联的焦距可以是可选的(例如，通过包括适当的透镜等等)，使得每个装置均获取在相对于车辆200的期望距离范围处的对象的图像。例如，在一些实施方式中，图像捕获装置122、124和126可获取距车辆几米内的特写对象的图像。图像捕获装置122、124和126还可构造成获取更远离车辆的范围(例如，25m、50m、100m、150m以上)的对象的图像。进一步，图像捕获装置122、124和126的焦距可选择为使得一个图像捕获装置(例如，图像捕获装置122)可以获取相对接近车辆(例如，10m内或20m内)的对象的图像，而其它图像捕获装置(例如，图像捕获装置124和126)可以获取距车辆200更远的对象(例如，大于20m、50m、100m、150m，等等)的图像。

[0141] 根据一些实施方式，一个或多个图像捕获装置122、124和126的FOV可具有宽角度。例如，尤其对于可用于捕获车辆200附近的区域的图像的图像捕获装置122、124和126，可有利的是具有140度的FOV。例如，图像捕获装置122可用于捕获车辆200右方或左方的区域的图像，并且在这样的实施方式中，图像捕获装置122可期望的是具有宽FOV(例如，至少140度)。

[0142] 与图像捕获装置122、124和126中的每个关联的视场可取决于相应的焦距。例如，随着焦距的增加，对应的视场降低。

[0143] 图像捕获装置122、124和126可构造成具有任何合适的视场。在一个特定示例中，图像捕获装置122可具有46度的水平FOV，图像捕获装置124可具有23度的水平FOV，并且图像捕获装置126可具有介于23度到46度之间的水平FOV。在另一实例中，图像捕获装置122可具有52度的水平FOV，图像捕获装置124可具有26度的水平FOV，并且图像捕获装置126可具有26度到52度之间的水平FOV。在一些实施方式中，图像捕获装置122的FOV与图像捕获装置124和/或图像捕获装置126的FOV的比率可从1.5变化到2.0。在其它实施方式中，该比率可在1.25到2.25之间变化。

[0144] 系统100可构造成使得图像捕获装置122的视场与图像捕获装置124和/或图像捕获装置126的视场至少部分地或完全地重叠。在一些实施方式中，系统100可构造成使得图像捕获装置124和126的视场例如落入(例如，窄于)图像捕获装置122的视场内并且与图像捕获装置122的视场共享共同的中心。在其它实施方式中，图像捕获装置122、124和126可捕获相邻FOV，或者可使它们的FOV部分地重叠。在一些实施方式中，图像捕获装置122、124和126的视场可对准，使得较窄FOV图像捕获装置124和/或126的中心可位于较宽FOV装置122的视场的下半部中。

[0145] 图2F是与公开的实施方式相一致的示例性车辆控制系统的概略表示。如图2F中指示的，车辆200可包括节流系统220、制动系统230和转向系统240。系统100可经一个或多个数据链路(例如，用于发送数据的任何有线和/或无线的一个或多个链路)向节流系统220、制动系统230和转向系统240中的一个或多个提供输入(例如，控制信号)。例如，基于对由图像捕获装置122、124和/或126获取的图像的分析，系统100可向节流系统220、制动系统230和转向系统240中的一个或多个提供控制信号，以(例如，通过致使加速、转弯、车道移位，等等)导航车辆200。进一步，系统100可接收来自节流系统220、制动系统230和转向系统240中的一个或多个的输入，指示车辆200的操作条件(例如，速度，车辆200是否制动和/或转弯，等等)。下面，进一步细节结合图4至图7来提供。

[0146] 如图3A所示，车辆200还可包括用于与车辆200的驾驶员或乘客交互的用户接口

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170。例如，在车辆应用中，用户接口170可包括触摸屏320、旋钮330、按钮340和麦克风350。车辆200的驾驶员或乘客还可使用手柄(例如，位于车辆200的转向柱之上或附近，例如包括转向信号手柄)、按钮(例如，位于车辆200的方向盘上)等，以与系统100交互。在一些实施方式中，麦克风350可定位成与后视镜310相邻。类似地，在一些实施方式中，图像捕获装置122可位于后视镜310附近。在一些实施方式中，用户接口170还可包括一个或多个扬声器360(例如，车辆音频系统的扬声器)。例如，系统100可经由扬声器360提供各种通知(例如，提示)。

[0147] 图3B至图3D是与公开的实施方式相一致的示例性相机安装件370的图示，相机安装件370被构造成定位在后视镜(例如，后视镜310)后面并且抵着车辆挡风玻璃。如图3B所示，相机安装件370可包括图像捕获装置122、124和126。图像捕获装置124和126可定位在遮光板380后面，遮光板380可与车辆挡风玻璃齐平并且包括薄膜和/或抗反射材料的组合物。例如，遮光板380可定位成使得其抵着具有配合斜度的车辆挡风玻璃而对准。在一些实施方式中，例如，如图3D中描绘的，图像捕获装置122、124和126中的每个均可定位在遮光板380后面。公开的实施方式并不限于任何特定构造的图像捕获装置122、124和126、相机安装件370和遮光板380。图3C是图3B中示出的相机安装件370从正面视角的图示。

[0148] 如受益于本公开的本领域技术人员将了解的，对于前面的公开的实施方式可做出许多变型和/或修改。例如，并非所有部件对于系统100的操作都是至关重要的。进一步，任何部件都可位于系统100的任何适当的部分中，并且所述部件可重新布置成各种构造，同时提供公开的实施方式的功能性。因此，前面的构造是示例并且与上面讨论的构造无关，系统100可以提供宽范围的功能性，用以分析车辆200的周边环境并且响应于所述分析来导航车辆200。

[0149] 如下面进一步详细地讨论且与各种公开的实施方式相一致，系统100可提供与自主驱动和/或驾驶员辅助技术相关的各种特征。例如，系统100可分析图像数据、位置数据(例如，GPS地点信息)、地图数据、速度数据和/或来自包括在车辆200中的传感器的数据。系统100可收集来自例如图像获取单元120、位置传感器130及其它传感器的数据以供分析。进一步，系统100可分析所收集的数据以确定车辆200是否应该采取某些动作，然后在无人为干预的情况下自动采取确定的动作。例如，当车辆200在无人为干预的情况下导航时，系统100可(例如，通过向节流系统220、制动系统230和转向系统240中的一个或多个发送控制信号)自动控制车辆200的制动、加速和/或转向。进一步，系统100可分析所收集的数据并发出警告，和/或基于所收集的数据的分析来提示车辆驾乘人员。

[0150] 进一步，与公开的实施方式相一致，由系统100提供的功能性可致使车辆200采取不同的动作以在车道内和/或相对于其它车辆和/或对象来导航车辆200。例如，系统100可调整车辆200相对于车辆200行进的车道和/或相对于定位在车辆200附近的对象的定位，针对车辆200选择特定车道以在行进的同时使用，并且响应于侵入车辆(诸如试图进入车辆200行进的车道中的车辆)采取动作。另外，系统100可控制车辆200在不同场景(诸如当车辆200进行转弯时)下的速度。系统100可进一步致使车辆200模仿前车的动作或监测目标车辆，并且导航车辆200使之超越目标车辆。下面提供关于系统100所提供的各种实施方式的额外细节。

[0151] 朝前多成像系统

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[0152] 如上面讨论的，系统100可提供使用多相机系统的驱动辅助功能性。多相机系统可使用面对车辆向前方向的一个或多个相机。在其它实施方式中，多相机系统可包括面对车辆侧面或车辆后面的一个或多个相机。在一个实施方式中，例如，系统100可使用双相机成像系统，其中第一相机和第二相机(例如，图像捕获装置122和124)可定位在车辆(例如，车辆200)的前面和/或侧面。第一相机的视场可大于、小于第二相机的视场，或者与第二相机的视场部分地重叠。另外，第一相机可连接到第一图像处理器，以执行第一相机所提供的图像的单眼图像分析，并且第二相机可连接到第二图像处理器，以执行第二相机所提供的图像的单眼图像分析。第一图像处理器和第二图像处理器的输出(例如，处理后的信息)可组合。在一些实施方式中，第二图像处理器可接收来自第一相机和第二相机两者的图像以执行立体分析。在另一实施方式中，系统100可使用三相机成像系统，其中每个相机均具有不同的视场。因此，这样的系统可基于从位于车辆前面和侧面两者的变化距离处的对象得到的信息做出决定。提到单眼图像分析可指这样的实例，即：基于从单个观察点(例如，从单个相机)捕获的图像来执行图像分析。立体图像分析可指这样的实例，即：基于用图像捕获参数的一个或多个变型捕获的两个或更多个图像来执行图像分析。例如，适于执行立体图像分析的被捕获图像可包括采取以下手段捕获的图像：根据两个或更多个不同位置，从不同的视场，使用不同的焦距，结合视差信息，等等。

[0153] 例如，在一个实施方式中，系统100可实施使用图像捕获装置122-126的三相机构造。在这样的构造中，图像捕获装置122可提供窄视场(例如1，34度，或选自约20度到45度范围的其它值，等等)，图像捕获装置124可提供宽视场(例如，150度或选自约100度到约180度范围的其它值)，并且图像捕获装置126可提供中间视场(例如，46度或选自约35度到约60度范围的其它值)。在一些实施方式中，图像捕获装置126可作为主相机或主要相机。图像捕获装置122-126可定位在后视镜310后面并且基本上并排定位(例如，6cm间隔)。进一步，在一些实施方式中，如上面讨论的，图像捕获装置122-126中的一个或多个可安装在与车辆200的挡风玻璃齐平的遮光板380后面。这样的遮光可将来自车内的任何反射对图像捕获装置122-126造成的影响降到最低。

[0154] 在另一实施方式中，如上面结合图3B和图3C讨论的，宽视场相机(例如，上面示例中的图像捕获装置124)可安装得低于窄的主视场相机(例如，上面示例中的图像装置122和126)。该构造可提供来自宽视场相机的自由视线。为了减少反射，相机可安装得接近车辆200的挡风玻璃，并且可包括相机上的偏光器用以抑制反射光。

[0155] 三相机系统可提供某些性能特性。例如，一些实施方式可包括如下能力：基于另一相机的检测结果来验证一个相机针对对象的检测。在上面讨论的三相机构造中，处理单元110可包括例如三个处理装置(例如，如上面讨论的，三个EyeQ系列的处理器芯片)，每个处理装置均专用于处理由图像捕获装置122-126中的一个或多个捕获的图像。

[0156] 在三相机系统中，第一处理装置可接收来自主相机和窄视场相机两者的图像，并且执行窄FOV相机的视觉处理以例如检测其它车辆、行人、车道标线、交通标志、交通灯及其它道路对象。进一步，第一处理装置可计算主相机和窄相机的图像之间的像素差距并且创建车辆200的环境的三维重构。然后，第一处理装置可将三维重构与三维地图数据组合，或者与基于另一相机的信息计算的三维信息组合。

[0157] 第二处理装置可接收来自主相机的图像并且执行视觉处理以检测其它车辆、行

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人、车道标线、交通标志、交通灯及其它道路对象。另外，第二处理装置可计算相机位移，并且基于该位移计算连续图像之间的像素差距并创建场景的三维重构(例如，根据运动的结构)。第二处理装置可将来自基于运动的三维重构的结构发送到第一处理装置以与立体三维图像组合。

[0158] 第三处理装置可接收来自宽FOV相机的图像并且处理所述图像，以检测车辆、行人、车道标线、交通标志、交通灯及其它道路对象。第三处理装置可进一步执行额外处理指令以分析图像来识别在图像中移动的对象，诸如变道的车辆、行人，等等。

[0159] 在一些实施方式中，使基于图像的信息流被独立地捕获并处理可提供：提供系统冗余的机会。例如，这样的冗余可包括：使用第一图像捕获装置和从该装置处理的图像以验证和/或补充通过捕获并处理至少来自第二图像捕获装置的图像信息而获得的信息。

[0160] 在一些实施方式中，系统100可使用两个图像捕获装置(例如，图像捕获装置122和124)来为车辆200提供导航辅助，并且使用第三图像捕获装置(例如，图像捕获装置126)以提供冗余并验证从其它两个图像捕获装置接收的数据的分析。例如，在这样的构造中，图像捕获装置122和124可为系统100的立体分析提供图像以导航车辆200，而图像捕获装置126可为系统100的单眼分析提供图像以提供冗余并验证基于从图像捕获装置122和/或图像捕获装置124捕获的图像而获得的信息。即，图像捕获装置126(及对应的处理装置)可被认为提供冗余子系统，以提供对从图像捕获装置122和124得到的分析的检查(例如，提供自动紧急制动(AEB)系统)。

[0161] 本领域技术人员将辨识到，上面的相机构造、相机放置、相机数目、相机地点等等仅是示例。这些部件及相对于整体系统描述的其它部件可组装并用在各种不同构造中而不脱离公开的实施方式的范围。下面是关于多相机系统的使用的进一步细节，用以提供驾驶员辅助和/或自主车辆功能性。

[0162] 图4是与公开的实施方式相一致的存储器140和/或150的示例性功能框图，存储器140和/或150可存储/编程有用于执行一个或多个操作的指令。虽然以下是参照存储器140，但是本领域技术人员将辨识到，指令可存储在存储器140和/或150中。

[0163] 如图4所示，存储器140可存储单眼图像分析模块402、立体图像分析模块404、速度和加速度模块406以及导航响应模块408。公开的实施方式并不限于任何特定构造的存储器140。进一步，应用处理器180和/或图像处理器190可执行存储于包括在存储器140中的任何模块402-408之中的指令。本领域技术人员将理解，以下讨论中对处理单元110的引用可单独或共同地指应用处理器180和图像处理器190。因此，任何以下过程的步骤可由一个或多个处理装置执行。

[0164] 在一个实施方式中，单眼图像分析模块402可存储指令(诸如计算机视觉软件)，当由处理单元110执行时，该指令执行由图像捕获装置122、124和126之一获取的一组图像的单眼图像分析。在一些实施方式中，处理单元110可将来自一组图像的信息与额外的感觉信息(例如，来自雷达的信息)组合，以执行单眼图像分析。如下面结合图5A至图5D描述的，单眼图像分析模块402可包括用于检测一组图像内的一组特征(诸如车道标记、车辆、行人、道路标志、高速公路出口匝道、交通灯、危险对象及与车辆环境关联的任何其它特征)的指令。基于此分析，系统100(例如，经由处理单元110)可在车辆200中产生一个或多个导航响应，诸如转弯、车道移位、加速度改变，等，这在下面结合导航响应模块408讨论。

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[0165] 在一个实施方式中，立体图像分析模块404可存储指令(诸如计算机视觉软件)，当由处理单元110执行时，该指令执行通过选自任何图像捕获装置122、124和126的图像捕获装置的组合而获取的第一组和第二组图像的立体图像分析。在一些实施方式中，处理单元110可将来自第一组和第二组图像的信息与额外感觉信息(例如，来自雷达的信息)组合，以执行立体图像分析。例如，立体图像分析模块404可包括用于基于图像捕获装置124获取的第一组图像和图像捕获装置126获取的第二组图像来执行立体图像分析的指令。如下面结合图6描述的，立体图像分析模块404可包括用于检测第一组和第二组图像内的一组特征(诸如车道标记、车辆、行人、道路标志、高速公路出口匝道、交通灯、危险对象，等)的指令。基于此分析，处理单元110可在车辆200中产生一个或多个导航响应，诸如转弯、车道移位、加速度改变，等，这在下面结合导航响应模块408讨论。

[0166] 在一个实施方式中，速度和加速度模块406可存储构造成分析从车辆200的一个或多个计算机电装置接收的数据的软件，所述计算机电装置被构造成致使车辆200的速度和/或加速度改变。例如，处理单元110可执行与速度和加速度模块406关联的指令，以基于从执行单眼图像分析模块402和/或立体图像分析模块404得到的数据来计算车辆200的目标速度。例如，这样的数据可包括：目标位置、速度和/或加速度；车辆200相对于近旁车辆、行人或道路对象的位置和/或速度；车辆200相对于道路的车道标记的位置信息，等。另外，处理单元110可基于感觉输入(例如，来自雷达的信息)和来自车辆200的其它系统(诸如车辆200的节流系统220、制动系统230和/或转向系统240)的输入来计算车辆200的目标速度。基于计算出的目标速度，处理单元110可向车辆200的节流系统220、制动系统230和/或转向系统240发送电子信号，以通过例如物理踩下制动器或松开车辆200的加速器来触发速度和/或加速度的改变。

[0167] 在一个实施方式中，导航响应模块408可存储可由处理单元110执行的软件，以基于从单眼图像分析模块402和/或立体图像分析模块404的执行得到的数据来确定期望导航响应。这样的数据可包括与近旁车辆、行人和道路对象关联的位置和速度信息、车辆200的目标位置信息，等。另外，在一些实施方式中，导航响应可(部分地或完全地)基于地图数据、车辆200的预定位置和/或车辆200与从单眼图像分析模块402和/或立体图像分析模块404的执行而检测的一个或多个对象之间的相对速度或相对加速度。导航响应模块408还可基于感觉输入(例如，来自雷达的信息)和来自车辆200的其它系统(诸如车辆200的节流系统220、制动系统230和转向系统240)的输入来确定期望导航响应。基于所述期望导航响应，处理单元110可向车辆200的节流系统220、制动系统230和转向系统240发送电子信号，以触发期望导航响应，例如，通过使车辆200的方向盘转动以实现预定角度旋转。在一些实施方式中，处理单元110可使用导航响应模块408的输出(例如，期望导航响应)作为输入，以执行速度和加速度模块406来计算车辆200的速度改变。

[0168] 图5A是示出与公开的实施方式相一致的用于基于单眼图像分析来产生一个或多个导航响应的示例性过程500A的流程图。在步骤510，处理单元110可经由处理单元110与图像获取单元120之间的数据接口128接收多个图像。例如，包括在图像获取单元120中的相机(诸如具有视场202的图像捕获装置122)可捕获车辆200的前面(例如，或是车辆的侧面或后面)的区域的多个图像并且经数据连接(例如，数字、有线、USB、无线、蓝牙，等等)将图像发送到处理单元110。在步骤520，处理单元110可执行单眼图像分析模块402以分析多个图像，

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这在下面结合图5B至图5D进一步详细地描述。通过执行所述分析，处理单元110可检测一组图像内的一组特征，诸如车道标记、车辆、行人、道路标志、高速公路出口匝道、交通灯，等。

[0169] 在步骤520，处理单元110还可执行单眼图像分析模块402以检测各种道路危险，例如，卡车轮胎的一部分、跌落的道路标志、松动的货物、小动物，等。道路危险可能存在结构、形状、大小和颜色上的变化，可能使检测这样的危险更具挑战性。在一些实施方式中，处理单元110可执行单眼图像分析模块402，以对多个图像进行多帧分析来检测道路危险。例如，处理单元110可估算连贯图像帧之间的相机运动，并且计算帧之间的像素差距以构建道路的三维地图。然后，处理单元110可使用三维地图来检测路面以及存在于路面上方的危险。

[0170] 在步骤530，处理单元110可执行导航响应模块408，以基于步骤520执行的分析以及如上面结合图4描述的技术来产生车辆200的一个或多个导航响应。例如，导航响应可包括转弯、车道移位、加速度改变，等。在一些实施方式中，处理单元110可使用从执行速度和加速度模块406得到的数据，以产生一个或多个导航响应。另外，多个导航响应可同时、顺次或按其任何组合而发生。例如，处理单元110可致使车辆200变换一个车道，然后通过例如向车辆200的转向系统240和节流系统220依次发送控制信号来加速。替代地，处理单元110可致使车辆200制动，同时通过例如向车辆200的制动系统230和转向系统240同时发送控制信号来使变道。

[0171] 图5B是示出与公开的实施方式相一致的用于检测一组图像中的一个或多个车辆和/或行人的示例性过程500B的流程图。处理单元110可执行单眼图像分析模块402以实施过程500B。在步骤540，处理单元110可确定表示可能的车辆和/或行人的一组候选对象。例如，处理单元110可扫描一个或多个图像，将所述图像与一个或多个预定图案比较，并且在每个图像内识别可包含关注对象(例如，车辆、行人，或其一部分)的可能地点。预定图案可采取实现高比率“错误击中”和低比率“未击中”这样的方式来设计。例如，处理单元110可使用与预定图案低阈值的相似度来识别候选对象作为可能的车辆或行人。这样做可允许处理单元110减少未击中(例如，未识别)表示车辆或行人的候选对象的概率。

[0172] 在步骤542，处理单元110可过滤这一组候选对象以基于分类标准来排除某些候选(例如，无关或不太相关的对象)。这样的标准可从与存储在数据库(例如，存储在存储器140中的数据库)中的对象类型关联的各种属性得到。属性可包括对象形状、尺寸、质地、(例如，相对于车辆200的)位置，等。由此，处理单元110可使用一组或多组标准以拒绝来自一组候选对象的错误候选。

[0173] 在步骤544，处理单元110可分析图像的多个帧，以确定一组候选对象中的对象是否表示车辆和/或行人。例如，处理单元110可跨越连贯的帧来跟踪被检测候选对象并且积累与被检测对象关联的逐帧数据(例如，大小、相对于车辆200的位置，等等)。另外，处理单元110可估算被检测对象的参数并且将对象的逐帧位置数据与预测位置比较。

[0174] 在步骤546，处理单元110可构建被检测对象的一组测量结果。例如，这样的测量结果可包括与被检测对象关联的(相对于车辆200的)位置、速度和加速度值。在一些实施方式中，处理单元110可基于以下技术来构建测量结果：基于估算技术使用一系列基于时间的观察(诸如卡尔曼滤波器或线性二次估算(LQE))；和/或基于不同对象类型(例如，汽车、卡车、行人、自行车、道路标志，等等)的可用建模数据。卡尔曼滤波器可基于对象尺度的测量结果，其中尺度测量结果与将要碰撞的时间(例如，车辆200到达对象的时间量)成比例。由此，

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通过执行步骤540-546，处理单元110可识别出现在一组被捕获图像内的车辆和行人并且得到与车辆和行人关联的信息（例如，位置、速度、大小）。基于识别和得到的信息，处理单元110可产生车辆200的一个或多个导航响应，这在上面结合图5A描述。

[0175] 在步骤548，处理单元110可执行一个或多个图像的光流分析，以减少检测“错误击中”以及未击中表示车辆或行人的候选对象的概率。光流分析可指的是，例如，分析相对于与其它车辆和行人关联的一个或多个图像中的车辆200的运动图案，并且区别于路面运动。处理单元110可通过观察跨越多个图像帧（在不同的时间被捕获）的对象的不同位置来计算候选对象的运动。处理单元110可使用位置和时间值作为用于计算候选对象运动的数学模型的输入。由此，光流分析可提供检测在车辆200近旁的车辆和行人的另一种方法。处理单元110可与步骤540-546组合来执行光流分析，为检测车辆和行人提供冗余并且增加系统100的可靠性。

[0176] 图5C是示出与公开的实施方式相一致的用于检测一组图像中的路标和/或车道几何信息的示例性过程500C的流程图。处理单元110可执行单眼图像分析模块402以实施过程500C。在步骤550，处理单元110可通过扫描一个或多个图像来检测一组对象。为了检测一段车道标记、车道几何信息及其它相关路标，处理单元110可过滤一组对象以排除确定无关的这些对象（例如，轻微的坑洼、小石头，等等）。在步骤552，处理单元110可将步骤550中检测的属于相同路标或车道标线的区段分组到一起。基于该分组，处理单元110可建立表示被检测区段的模型，诸如数学模型。

[0177] 在步骤554，处理单元110可构建与被检测区段关联的一组测量结果。在一些实施方式中，处理单元110可创建被检测区段从图像平面向现实世界平面的投影。该投影可使用第三多项式来表征，该第三多项式具有对应于物理属性（诸如位置、斜度、曲率和被检测道路的曲率衍生）的系数。在生成投影时，处理单元110可考虑路面改变，以及与车辆200关联的俯仰和横摆速率。另外，处理单元110可通过分析存在于路面上的位置和运动线索来建模道路标高。进一步，处理单元110可通过跟踪一个或多个图像中的一组特征点来估算与车辆200关联的俯仰和横摆速率。

[0178] 在步骤556，处理单元110可通过例如跟踪跨越连贯图像帧的被检测区段以及积累与被检测区段关联的逐帧数据来执行多帧分析。在处理单元110执行多帧分析时，在步骤554构建的一组测量结果可变得更可靠并且与更高的置信水平关联。由此，通过执行步骤550-556，处理单元110可识别出现在一组被捕获图像内的路标并且得到车道几何信息。基于该识别和得到的信息，处理单元110可产生车辆200的一个或多个导航响应，这在上面结合图5A描述。

[0179] 在步骤558，处理单元110可考虑额外信息源来进一步在其周边环境的背景下建立车辆200的安全模型。处理单元110可使用安全模型来限定以下背景，即：系统100可采取安全的方式来执行车辆200的自主控制。为了建立安全模型，在一些实施方式中，处理单元110可考虑其它车辆的位置和运动、被检测道路的路边和障碍和/或从地图数据（诸如地图数据库160的数据）提取的总体道路形状描述。通过考虑额外信息源，处理单元110可提供冗余来检测路标和车道几何形状并且增加系统100的可靠性。

[0180] 图5D是示出与公开的实施方式相一致的用于检测一组图像中的交通灯的示例性过程500D的流程图。处理单元110可执行单眼图像分析模块402以实施过程500D。在步骤

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560，处理单元110可扫描一组图像并且识别出现在可能包含交通灯的图像中的地点处的对象。例如，处理单元110可过滤被识别对象以构建一组候选对象，排除不可能对应于交通灯的这些对象。过滤可基于与交通灯关联的各种属性(诸如形状、尺寸、质地、(例如，相对于车辆200的)位置，等)来完成。这样的属性可基于交通灯和交通控制信号的多个示例并且存储在数据库中。在一些实施方式中，处理单元110可在反映可能交通灯的一组候选对象上执行多帧分析。例如，处理单元110可跟踪跨越连贯图像帧的候选对象，估算候选对象的现实世界位置，并且过滤出移动的那些对象(不可能是交通灯)。在一些实施方式中，处理单元110可执行候选对象的颜色分析，并且识别出现在可能交通灯内侧的被检测颜色的相对位置。

[0181] 在步骤562，处理单元110可分析枢纽的几何形状。该分析可基于以下的任何组合：(i)在车辆200的任一侧的检测的车道数目；(ii)在道路上检测的标记(诸如箭头标线)；以及(iii)从地图数据(诸如地图数据库160的数据)提取的枢纽的描述。处理单元110可使用从执行单眼分析模块402得到的信息来进行分析。另外，处理单元110可确定在步骤560检测的交通灯与出现在车辆200附近的车道之间的对应性。

[0182] 在车辆200接近枢纽时，在步骤564，处理单元110可更新与被分析的枢纽几何形状和被检测交通灯关联的置信水平。例如，与实际出现在枢纽处的交通灯数目比较，估算的出现在枢纽处的交通灯数目可能影响置信水平。由此，基于该置信水平，处理单元110可授权车辆200的驾驶员进行控制，以便改进安全条件。通过执行步骤560-564，处理单元110可识别出现在一组被捕获图像内的交通灯并且分析枢纽几何形状信息。基于该识别以及分析，处理单元110可产生车辆200的一个或多个导航响应，这在上面结合图5A描述。

[0183] 图5B是示出与公开的实施方式相一致的用于基于车辆路径来在车辆200中产生一个或多个导航响应的示例性过程500B的流程图。在步骤570，处理单元110可构建与车辆200关联的初始车辆路径。车辆路径可使用以坐标(x，z)表达的一组点来表示，并且一组点的两点之间的距离d_i可落入1米到5米的范围内。在一个实施方式中，处理单元110可使用诸如左右道路多项式的两个多项式来构建初始车辆路径。处理单元110可计算两个多项式之间的几何中点，并且如果有偏移的话，使包括在所得的车辆路径中的每个点偏移预定偏移量(例如，智能车道偏移)，(零偏移可对应于行进在车道的中间)。偏移的方向可垂直于车辆路径中的任何两点之间的区段。在另一实施方式中，处理单元110可使用一个多项式和估算的车道宽度使车辆路径的每个点偏移达：估算的车道宽度的一半加上预定偏移量(例如，智能车道偏移)。

[0184] 在步骤572，处理单元110可更新在步骤570构建的车辆路径。处理单元110可使用更高分辨率来重新构建在步骤570构建的车辆路径，使得表示车辆路径的一组点的两点之间的距离d_k小于上面描述的距离d_i。例如，距离d_k可落入0.1米到0.3米的范围内。处理单元110可使用抛物面样条算法来重新构建车辆路径，这可产生对应于车辆路径的总长度的累计距离向量S(即，基于表示车辆路径的一组点)。

[0185] 在步骤574，处理单元110可基于在步骤572构建的更新车辆路径来确定前瞻点(以坐标(x_l，z_l)表达)。处理单元110可从累计距离向量S提取前瞻点，并且前瞻点可与前瞻距离和前瞻时间关联。下限范围可从10米到20米的前瞻距离可计算为车辆200的速度和前瞻时间的乘积。例如，随着车辆200的速度降低，前瞻距离也可减小(例如，直到前瞻距离达到下限)。范围可从0.5秒到1.5秒的前瞻时间可与在车辆200中产生导航响应相关联的一个或多

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个控制环的增益(诸如跟踪控制环的航向误差)成反比。例如,跟踪控制环的航向误差的增益可取决于偏航率环的带宽、转向致动器环、汽车侧向动态,等。由此,跟踪控制环的航向误差的增益越大,前瞻时间越短。

[0186] 在步骤576,处理单元110可基于在步骤574确定的前瞻点来确定航向误差和偏航率命令。处理单元110可通过计算前瞻点的反正切(例如,$\arctan(x_1/z_1)$)来确定航向误差。处理单元110可将偏航率命令确定为航向误差和高水平控制增益的乘积。如果前瞻距离未处于下限,则高水平控制增益可等于:(2/前瞻时间)。以其它方式,高水平控制增益可等于:(车辆200的2倍速度/前瞻距离)。

[0187] 图5F是示出与公开的实施方式相一致的用于确定前车是否变道的示例性过程500F的流程图。在步骤580,处理单元110可确定与前车(例如,行进在车辆200之前的车辆)关联的导航信息。例如,处理单元110可使用上面结合图5A和图5B描述的技术来确定前车的位置、速度(例如,方向和速度)和/或加速度。处理单元110还可使用上面结合图5E描述的技术来确定一个或多个道路多项式、(与车辆200关联的)前瞻点和/或缓慢移动踪迹(例如,描述前车采取的路径的一组点)。

[0188] 在步骤582,处理单元110可分析在步骤580确定的导航信息。在一个实施方式中,处理单元110可计算缓慢移动踪迹与道路多项式(例如,沿着踪迹)之间的距离。如果沿着踪迹的该距离的方差超过预定阈值(例如,笔直道路上为0.1米到0.2米,适度弯曲的道路上为0.3米到0.4米,并且急剧弯曲的道路上为0.5米到0.6米),处理单元110可确定:前车可能变道。在检测有多个车辆行进在车辆200之前的情况下,处理单元110可比较与每个车辆关联的缓慢移动踪迹。基于该比较,处理单元110可确定:缓慢移动踪迹与其它车辆的缓慢移动踪迹不匹配的车辆可能变道。处理单元110可另外将(与前车关联的)缓慢移动踪迹的曲率与前车行进的道路区段的预期曲率比较。预期曲率可从地图数据(例如,地图数据库160的数据)、道路多项式、其它车辆的缓慢移动踪迹、关于道路的现有知识等之中提取。如果缓慢移动踪迹与道路区段的预期曲率的曲率差超过预定阈值,则处理单元110可确定:前车可能变道。

[0189] 在另一实施方式中,处理单元110可在具体时间段(例如,0.5秒到1.5秒)内将前车的瞬时位置与(与车辆200关联的)前瞻点比较。如果前车瞬时位置与前瞻点之间的距离在具体时间段期间变化,并且变化的累计总和超过预定阈值(例如,笔直道路上为0.3米到0.4米,适度弯曲的道路上为0.7米到0.8米,并且急剧弯曲的道路上为1.3米到1.7米),则处理单元110可确定:前车可能变道。在另一实施方式中,处理单元110可通过将沿着踪迹行进的侧向距离与缓慢移动踪迹的预期曲率比较来分析缓慢移动踪迹的几何形状。预期曲率半径可根据下面的计算来确定:$(\delta_z^2+\delta_x^2)/2/(\delta_x)$,其中$\delta_x$表示行进的侧向距离,并且$\delta_z$表示行进的纵向距离。如果行进的侧向距离与预期曲率之间的差超过预定阈值(例如,500米到700米),则处理单元110可确定:前车可能变道。在另一实施方式中,处理单元110可分析前车的位置。如果前车的位置掩盖了道路多项式(例如,前车覆盖在道路多项式的顶部),则处理单元110可确定:前车可能变道。在前车的位置使得另一车辆被检测位于前车之前并且两个车辆的缓慢移动踪迹不平行的情况下,处理单元110可确定:(更接近的)前车可能变道。

[0190] 在步骤584,处理单元110可基于在步骤582执行的分析来确定前车200是否变道。例如,处理单元110可基于在步骤582执行的各个分析的加权平均来做出确定。在这样的方

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案之下，例如，处理单元110基于特定类型的分析做出的前车可能变道的决定可被分配值“1”(而“0”表示确定前车不可能变道)。在步骤582执行的不同分析可被分配不同的权重，并且公开的实施方式并不限于任何特定组合的分析和权重。

[0191] 图6是示出与公开的实施方式相一致的用于基于立体图像分析来产生一个或多个导航响应的示例性过程600的流程图。在步骤610，处理单元110可经由数据接口128接收第一和第二多个图像。例如，包括在图像获取单元120中的相机(诸如具有视场202和204的图像捕获装置122和124)可捕获车辆200前方的区域的第一和第二多个图像并且经数字连接(例如，USB、无线、蓝牙，等等)将第一和第二多个图像发送到处理单元110。在一些实施方式中，处理单元110可经由两个或更多个数据接口接收第一和第二多个图像。公开的实施方式并不限于任何特定的数据接口构造或协议。

[0192] 在步骤620，处理单元110可执行立体图像分析模块404来执行第一和第二多个图像的立体图像分析，以创建车辆前方道路的三维地图并且检测图像内的特征，诸如车道标记、车辆、行人、道路标志、高速公路出口匝道、交通灯、道路危险，等。立体图像分析可采取类似于上面结合图5A至图5D描述的步骤的方式执行。例如，处理单元110可执行立体图像分析模块404以检测第一和第二多个图像内的候选对象(例如，车辆、行人、路标、交通灯、道路危险，等等)，基于各种标准来过滤出候选对象的子集，并且执行多帧分析、构建测量结果并确定其余候选对象的置信水平。在执行上面的步骤时，处理单元110可考虑来自第一和第二多个图像两者的信息，而非单独来自一组图像的信息。例如，处理单元110可针对出现在第一和第二多个图像两者中的候选对象分析像素水平数据(或来自两个被捕获图像流之中的其它数据子集)的差别。作为另一示例，处理单元110可通过观察对象出现在多个图像中的一个之中但不出现在另一个中或者相对于出现在两个图像流中的对象可能存在的其它差别来估算候选对象(例如，相对于车辆200)的位置和/或速度。例如，相对于车辆200的位置、速度和/或加速度可基于与出现在图像流的一者或两者中的对象关联的特征的轨迹、位置、移动特性等等来确定。

[0193] 在步骤630，处理单元110可基于在步骤620执行的分析和上面结合图4描述的技术来执行导航响应模块408，以在车辆200中产生一个或多个导航响应。例如，导航响应可包括转弯、车道移位、加速度改变、速度改变、制动，等。在一些实施方式中，处理单元110可使用从执行速度和加速度模块406中得到的数据，以产生一个或多个导航响应。另外，多个导航响应可同时、顺次或按其任何组合而发生。

[0194] 图7是示出与公开的实施方式相一致的用于基于对三组图像的分析来产生一个或多个导航响应的示例性过程700的流程图。在步骤710，处理单元110可经由数据接口128接收第一、第二和第三多个图像。例如，包括在图像获取单元120中的相机(诸如具有视场202、204和206的图像捕获装置122、124和126)可捕获车辆200前方和/或侧面的区域的第一、第二和第三多个图像并且经数字连接(例如，USB、无线、蓝牙，等等)将第一、第二和第三多个图像发送到处理单元110。在一些实施方式中，处理单元110可经由三个以上数据接口接收第一、第二和第三多个图像。例如，图像捕获装置122、124、126中的每个均可具有关联的数据接口用于与处理单元110通信数据。公开的实施方式并不限于任何特定的数据接口构造或协议。

[0195] 在步骤720，处理单元110可分析第一、第二和第三多个图像以检测图像内的特征，

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诸如车道标记、车辆、行人、道路标志、高速公路出口匝道、交通灯、道路危险，等。该分析可采取类似于上面结合图5A至图5D和图6描述的步骤的方式执行。例如，处理单元110可对第一、第二和第三多个图像中的每个执行单眼图像分析（例如，经由执行单眼图像分析模块402并且基于上面结合图5A至图5D描述的步骤）。替代地，处理单元110可对第一和第二多个图像、第二和第三多个图像和/或第一和第三多个图像执行立体图像分析（例如，经由执行立体图像分析模块404并且基于上面结合图6描述的步骤）。对应于第一、第二和/或第三多个图像的分析的处理后的信息可加以组合。在一些实施方式中，处理单元110可执行单眼图像分析和立体图像分析的组合。例如，处理单元110可对第一多个图像执行单眼图像分析（例如，经由执行单眼图像分析模块402）以及对第二和第三多个图像执行立体图像分析（例如，经由执行立体图像分析模块404）。图像捕获装置122、124和126的构造（包括其相应地点和视场202、204和206）可影响对第一、第二和第三多个图像进行的分析的类型。公开的实施方式并不限于特定构造的图像捕获装置122、124和126，或者对第一、第二和第三多个图像进行的分析的类型。

[0196] 在一些实施方式中，处理单元110可基于在步骤710和720获取并分析的图像来执行系统100的测试。这样的测试可向某些构造的图像捕获装置122、124和126提供系统100的整体性能的指示器。例如，处理单元110可确定“错误击中”（例如，系统100不正确地确定存在车辆或行人的情况）和“未击中”的比例。

[0197] 在步骤730，处理单元110可基于从第一、第二和第三多个图像中的两者得到的信息来在车辆200中产生一个或多个导航响应。选择第一、第二和第三多个图像中的两者可取决于各种因素，例如，多个图像中的每个中检测的对象的数目、类型和大小。处理单元110还可基于以下做出选择：图像质量和分辨率、图像中反射的有效视场、被捕获帧的数目、关注的一个或多个对象实际出现在帧中的程度（例如，对象出现的帧的百分比、出现在每个这样的帧中的对象的比例，等等），等。

[0198] 在一些实施方式中，处理单元110可通过确定从一个图像源得到的信息与从其它图像源得到的信息的一致程度来选择从第一、第二和第三多个图像中的两者得到的信息。例如，处理单元110可组合从图像捕获装置122、124和126中的每个得到的被处理信息（不论通过单眼分析、立体分析或两者的任何组合）并且确定跨越从图像捕获装置122、124和126中的每个捕获的图像呈现一致的视觉指示器（例如，车道标记、被检测车辆及其地点和/或路径、被检测交通灯，等等）。处理单元110还可排除跨越被捕获图像不一致的信息（例如，变道的车辆，指示太接近车辆200的车辆的车道模型，等等）。由此，处理单元110可基于一致和不一致信息的确定来选择从第一、第二和第三多个图像中的两者得到的信息。

[0199] 例如，导航响应可包括转弯、车道移位、加速度改变，等。处理单元110可基于在步骤720执行的分析以及上面结合图4描述的技术来产生一个或多个导航响应。处理单元110还可使用从执行速度和加速度模块406得到的数据，以产生一个或多个导航响应。在一些实施方式中，处理单元110可基于车辆200与任何第一、第二和第三多个图像内的被检测对象之间的相对位置、相对速度和/或相对加速度来产生一个或多个导航响应。多个导航响应可同时、顺次或按其任何组合而发生。

[0200] 智能车道偏移

[0201] 系统100可提供驾驶员辅助功能性，以监测并且调整车辆200与车辆200的行进边

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界(例如,车道边界)之间的自由空间。车道可指车辆的指定或预期行进路径并且可具有标记边界(例如,道路上的线)或未标记边界(例如,道路路边、道路障碍、护栏、停放的车辆,等等)。例如,默认地,系统100可最大化或增加车辆200与当前车道边界之间的自由空间。进一步,在某些条件下,系统100可使车辆200朝向当前行进车道的一侧偏移而不离开车道。例如,在车辆200围绕弯道行进的情况下,系统100可降低朝向弯道内侧的偏移(例如,调整车辆200的位置使之更接近弯道的内侧)。作为另一示例,在障碍(诸如停放的车、行人或骑自行车的人)存在于车道一侧的情况下,系统100可在车辆200的存在障碍的那一侧增加偏移(例如,调整车辆200的位置使得更远离障碍)。

[0202] 图8A图示了行进在道路800上的车辆200,其中可使用用于识别车道约束并且在车道约束内操作车辆200的公开的系统和方法。如图所示,车辆200可具有第一车辆侧802,第一车辆侧802距第一车道约束810可以是第一距离805。类似地,车辆200可具有与第一车辆侧802相反的第二车辆侧812,并且第二车辆侧812距第二车道约束820可以是第二距离815。以这种方式,第一车道约束810和第二车道约束820可限定可供车辆200行进的车道。

[0203] 处理单元110可构造成基于处理单元110可经由数据接口128接收的由图像捕获装置122-126获取的多个图像来确定第一车道约束810和第二车道约束820。根据一些实施方式,第一车道约束810和/或第二车道约束820可由可见的车道边界(诸如标记在路面上的虚线或实线)识别。另外地或替代地,第一车道约束810和/或第二车道约束820可包括路面的路边或障碍。另外地或替代地,第一车道约束810和/或第二车道约束820可包括标记物(例如,博茨点)。根据一些实施方式,处理单元110可通过识别路面宽度的中点来确定第一车道约束810和/或第二车道约束820。根据一些实施方式,如果处理单元110仅识别第一车道约束810,则处理单元110可诸如基于估算的车道宽度或道路宽度来估算第二车道约束820。当例如指定道路车道的线未被喷涂或以其它方式贴标签时,处理单元110可采取这种方式识别车道约束。

[0204] 检测第一车道约束810和/或第二车道约束820可包括:处理单元110确定其在相机坐标系统中的三维模型。例如,第一车道约束810和/或第二车道约束820的三维模型可由第三多项式描述。除了三维建模第一车道约束810和/或第二车道约束820,处理单元110可执行主机运动参数(诸如车辆200的速度、偏航和俯仰速率以及加速度)的多帧估算。可选地,处理单元110可检测静态和移动车辆及其位置、航向、速度和加速度(都相对于车辆200)。处理单元110可进一步确定道路标高模型以将从多个图像获取的所有信息转换为三维空间。

[0205] 一般,作为默认条件,车辆200可在第一车道约束和第二车道约束810和/或820内相对居中地行进。然而,在一些情形下,环境因素可使之非期望或不可行,诸如当对象或结构存在于道路的一侧的时候。由此,可存在以下情形,即车辆200可期望或有利地更接近一个车道约束或另一个。处理单元110还可构造成确定被称为车道偏移条件的这样的情形是否基于多个图像存在。

[0206] 为了确定车道偏移条件是否存在,处理单元110可构造成确定一个或多个对象825存在于车辆200附近。例如,对象825可包括在道路800上行进的另一车辆,诸如汽车、卡车或摩托车。对于每个对象825,处理单元110可确定偏移轮廓。偏移轮廓可包括确定在其当前预测位置中对象825是否将位于车辆200的预定范围内。如果处理单元110确定对象825位于或将位于车辆200的预定范围内,则处理单元110可确定:为使车辆200绕过对象825,在第一车

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道约束810和第二车道约束820内是否有足够的空间。如果没有足够的空间，则处理单元110可执行变道。如果有足够的空间，则处理单元110可确定在车辆200与对象825之间的距离接近之前是否有足够的时间绕过对象825。如果有足够的时间，则处理单元110可启动或激活偏移机动以绕过对象825。偏移机动可由处理单元110执行，使得车辆200的移动对驾驶员而言平稳而舒适。例如，偏移摆率可大约为0.15米/秒到0.75米/秒。偏移机动可执行为使得偏移机动的最大振幅将发生在车辆200与对象825之间的间距缩短的时候。如果没有足够的时间，则处理单元110可启动制动(例如，通过向制动系统230发送电子信号)，然后启动偏移机动。

[0207] 在为每个对象825设定好每个偏移轮廓均之后，处理单元可组合偏移轮廓，使得与车辆200绕过的每个对象825保持最大侧向距离。即，偏移机动可被修改和/或执行为使得车辆200与车辆200绕过的每个对象825之间的侧向距离被最大化。

[0208] 另外地或替代地，对象825可以是停放或静止的车辆、墙或人(诸如行人)或自行车交通。处理单元110可确定：基于对象825的某些特性存在车道偏移条件。例如，处理单元110可确定：如果对象825的高度超过预定阈值，诸如距路面10cm，则对象825构成车道偏移条件。以这种方式，处理单元110可构造成过滤出将不会出现车道偏移条件的对象，诸如小件碎片。

[0209] 另外地或替代地，处理单元110可构造成基于目标对象830在车辆第一侧802的位置来确定车道偏移条件是否存在于第一车辆侧802。目标对象830可包括构成车道偏移条件的一个或多个对象。另外地或替代地，目标对象830可不构成车道偏移条件。例如，目标对象830可以是街道标志或足够远离行进车道或足以不频繁发生的其它对象(不构成车道偏移条件)。处理单元110可构造成如果这样的目标对象830被检测则得出结论车道偏移条件不存在。

[0210] 处理单元110可构造成致使车辆200行进，使得第一距离805和第二距离810基本不同，以避免或保持更远离对象825。例如，如果车道偏移条件存在于第一车辆侧802，则处理单元110可构造成致使车辆200在第一车道约束810和第二车道约束820内行进，使得第一距离805大于第二距离815。这例如在图8A中图示。替代地，如果车道偏移条件存在于第二车辆侧812上，则处理单元110可创建或执行这样的偏移轮廓，该偏移轮廓被构造成致使车辆200在第一车道约束810和第二车道约束820内行进，使得第一距离805小于第二距离815。这例如在图8B中图示。

[0211] 作为另一示例，停放的车辆可位于车辆200的一侧，并且行人可位于车辆200的另一侧。在这样的情形下，系统100可确定：期望减小车辆200与停放的车辆之间的距离，以便在车辆200与行人之间提供更多空间。因此，处理单元110可致使车辆200行进，使得停放的车辆之间的距离减小。

[0212] 第一车辆侧802和第二车辆侧812的识别需要不是静态的，使得在不同的时间点，处理单元110可将第一车辆侧802识别为车辆200的驾驶员侧或乘客侧。例如，取决于一个或多个对象825存在于车辆200的哪一侧，第一车辆侧802的识别可改变，使得如果基于对象825存在一个车道偏移条件，则对象825存在于第一车辆侧802上。在这样的情形下，处理单元110可创建或执行这样的偏移轮廓，该偏移轮廓被构造成致使车辆200在第一车道约束810和第二车道约束820内行进，使得大于第二距离815的第一距离805被朝向对象825提供。

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[0213] 根据一些实施方式，当车道偏移条件存在于第一车辆侧802时，处理单元110可创建这样的偏移轮廓，该偏移轮廓被构造成致使车辆200在第一车道约束810和第二车道约束820内行进，使得第一距离805比第二距离815大至少1.25倍。另外地或替代地，当车道偏移条件存在于第一车辆侧802上时，处理单元110可创建这样的偏移轮廓，该偏移轮廓被构造成致使车辆200在第一车道约束810和第二车道约束820内行进，使得第一距离805比第二距离815大至少2倍。

[0214] 在一些实施方式中，如图8C所示，处理单元110可确定车道偏移条件存在于第一车辆侧802和第二车辆侧812两者上。然后，处理单元110可针对该偏移条件创建这样的偏移轮廓，该偏移轮廓被构造成致使车辆200在第一车道约束810和第二车道约束820内行进，使得第一距离805基本上等于第二距离815。

[0215] 处理单元110可构造成使得用于移动对象825以及静止对象825的偏移轮廓优先。例如，处理单元110可优先偏移轮廓，以保持车辆200与移动对象825和/或静态对象825之间的预定距离。处理单元200可基于某些车道特性(诸如弯道)优先这些偏移条件(优于这些偏移条件)。最后优先车道偏移条件可包括模仿前车。

[0216] 处理单元110可将偏移轮廓或偏移条件化为期望的前瞻点，该期望的前瞻点可位于由第一车道约束810和第二车道约束820限定的车道的中间处。处理单元110可基于前瞻点和偏移轮廓来计算并实施偏航率命令。偏航率命令可用于基于偏航率命令和车辆200的通过使用陀螺仪测量的偏航率来计算扭矩命令。处理单元110可向车辆200的转向系统(例如，转向系统240)发送扭矩命令。

[0217] 根据一些实施方式，诸如经由用户接口170，来自车辆200的驾驶员的输入可撤销处理单元110。例如，用户输入可撤销处理单元110的控制，致使车辆200在第一车道约束810和第二车道约束820内行进，使得第一距离805大于第二距离815。

[0218] 另外地或替代地，处理单元110可构造成基于由图像捕获装置122捕获的多个图像来确定车道偏移条件是否基本上不存在。这可包括以下情形，其中低于某些大小阈值的一个或多个对象825被检测，和/或当无对象825被检测时，被检测的一个或多个对象825位于距车道约束的预定距离的外侧。在这样的情形下，处理单元110可构造成致使车辆200在第一车道约束810和第二车道约束820内行进，使得第一距离805等于或基本上等于第二距离815。

[0219] 如图8D中图示的，车道偏移条件可包括弯路。处理单元110可构造成致使车辆200在第一车道约束810和第二车道约束820内行进，使得第一距离805相对于车辆200朝向弯路的外侧，并且第二距离815相对于车辆200朝向弯路的内侧。例如，第一距离805可小于第二距离815。

[0220] 图9是与公开的实施方式相一致的存储器140和/或150的示例性框图，存储器140和/或150可存储用于执行一个或多个操作的指令。如图9中图示的，存储器140可存储用于执行本文中描述的车道偏移条件检测和响应的一个或多个模块。例如，存储器140可存储车道约束模块910和车道偏移模块920。应用处理器180和/或图像处理器190可执行存储在任何模块910和920(包括在存储器140中)中的指令。本领域技术人员将理解的是，以下讨论对处理单元110的引用可单独或共同指应用处理器180和图像处理器190。因此，任何以下过程的步骤可由一个或多个处理装置执行。

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[0221] 车道约束模块910可存储指令，当由处理单元110执行时，该指令可检测并且限定第一车道约束810和第二车道约束820。例如，车道偏移模块910可处理从至少一个图像捕获装置122-124接收的多个图像，以检测第一车道约束810和第二车道约束820。如上面讨论的，这可包括识别喷涂的车道线和/或测量路面的中点。

[0222] 车道偏移模块920可存储指令，当由处理单元110执行时，该指令可检测车道偏移条件的存在和/或识别车道偏移条件是否存在于第一车辆侧802和/或第二车辆侧812上。例如，车道偏移模块920可处理多个图像，以检测对象825存在于第一车辆侧802和/或第二车辆侧812上。车道偏移模块920可处理多个图像，以检测车辆200行进的道路中的弯道。另外地或替代地，车道偏移模块920可接收来自指示存在对象825和/或弯曲车道的另一模块或其它系统的信息。车道偏移模块920可执行控制，以改变车辆200相对于第一车道约束810和/或第二车道约束820的位置。例如，如果车道偏移模块920确定车道偏移条件仅在第一车辆侧802上，则车道偏移模块920可使车辆200移动得更接近第二车道约束820。另一方面，如果车道偏移模块920确定车道偏移条件仅在第二车辆侧812上，则车道偏移模块920可使车辆200移动得更接近第一车道约束810。

[0223] 图10图示了与公开的实施方式相一致的用于导航车辆200的过程1000。过程1000可识别限定了车辆行进的行进车道的车道约束。过程1000包括：响应于检测车道偏移条件而致使车辆200行进得更接近一个或另一个车道约束，诸如第一车道约束810或第二车道约束820。以这种方式，过程1000可用于在车道约束内驾驶车辆200以及考虑可能更期望使车辆200在第一车道约束810和第二车道约束820内移位的环境因素。

[0224] 在步骤1010，过程1000可包括：使用至少一个图像捕获装置122、124和/或126来获取车辆200附近区域的多个图像。例如，处理单元110可经由数据接口128接收多个图像。例如，处理单元110可构造成确定一个或多个对象825存在于道路的一侧上。例如，对象825可以是停放或静止的车辆、墙或人(诸如行人)或自行车交通。处理单元110可基于对象825的某些特性来确定车道偏移条件是否存在。例如，处理单元110可确定：如果对象825的高度超过预定阈值，诸如距路面10cm，则对象825构成车道偏移条件。以这种方式，处理单元110可构造成过滤出将不会出现车道偏移条件的对象，诸如小件碎片。

[0225] 另外地或替代地，处理单元110可构造成基于目标对象830在车辆第一侧802上的位置来确定车道偏移条件是否存在于第一车辆侧802上。目标对象830可以是构成车道偏移条件的一个或多个对象。另外地或替代地，目标对象830可不构成车道偏移条件。例如，目标对象830可以是道路障碍或街道标志。处理单元110可构造成：如果这样的目标对象830被检测则得出结论车道偏移条件不存在。

[0226] 在步骤1020，过程1000可根据多个图像确定在第一车辆侧802的第一车道约束和在第二车辆侧812的第二车道约束。例如，处理单元110可构造成基于经由数据接口128接收的多个图像来确定第一车道约束810和第二车道约束820。

[0227] 在步骤1030，过程1000可确定车道偏移条件是否存在于第一车辆侧802上。如果车道偏移条件确实存在于第一车辆侧802上，则在步骤1040，过程1000可包括：致使车辆200在第一车道约束810和第二车道约束820内行进，使得第二距离815小于第一距离805。处理单元110可构造成致使车辆200行进，使得第一距离805和第二距离810基本上不同，以避免或保持更远离对象825。例如，如果车道偏移条件存在于第一车辆侧802上，则处理单元110可

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构造成致使车辆200在第一车道约束810和第二车道约束820内行进，使得第一距离805大于第二距离815。这例如在图8A中图示。替代地，如果车道偏移条件存在于第二车辆侧812上，则处理单元110可构造成致使车辆200在第一车道约束810和第二车道约束820内行进，使得第一距离805小于第二距离815。这例如在图8B中图示。例如，为了根据过程1000导航车辆200，处理单元110可向车辆200的节流系统220、制动系统230和/或转向系统240中的一个或多个发送电子信号。

[0228] 如果车道偏移条件不存在于第一车辆侧802上，则在步骤1050中，方法可包括：确定车道偏移条件是否存在于第二车辆侧812上。如果车道偏移条件存在于第二车辆侧812上，所述方法可包括：致使车辆200在第一车道约束810和第二车道约束820之间行进，使得第一距离805小于第二距离815。

[0229] 将车辆导航至默认车道

[0230] 系统100可提供驾驶员辅助功能性，用于监测车辆200在当前行进车道中的地点并且如果当前行进车道并非预定的默认行进车道则使车辆200进入预定的默认行进车道。预定的默认行进车道可由用户输入限定和/或作为处理从至少一个图像捕获装置122-126接收的图像的结果。

[0231] 系统100还可为车辆200的驾驶员和乘客和/或其它驾驶员提供即将发生车辆200向预定的默认行进车道变道的通知。例如，系统100可激活定位在保险杠区域210之一处或附近的转向信号。另外地或替代地，系统100可诸如通过扬声器360发出语音通知。当车辆行进时，车辆200可使用系统100将特定车道选择为预定的默认行进车道。当车辆200行进的当前车道(例如，当前行进车道)不同于预定的默认行进车道时，系统100可致使车辆200做出变道，例如，进入预定的默认行进车道。

[0232] 图11图示了在道路800的当前行进车道1110中行进的车辆200。根据一些实施方式，车辆200可具有预定的默认行进车道1120。例如，预定的默认行进车道1120可以是道路800的最右车道。导航系统100可构造成确定车辆200是否行进在预定的默认行进车道1120中，如果否，则致使车辆200改变至预定的默认行进车道1120。例如，处理单元110可构造成将当前行进车道1110与预定的默认行进车道1120进行比较，并且致使车辆200返回到预定的默认行进车道1120。

[0233] 根据一些实施方式，处理单元110可基于由图像捕获装置122-126中的一个或多个获取的多个图像来检测预定的默认行进车道1120中的对象1130。处理单元110可通过使用上面结合图5A至图5D描述的技术来分析图像而检测车辆200相对于对象1130的位置和速度。根据一些实施方式，处理单元110可确定车辆200是否应该超越对象1130。这可能期望的是，例如车辆200相对于对象1130的速度和/或加速度超过某一阈值。

[0234] 图12A是与公开的实施方式相一致的存储器140的示例性框图，存储器140可存储用于执行一个或多个操作的指令。如图12A中图示的，存储器140可存储用于执行本文中描述的默认行进车道和当前行进车道的检测和响应的一个或多个模块。例如，存储器140可存储当前车道检测模块1210、默认车道检测模块1220和动作模块1230。

[0235] 当前车道检测模块1210可存储指令，当由处理单元110执行时，该指令可检测并且限定当前行进车道1110。例如，处理单元110可执行当前车道检测模块1212，以处理从至少一个图像捕获装置122-124接收的多个图像并且检测当前行进车道1110。这可包括检测车

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辆200相对于道路800的路边、道路800的中点和/或车道标记物(诸如喷涂的车道线)的相对位置。处理单元110可通过使用上面结合图5A至图5D描述的技术来分析图像而检测车辆200相对于道路800的位置。

[0236] 默认车道检测模块1220可存储指令,当由处理单元110执行时,该指令可识别预定的默认行进车道1120并且将默认车道检测模块1220与由当前车道检测模块1210识别的当前行进车道1110进行比较。默认车道检测模块1220可基于用户输入和/或从至少一个图像捕获装置122-124接收的多个图像来识别预定的默认行进车道1120。例如,用户可通过扬声器360接收的语音命令或者通过选择显示在触摸屏320上的菜单来选择默认车道。

[0237] 在一些实施方式中,预定的默认行进车道1120可以是最右行进车道,或者可以是具有更期望特征的车道。例如,默认车道检测模块1220可包括指令,该指令用于选择交通量更少的车道、最接近车辆200速度行进的车辆的车道和/或最接近一个接近出口或车辆200将转向的街道的车道。在一些实施方式中,预定的默认行进车道1120可基于从位置传感器130(诸如全球定位系统)接收的数据来确定。

[0238] 动作模块1230可存储指令,当由处理单元110执行时,该指令可产生识别当前行进车道1110和预定的默认行进车道1120的响应。例如,处理单元110可执行动作模块1230,以在当前行进车道1110与预定的默认行进车道1120不相同的情况下致使车辆200变道。另外地或替代地,动作模块1230可启动变道的通知,诸如激活转向信号210或者产生语音通知。

[0239] 动作模块1230可包括致使处理单元110确定车辆200是否应该移出预定的默认行进车道1120的指令。例如,动作模块1230可确定:预定的默认行进车道1120中的对象1130应该由车辆200绕过。

[0240] 动作模块1230可进一步包括致使处理单元110确定进行变道是否安全的指令。例如,在执行变道之前,处理单元110可基于例如使用上面结合图5A至图5D描述的技术进行的多个图像的分析来评估确定道路800的一个或多个特性。如果分析指示变道条件是不安全的,则处理单元110可确定:车辆200应该保持在当前车道中。

[0241] 动作模块1230可包括用于操纵车辆200以机动离开和返回到预定的默认行进车道1120(诸如绕过对象1130)的额外指令。当执行这些指令时,处理单元110可使用车辆200的估算运动来估算预定的默认行进车道1120的地点。这在以下情形下可能是有利的,即预定的默认行进车道1120不能保持为由图像捕获装置122-124检测到。

[0242] 处理单元110可构造成执行偏移轮廓,该偏移轮廓使车辆200从预定的默认行进车道1120偏移完整的车道宽度,其可基于被检测的车道标记物之间的距离来估算。由偏移轮廓限定的偏移机动可由处理单元110执行,使得车辆200的移动对驾驶员而言平稳而舒适。例如,偏移摆率可大约为0.15米/秒到0.75米/秒。在偏移机动期间,处理单元110可执行来自动作模块1230的指令,该指令切换至跟随当前行进车道1110的中央。这些指令可包括从跟随带偏移的预测车道逐渐过渡到跟随当前行进车道1110。逐渐过渡可通过限定期望的前瞻点来完成,使得不允许在时间中的改变多于建议的摆率(可约为0.25米/秒)。

[0243] 用于使车辆200从预定的默认行进车道1120过渡的指令可用于使车辆200过渡回到预定的默认行进车道中。例如,处理单元110可构造成执行偏移轮廓,该偏移轮廓使车辆200从当前行进车道1110偏移完整车道宽度,其可基于被检测的车道标记物之间的距离来估算。由偏移轮廓限定的偏移机动可由处理单元110执行,使得车辆200的移动对驾驶员而

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言平稳而舒适。例如，偏移摆率可大约为0.15米/秒到0.75米/秒。在偏移机动期间，处理单元110可执行来自动作模块1230的指令，该指令切换至跟随预定的默认行进车道1120的中央。这些指令可包括从跟随带偏移的预测车道逐渐过渡到跟随预定的默认行进车道1120。逐渐过渡可通过限定期望的前瞻点来完成，使得不允许在时间中的改变多于建议的摆率(可约为0.25米/秒)。

[0244] 在使车辆200在两个车道之间过渡的一个或多个步骤，处理单元110可基于前瞻点和偏移轮廓来计算并实施偏航率命令。偏航率命令可用于基于偏航率命令和使用陀螺仪测量的车辆200的偏航率来计算扭矩命令。处理单元110可向车辆200的转向系统(例如，转向系统240)发送扭矩命令。

[0245] 图12B图示了与公开的实施方式相一致的用于将车辆200导航至默认车道的过程1250。根据一些实施方式，过程1250可由导航系统100的一个或多个部件(诸如至少一个处理单元110)实施。过程1250可识别车辆200的当前行进车道1110并且将之与预定的默认行进车道1120比较，以确定车辆200是否行进在预定的默认行进车道1120内。如果车辆200并未行进在预定的默认行进车道1120中，则处理单元110可致使车辆200变道，使得导航至默认行进车道1120。

[0246] 在步骤1260，图像捕获装置122-124中的一个或多个可获取车辆200附近区域的多个图像。处理单元110可经由数据接口128接收多个图像。

[0247] 在步骤1270，处理单元110可执行当前车道检测模块1210以检测并且限定当前行进车道1110。例如，处理单元110可处理多个图像，以例如检测车辆200相对于道路100的路边、道路100的中点和/或喷涂的车道标记物的相对位置。处理单元110可通过使用上面结合图5A至图5D描述的技术来分析图像而检测车辆200相对于道路800的位置。

[0248] 在步骤1280，处理单元110可执行默认车道检测模块1220，以识别预定的默认行进车道1120并且将默认车道检测模块1220与由当前车道检测模块1210识别的当前行进车道1110比较。默认车道检测模块1220可基于用户输入和/或从至少一个图像捕获装置122-124接收的多个图像来识别预定的默认行进车道1120。

[0249] 例如，如上面讨论的，处理单元110可基于任何数目的因素来确定预定的默认行进车道1120。预定的默认行进车道1120可以是在多个行进车道1110和1120之中的最右车道。另外地或替代地，预定的默认行进车道1120的确定可基于通过处理多个图像经由用户接口170从用户接收的输入，和/或基于从位置传感器130(诸如全球定位系统)接收的数据。预定的默认行进车道1120可在每次车辆行程确定一次，或者定期确定。例如，预定的默认行进车道1120可响应于给定地点的条件动态地确定。

[0250] 如果当前车道1110与预定的默认行进车道1120不相同，则处理单元110可执行动作模块1230以致使车辆100导航至默认行进车道1120。例如，处理单元110可向车辆200的节流系统220、制动系统230和/或转向系统240中的一个或多个发送电子信号，以触发期望的响应。例如，处理单元110可致使转向系统240将车辆200的方向盘转向以实现预定角度的旋转。

[0251] 进一步，在执行变道之前，处理单元110可确定变道是否安全(例如，路中没有车辆或对象)。如上面讨论的，处理单元110可基于例如使用上面结合图5A至图5D描述的技术进行的多个图像的分析来评估道路800的一个或多个特性。如果变道条件是不安全的，则处理

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单元110可确定：车辆200应该保持在当前车道中。

[0252] 在一些实施方式中，执行动作模块1230可启动变道的通知。例如，处理单元110可产生信号以激活转向信号和/或经由扬声器360产生语音通知。因此，这样的通知可发生在车辆200变道之前。在其它实施方式中，执行动作模块1230可向车辆200的驾驶员启动在不致使变道发生的情况下则车辆200并未行进在默认车道中的通知。因此，在这样的实施方式中，车辆200的驾驶员可确定是否手动采取动作以及使车辆200转向以变道。

[0253] 在一些实施方式中，系统100可通知车辆200的用户和/或车辆200附近的其它驾驶员：如果车辆200将移向预定的默认行进车道1120，则车辆200将变道。例如，处理单元110可在致使车辆200变道之前激活车辆200的转向信号。另外地或替代地，通知附近的其它驾驶员的语音通知可由处理单元110产生。语音通知可经由例如蓝牙发送到包括在其它近旁车辆中的接收器。另外地或替代地，至少一个处理单元110可在致使车辆200切换车道之前致使语音指示器通知车辆200的驾驶员。以这种方式，车辆200的驾驶员可以预料：控制系统100将施加在车辆200上。

[0254] 控制转弯车辆的速度

[0255] 系统100可提供驾驶员辅助功能性，用于控制车辆200在不同场景(诸如做出转弯(例如，通过弯道)时)下的速度(即，速度和/或方向)。例如，系统100可构造成使用地图、位置和/或视觉数据的组合，以控制车辆200在转弯时的速度。特别是，系统100可控制车辆200在接近弯道时(在导航弯道的同时)和/或在离开弯道时的速度。系统100可考虑用以控制速度的不同因素，这取决于在给定的时间车辆200相对于弯道的位置。例如，系统100可初始响应于获知到弯道位于车辆200之前的某一距离来致使车辆200减速。然而，在车辆200转弯经过弯道的同时，系统100可基于对弯道特性的分析来致使车辆200加速和/或改变方向。

[0256] 图13A和图13B是与公开的实施方式相一致的使车辆(例如，车辆200)接近并导航具有道路1300的一个或多个特性的弯道的概略表示。如图13A中图示的，视觉指示器(诸如位于道路1300附近的道路标志1302)可告知车辆200弯道在前面。响应于由道路标志1302提供的警告，车辆200的驾驶员和/或为车辆200提供驾驶员辅助功能性的系统100可调整车辆200的速度(例如，通过减速和/或转向)，以安全地导航弯道。

[0257] 在车辆200接近弯道时，系统100可通过使用车辆200的图像捕获装置122和/或124(可以是相机)来检测车道宽度1306和弯道半径1308。基于弯道半径1308、车道宽度1306以及使用图像捕获装置122和/或124检测的与弯道关联的其它特性，系统100可调整车辆200的速度。具体地，系统100可调整车辆200接近弯道和/或车辆200导航弯道时的速度。系统100还可响应于例如出现在弯道之后的交通灯1304来调整车辆200离开弯道时的速度。下面结合图14和图15描述关于调整车辆200的速度以及检测车道宽度1306、曲率半径或弯道半径1308及与弯道关联的特性的进一步细节。

[0258] 在一些实施方式中，系统100可基于地图数据和/或车辆位置信息(例如，GPS数据)来辨识将被导航的弯道。系统100可基于反映在地图数据中的弯道的一个或多个特性来确定车辆的初始目标速度。系统100可将车辆的速度调整至初始目标速度，并且基于由图像捕获装置122-126中的一个或多个获取的一个或多个图像来确定弯道的观察到的一个或多个特性。系统100可基于弯道的观察到的一个或多个特性来确定更新的目标速度，并且将车辆的速度调整至更新的目标速度。

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[0259] 图14是与公开的实施方式相一致的存储器的示例性框图，该存储器被构造成存储用于执行一个或多个操作的指令。如图14中指示的，存储器140可存储弯道辨识模块1402、特性观察模块1404和速度模块1406。公开的实施方式并不限于任何特定构造的存储器140。进一步，处理单元110可执行存储在任何模块1402-1406(包括在存储器140中)中的指令。

[0260] 在一个实施方式中，弯道辨识模块1402可存储软件指令(诸如计算机视觉软件)，当由处理单元110执行时，该软件指令通过例如分析一组或多组图像和/或使用地图和/或位置数据(例如，存储在地图数据库160中的数据)来检测弯道。图像组可由图像捕获装置122、124和126中的一个或多个获取。基于该分析，系统100(例如，经由处理单元110)可致使车辆200的速度改变。例如，如果处理单元110检测到存在位于车辆200之前的最小阈值距离内的弯道，则处理单元110可致使车辆200的速度降低预定的量和/或将车辆200的方向调整特定的角度。

[0261] 在一个实施方式中，特性观察模块1404可存储软件指令(诸如计算机视觉软件)，当由处理单元110执行时，该软件指令观察与系统100(例如，经由执行弯道辨识模块1402)检测的弯道关联的特性。处理单元110可通过分析由图像捕获装置122、124和126中的一个或多个获取的一组或多组图像和/或使用地图和/或位置数据(例如，存储在地图数据库160中的数据)来观察与被检测弯道关联的特性。该分析可产生与弯道关联的信息，诸如弯道半径1308、车道宽度1306、曲率的程度、曲率变化率、转弯倾斜度、弯道的长度或弧长，等。这些特性可包括估值(例如，使用预先存在的数据和/或基于这样的数据的数学模型计算的弯道特性)和实际值(例如，通过分析弯道的被捕获图像计算的弯道特性)。基于该分析，处理单元110可致使车辆200的速度改变。例如，鉴于与位于车辆200之前25米的弯道关联的曲率变化率较高，处理单元110可致使车辆200的速度降低和/或将车辆200的方向调整特定的角度。

[0262] 在一个实施方式中，速度模块1406可存储被构造成分析来自一个或多个计算机电装置的数据的软件指令，该一个或多个计算机电装置被构造成确定目标速度并且致使车辆200的速度改变为目标速度。例如，处理单元110可执行速度模块1406，以基于从执行弯道辨识模块1402和特性观察模块1404得到的数据来计算车辆200的目标速度。例如，这样的数据可包括初始目标位置和初始速度、更新目标位置和更新速度、最终目标位置和最终速度，等。另外，处理单元110可基于来自车辆200的其它系统(诸如车辆200的节流系统220、制动系统230和/或转向系统240)的输入来计算车辆200的速度。基于计算的目标速度，处理单元110可向车辆200的节流系统220、制动系统230和/或转向系统240发送电子信号(例如，经由控制器区域网络总线(“CAN总线”))，以通过例如物理踩下制动器、松开车辆200的加速器或者使车辆200沿特定方向转向(例如，以特定角度)来触发车辆200的速度和/或方向的改变。速度增加可与对应的加速度(例如，介于0.2米/秒^{2}到3.0米/秒^{2}之间)关联。反过来，速度降低可与对应的减速度关联。另外，加速度或减速度可基于道路类型(例如，高速公路、城市街道、乡村道路，等等)、近旁任何速度约束的存在(例如，急剧弯道、交通灯)以及道路宽度或车道宽度1306。出于本公开的目的，减速可指具有负值的加速度。

[0263] 图15是示出与公开的实施方式相一致的用于基于被检测弯道和观察的弯道特性和/或关于弯道的地图数据来控制车辆速度的示例性过程1500的流程图。在步骤1510，处理单元110可经由位于处理单元110与图像获取单元120之间的数据接口128接收多个图像。例

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如，包括在图像获取单元120中的相机(诸如图像捕获装置122)可捕获多个图像并且经数字连接(例如，USB、无线、蓝牙，等等)将图像发送到处理单元110。在一些实施方式中，处理单元110可经由多个数据接口接收多于一个的多个图像。例如，处理单元110可从图像捕获装置122、124、126中的每个接收多个图像，图像捕获装置122、124、126中的每个均可具有关联的数据接口用于与处理单元110通信数据。公开的实施方式并不限于任何特定的数据接口构造或协议。

[0264] 在步骤1520，处理单元110可执行弯道辨识模块1502，以基于例如地图和/或位置数据(例如，存储在地图数据库160中的数据)来检测位于车辆200之前的弯道。这样的数据可指示存在于于给定道路上的弯道的地点。数据可指示特定弯道的绝对位置(例如，经由GPS坐标)或弯道的相对位置(例如，通过相对于车辆200、道路标志1302、交通灯1304和/或其它描述性地标来描述弯道)。在一些实施方式中，处理单元110可执行弯道辨识模块1502，以通过分析多个图像来检测弯道。该分析可使用上面结合图5A至图5D和图6描述的技术来进行。

[0265] 在步骤1530，处理单元110可执行速度模块1406，以基于例如从执行弯道辨识模块1402得到的数据来确定车辆200的初始目标速度。初始目标速度可反映车辆200的速度和方向以安全地进入即将到来的弯道，并且可使用上面结合图14描述的技术来确定。例如，速度模块1406可基于与即将到来的弯道关联的已知或估算的特性(诸如弯道半径1308和转弯倾斜度)来确定初始目标速度。速度模块1406可依据数学模型和/或公式并且基于各种约束来计算初始目标速度。在一些实施方式中，例如，速度模块1406可基于交通灯(诸如交通灯1304)存在于弯道之前、期间或之后、大气条件(例如，小雨、大雨、大风、多云，等等)、道路条件(例如，柏油路、土路、坑洼，等等)、限速、近旁存在车辆或行人等等来确定初始目标速度。初始目标速度还可基于与车辆200关联的侧向加速极限。在一些实施方式中，侧向加速极限可在0.2米/秒^{2}到3.0米/秒^{2}的范围内并且可取决于弯道特性、道路宽度或车道宽度1306来调整。另外，初始目标速度可基于与一个或多个相机(诸如图像捕获装置122和124)关联的焦距范围。

[0266] 例如，速度模块1406可基于车辆200之前的道路的曲率半径来确定初始目标速度。速度模块1406可确定距车辆200的各种距离处的曲率半径并且以向量R(1:n)存储信息。在一个实施方式中，速度模块1406可确定以下地点的曲率半径：(1)车辆200的当前位置；(2)距车辆200的距离$D_{终点}$，其中$D_{终点}$表示车辆200之前的、道路特性的认识允许系统100控制车辆200的导航响应使得驾驶员可感觉舒适的距离；以及(3)距车辆200的增量距离，诸如每1米，等等。距离$D_{终点}$的值可取决于车辆200的当前速度V_{ego}。例如，V_{ego}的值越大(例如，车辆200行进得越快)，$D_{终点}$的值越大(例如，可考虑越长的距离为系统100提供足够的时间来提供导航响应，诸如基于接近急剧转弯或弯道来舒适地减小车辆200的速度)。在一个实施方式中，$D_{终点}$可根据以下公式计算：$D_{终点}=(V_{ego}^2/2)/(0.7/40*V_{ego}+0.5)$。由此，向量D(1:n)＝[1:1:n]，其中n＝向下取整($D_{终点}$)。

[0267] 在一些实施方式中，速度模块1406可基于侧向加速度约束$a_{最大}$(例如，最大允许的侧向加速度)来确定初始目标速度。$a_{最大}$可落入1.5米/秒^{2}到3.5米/秒^{2}的范围内。基于$a_{最大}$和(上面讨论的)曲率半径向量R，速度模块1406可将(例如，距车辆200的当前位置的不同点或距离处的)车辆200的速度限制为速度$v_{极限}$，计算为：$v_{极限}(1:n)=(a_{最大}*R(1:n))^{1/2}$。另外，根据

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$v_{极限}$的确定而导出的减速度约束可计算为:$dcc_{极限}$=最小{(($v_{极限}(1:n)^2-V_{ego}^2$)/2),最大{$d_{最小}$,D(1:n)-2*V_{ego}}},其中$d_{最小}$等于40米。$d_{最小}$的值可表示对车辆200的驾驶员而言减速感觉舒适的点。

[0268] 在一些实施方式中,速度模块1406可基于曲率摆率约束$slew_{最大}$(可基于曲率变化率)来确定初始目标速度。$slew_{最大}$可落入0.5米/秒^{3}到1.5米/秒^{3}的范围内。速度模块1406可根据以下公式来确定$v_{极限}$:$v_{极限}(1:n)=(slew_{最大}/abs\{\{1/R(1:n)\}'\})^{1/3}$。进一步,速度模块1406可根据以下公式来确定$dec_{极限}$:$dec_{极限}$=最小{(($v_{极限}(1:n)^2-V_{ego}^2$)/2),最大{$d_{最小}$,D(1:n)-2*$V_{ego}$}},其中$d_{最小}$等于40米。

[0269] 在一些实施方式中,速度模块1406可确定舒适约束,使得在车辆200经历各种导航响应(诸如转弯或导航弯道)的同时车辆200的驾驶员是舒适的。速度模块1406可根据以下公式来确定$v_{极限}$:$v_{极限}(1:n)=4/500*R(1:n)+22.5$。进一步,速度模块1406可根据以下公式来确定$dec_{极限}$:$dec_{极限}$=最小{(($v_{极限}(1:n)^2-V_{ego}^2$)/2),最大{$d_{最小}$,D(1:n)-2*$V_{ego}$}},其中$d_{最小}$等于40米。

[0270] 速度模块1406可通过使用与每个约束关联计算的$dec_{极限}$的最小值来合并上面确定的三个约束,即侧向加速度约束、曲率摆率约束和舒适约束。在合并约束之后,速度模块1406可根据以下公式通过确定调整车辆200的速度的量来达到初始目标速度,记作$v_{舒适}$:$v_{舒适}=v_{舒适(先前)}+dec_{极限}*\Delta t$,其中$v_{舒适(先前)}$表示车辆200的先前速度(例如,先前确定的速度、在速度模块1406做任何调整之前的车辆200的速度,等等),并且Δt表示确定$v_{舒适}$与$v_{舒适(先前)}$之间的时间。

[0271] 在步骤1540,处理单元110可执行速度模块1406以将车辆200的速度调整至在步骤1530确定的初始目标速度。基于车辆200的当前速度以及在步骤1530确定的初始目标速度,处理单元110可向车辆200的节流系统220、制动系统230和/或转向系统240发送电子信号,以将车辆200的速度改变至初始目标速度。进一步,一个或多个致动器可控制节流系统220、制动系统230和/或转向系统240。例如,处理单元110可发送电子信号,致使系统100物理地踩下制动器达预定的量或者部分地松开车辆200的加速器。进一步,处理单元110可发送电子信号,致使系统100将车辆200沿特定方向转向。在一些实施方式中,加速度(或减速度)的幅值可基于车辆200的当前速度与初始目标速度之间的差。当该差较大时(例如,当前速度比初始目标速度大10km/hr),例如,系统100可通过采取使减速度最大化并且导致车辆200在最短的时间量内尽可能安全地实现初始目标速度的方式制动来改变当前速度。替代地,系统100可采取使减速度降到最低并且导致车辆200逐渐实现初始目标速度的方式来施加制动。更一般地,系统100可将当前速度改变至初始目标速度,根据任何特定的制动轮廓(例如,前两秒要求高制动水平且随后三秒要求低制动水平的制动轮廓)。公开的实施方式并不限于任何特定的制动轮廓或制动方式。

[0272] 在步骤1550,处理单元110可执行特性观察模块1404,以基于例如分析使用上面结合图5A至图5D描述的技术进行的多个图像来确定位于车辆200之前的弯道的一个或多个特性。例如,所述特性可包括与下列关联的估值和/或实际值:弯道半径1308、道路宽度或车道宽度1306、曲率的程度、曲率变化率、转弯倾斜度,等。例如,所述特性还可包括由一个或多个道路标志(诸如道路标志1302)传达的信息。此外,所述特性可包括被检测弯道的长度或弧长(可以是车辆200在接近弯道时的速度的函数)。处理单元110可执行特性观察模块

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1404，以基于数学模型和/或公式来计算与这些特性（例如，弯道半径1308、曲率的程度、曲率变化率、弯道弧长，等等）关联的值。在一些实施方式中，处理单元110可执行特性观察模块1404，以构建将弯道曲率表达为距离（例如，行进的距离）的函数的数学模型。这样的模型可能受约束，诸如最大侧向加速度约束（例如，在1.5米/秒^{2}到3.0米/秒^{2}的范围内）和/或最大侧向加速度衍生约束（例如，在0.8米/秒^{2}到1.2米/秒^{2}的范围内）。这些约束可产生车辆200的最大速度（作为行进距离的函数）。

[0273] 在步骤1560，处理单元110可执行速度模块1406，以基于在步骤1550确定的特性来计算更新的目标速度。更新的目标速度可反映车辆200的更新速度和/或方向以安全地执行下列的任何组合：(i)进入即将到来的弯道；(ii)导航通过弯道；或(iii)离开弯道。更新的目标速度可使用上面结合图14和步骤1530描述的技术来确定。例如，速度模块1406可基于与弯道关联的特性并且基于数学模型和/或公式来确定更新的目标速度。

[0274] 在步骤1570，处理单元110可执行速度模块1406，以将车辆200的速度调整至在步骤1560确定的更新的目标速度。这种调整可使用上面结合步骤1540描述的技术来完成。例如，基于车辆200的当前速度以及在步骤1560确定的更新的目标速度，处理单元110可向车辆200的节流系统220、制动系统230和/或转向系统240发送电子信号（例如，经由CAN总线），以将车辆200的速度改变至更新的目标速度。在这一点，车辆200的当前速度不一定与在步骤1530确定的初始目标速度相同。例如，处理单元110可在步骤1560已经确定更新的目标速度，同时将车辆200的速度调整至初始目标速度。这可能真正存在于车辆200的速度与初始目标速度的差较大（例如，大于10km/hr）并且关联的加速度较小的情况下。

[0275] 在一些实施方式中，系统100可基于对弯道特性的继续观察（例如，基于描绘弯道的车辆200接近的部分的图像数据）来常规更新到目标速度。另外，在系统100将车辆200导航通过弯道之后，系统100可致使车辆200加速至新的目标速度，该新的目标速度适于行进道路的不带弯道的区段，这通过分析由系统100获取的地图数据、位置数据和/或图像数据而确定。

[0276] 模仿前车

[0277] 系统100可提供驾驶员辅助功能性，用于致使车辆200模仿（或者拒绝模仿）不同场景（诸如当前车切换车道、加速或转弯时）下的前车。例如，系统100可构造成通过分析多个图像来检测前车并且确定前车采取的一个或多个动作。在一些场景下，诸如当前车在路口处转弯时，系统100可构造成致使车辆200拒绝模仿转弯。在其它场景下，诸如当前车在路口处转弯且在路口内不变道时，系统100可构造成致使车辆200模仿转弯。系统100还可构造成基于前车的导航历史致使车辆200模仿前车的一个或多个动作。

[0278] 图16A和图16B是与公开的实施方式相一致的模仿前车200b在道路1600a上的一个或多个动作的主车辆200a的概略表示。如图16A和图16B中图示的，主车辆200a可在道路1600a的同一车道中行进的同时追踪前车200b。车道可具有左边缘1620、右边缘1630和中点1610，w_1和w_2分别指示车道的左半边和右半边。主车辆200a和前车200b可定位在车道中，使得车辆都不居中于中点1610上。如图所示16A，例如，主车辆200a可居中于中点1610的右边，使得主车辆200a与左边缘1620之间的距离c_1大于主车辆200a与右边缘1630之间的距离c_2。对比之下，前车200b可居中于中点1610的左边，使得前车200b与左边缘1620之间的距离c_3小于前车200b与右边缘1630之间的距离c_4。主车辆200a和前车200b的位置可以有不同的构

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造。例如，主车辆200a和前车200b可定位在道路1600a上的任何地方。进一步，虽然图16A描绘了具有相机系统的前车200b，但是公开的实施方式并不限于前车200b包括相机系统的构造。

[0279] 主车辆200a的系统100可致使主车辆200a模仿前车200b的一个或多个动作。如图16B所示，例如，主车辆200a可模仿前车200b执行的车道移位。在模仿车道移位之后，距离c_1可等于距离c_3，并且距离c_2可等于距离c_4。在一些实施方式中，主车辆200a可模仿前车200b执行的车道移位，使得距离c_1和c_3与c_2和c_4不等。例如，在主车辆200a模仿主车辆200b的向左车道移位并且(在车道移位之后)定位至主车辆200a的左边的情况下，c_1将小于c_3并且c_2将大于c_4。替代地，在主车辆200a模仿主车辆200b的向左车道移位并且定位至主车辆200a的右边的情况下，c_1将大于c_3并且c_2将小于c_4。

[0280] 图16C和图16D是与公开的实施方式相一致的模仿前车200b在道路1600b上的一个或多个动作的主车辆200a的概略表示。如图16C中图示的，主车辆200a可在前车200b后面行进，前车200b可在路口处左转弯。主车辆200a的系统100可致使主车辆200a模仿前车200b的左转弯，如图16D所示。系统100可基于各种因素(诸如前车200b是否在路口内转弯的同时变道、与前车200b关联的导航历史、主车辆200a与前车200b之间的相对速度差，等)来致使主车辆200a模仿左转弯。另外，主车辆200a可在各种条件下(诸如基于前车200b是否沿着与主车辆200a行进沿着的路线的相同路线或相同部分行进)模仿前车200b。关于系统100可致使主车辆200a模仿前车200b的一个或多个动作的场景的进一步细节在下面结合图17至图22描述。

[0281] 在一些实施方式中，系统100可构造成确定是否模仿前车的特定移动。例如，系统100可确定：前车的某些移动不需要被模仿，因为这种移动不影响前车的路线。例如，系统100可确定：移动的少量改变(诸如在特定车道内移动)不需要被模仿。在其它实施方式中，系统100可实施平稳操作以过滤出前车的少量移动。平稳操作可致使主车辆实施前车的更显著和/或重要的移动(例如，变道)，同时过滤出较少量的不会影响前车的整体路线的移动。

[0282] 图17是与公开的实施方式相一致的存储器的示例性框图，该存储器被构造成存储用于执行一个或多个操作的指令。如图17所示，存储器140可存储车道约束模块1702、动作检测模块1704和动作响应模块1706。公开的实施方式并不限于任何特定构造的存储器140。进一步，处理单元110可执行存储在任何模块1702-1706(包括在存储器140中)中的指令。

[0283] 在一个实施方式中，车道约束模块1702可存储软件指令(诸如计算机视觉软件)，当由处理单元110执行时，该软件指令确定与主车辆200a的行进车道关联的一个或多个约束。车道约束可包括车道的中点1610、左边缘1620和右边缘1630。车道约束还可包括标记在道路1600a或1600b的表面上的一个或多个线或其它符号。处理单元110可执行车道约束模块1702，以通过例如分析一组或多组图像和/或使用地图和/或位置数据(例如，存储在地图数据库160中的数据)来确定约束。图像组可由图像捕获装置122、124和126中的一个或多个获取。基于该分析，系统100(例如，经由处理单元110)可致使主车辆200a在由左边缘1620和右边缘1630限定的车道内行进。在一些实施方式中，如果距离c_1或c_2之一小于预定阈值，则系统100可致使主车辆200a远离左边缘1620或右边缘1630。

[0284] 在一个实施方式中，动作检测模块1704可存储软件指令(诸如计算机视觉软件)，

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当由处理单元110执行时，该软件指令检测在主车辆200a前方行进的前车200b采取的一个或多个动作。前车200b可在与主车辆200a相同或不同的车道中行进。处理单元110可执行动作检测模块1704，以通过例如分析由图像捕获装置122、124和126中的一个或多个获取的一组或多组图像来检测前车200b采取的一个或多个动作。基于该分析，例如，处理单元110可确定前车200b已变换车道、已转弯、加速、减速、施加制动等。作为另一示例，前车200b可执行机动，使得前车200b的邻近第一车道约束的那一侧的第一偏移距离不同于前车200b的邻近第二车道约束的那一侧的第二偏移距离。例如，处理单元110可基于上面结合图5A至图5D描述的技术来执行这种分析。

[0285] 在一个实施方式中，动作响应模块1706可存储软件指令(诸如计算机视觉软件)，当由处理单元110执行时，该软件指令基于系统100(例如，经由执行动作检测模块1704)检测的前车200b所采取的一个或多个动作来确定主车辆200a采取的一个或多个动作。例如，处理单元110可执行动作响应模块1706，以确定是否模仿前车200b的一个或多个动作。该确定可基于前车200b的动作(例如，转弯、车道移位，等等)的性质、与主车辆200a关联的信息(例如，距车道路边的速度、距离c_1和c_2，等等)、道路和环境条件(例如，坑洼、大雨或风，等等)，等。在处理单元110确定模仿前车200b的一个或多个动作的情况下，处理单元110可通过以下手段完成这：例如向主车辆200a的节流系统220、制动系统230和/或转向系统240发送电子信号(例如，经由CAN总线)，以触发转弯、车道移位、主车辆200a的速度改变和/或方向改变。处理单元110可使用上面结合图4至图7描述的技术以致使主车辆200a模仿一个或多个动作。为了模仿一个或多个动作，系统100可向节流系统220、制动系统230和转向系统240中的一个或多个提供控制信号，以(例如，通过致使加速、转弯、车道移位，等等)导航车辆200。进一步，一个或多个致动器可控制节流系统220、制动系统230和/或转向系统240。

[0286] 图18是示出与公开的实施方式相一致的用于致使主车辆200a模仿前车200b的一个或多个动作的示例性过程的流程图。在步骤1810，处理单元110可经由位于处理单元110与图像获取单元120之间的数据接口128接收多个图像。例如，包括在图像获取单元120中的相机(诸如图像捕获装置122)可捕获多个图像并且经数字连接(例如，USB、无线、蓝牙，等等)将图像发送到处理单元110。在一些实施方式中，处理单元110可经由多个数据接口接收多于一个的多个图像。例如，处理单元110可从图像捕获装置122、124、126中的每个接收多个图像，图像捕获装置122、124、126中的每个均可具有关联的数据接口用于与处理单元110通信数据。公开的实施方式并不限于任何特定的数据接口构造或协议。

[0287] 在步骤1820和1830，处理单元110可执行车道约束模块1702，为主车辆200a的每侧确定与主车辆200a的行进车道关联的约束。处理单元110可通过分析在步骤1810接收的图像来确定约束。由此，在步骤1820，处理单元110可确定在主车辆200a的第一侧上的第一车道约束(例如，主车辆200a的左侧与车道的左边缘1620之间的距离，c_1)，以及在步骤1830，确定在与第一侧相反的第二侧上的第二车道约束(例如，主车辆200a的右侧与车道的右边缘1620之间的距离，c_2)。在一些实施方式中，处理单元110可通过使用地图和/或指示主车辆200a相对于车道的中点1610、左边缘1620和右边缘1630的位置的位置数据(例如，存储在地图数据库160中的数据)来确定约束。处理单元110可基于分析在步骤1810接收的图像以及地图和/或位置数据两者来确定约束；这样做可增加与约束关联的置信水平。

[0288] 在步骤1840，处理单元110可执行车道约束模块1702，以致使主车辆200a在步骤

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1820和1830确定的车道约束内行进。例如，主车辆200a的左侧可定位至左边缘1620的左边，或者主车辆200a的右侧可定位至右边缘1630的右边。在这样的情景下，处理单元110可向主车辆200a的节流系统220、制动系统230和/或转向系统240发送电子信号(例如，经由CAN总线)，以致使主车辆200a调整其位置并且在车道约束内行进。

[0289] 在步骤1850，处理单元110可执行动作检测模块1704，以通过分析图像将前车200b定位在在步骤1810接收的图像内。处理单元110可使用上面结合图5A和图5B描述的技术来检测车辆在图像中的存在。对于每个被检测车辆，处理单元110可构建被检测车辆相对于主车辆200a的位置、速度(例如，速度和方向)和加速度的多帧模型。处理单元110可使用上面结合图5A和图5B描述的技术来构建这样的模型。另外，处理单元110可确定与每个被检测车辆关联的行进车道，基于例如车道或其它道路标记以及在步骤1820和1830确定的车道约束。处理单元110可确定前车200b为最接近的被检测车辆，并且在与主车辆200a相同的车道中行进。在步骤1860，处理单元110可执行动作检测模块1704，以确定步骤1850在图像内检测的前车200b所采取的一个或多个动作。例如，处理单元110可确定：前车200b已变换车道、已转弯、加速、减速，等。另外，处理单元110可分析图像，以确定与前车200b关联的特性，诸如其(例如，相对于主车辆200a的)速度和位置。这些确定可基于上面结合图5A和图5B描述的技术。在一些实施方式中，处理单元110可分析图像，以确定与前车200b执行的动作关联的特性。例如，在前车200b转弯的情况下，处理单元110可确定前车200b正好在开始转弯之前的位置信息、前车200b在完成转弯时的位置信息、转弯半径以及描述前车200b在转弯时的速度改变(例如，经过一段时间)的速度轮廓。

[0290] 在步骤1870，处理单元110可执行动作响应模块1706，以致使主车辆200a模仿在步骤1850确定的前车200b的一个或多个动作。例如，处理单元110可向主车辆200a的节流系统220、制动系统230和/或转向系统240发送电子信号(例如，经由CAN总线)，以触发主车辆200a的转弯、车道移位、速度改变和/或方向改变。另外，处理单元110可构建一组路径点，以引导主车辆200a的位置和速度改变。路径点可基于由多项式(例如，第三多项式)和与目标车辆(诸如前车200b)关联的目标坐标表示的车道标线(例如，中点1610、左边缘1620、右边缘1630，等等)。处理单元110可调整多项式的系数，使得路径点超越目标坐标。处理单元110还可基于预定偏移量使路径点(例如，相对于左边缘1620和右边缘1630)偏移。在处理单元110调整多项式系数并使路径点偏移时，处理单元110还可针对形成在路径点之间的每个得到的区段来计算局部曲率信息。

[0291] 在一些实施方式中，处理单元110(例如，经由执行动作响应模块1706)可在与两个车辆关联的某一位置、速度和/或加速度约束内致使主车辆200a模仿前车200b。例如，约束可能需要主车辆200a与前车200b之间的预定最小距离(例如，安全距离)或车辆之间的速度和/或加速度的预定最大差。由此，如果模仿前车200b执行的动作将违反一个或多个约束(例如，模仿加速将导致主车辆200a太接近前车200b)，则处理单元110可致使主车辆200a拒绝模仿前车200b的一个或多个动作。另外，甚至在模仿前车200b执行的动作(例如，车道移位)的同时，处理单元110可致使主车辆200a跟随前车200b的速度轮廓并且维持与前车200b的预定距离或安全距离。处理单元110完成这可通过致使主车辆200a：(i)当间距大于预定最小距离时，不断缩短与前车200b的距离差距；(ii)不断缩短主车辆200a与前车200b的速度之间的差距；以及(iii)将前车200b的加速度匹配至与预定约束一致的程度。为了控制这

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些动作应该执行到什么程度，处理单元110可基于与前车200b的当前预测距离实时将每个动作与权重关联。由此，例如，在与前车200b的距离减小时，更大的权重可加到减速上，而非匹配前车200b的加速。

[0292] 作为另一示例，在主车辆200a以大于前车200b速度的速度接近前车200b的情况下，处理单元110可致使主车辆200a逐渐减速，使得当两个车辆之间的距离等于预定安全距离(诸如最小跟随距离)时，两个车辆的速度相同。在另一示例中，在前车200b突然出现在主车辆200a前方的情况下，致使两个车辆之间的距离小于最小跟随距离，处理单元110可致使主车辆200a逐渐减速以避免更接近前车200b，同时增加车辆之间的距离直到该距离到达最小跟随距离。

[0293] 图19是示出与公开的实施方式相一致的用于致使主车辆200a拒绝模仿前车200b的转弯的示例性过程1900的流程图。在步骤1910，如上面结合图18的步骤1810描述的，处理单元110可经由位于处理单元110与图像获取单元120之间的数据接口128接收多个图像。在步骤1920，如上面结合图18的步骤1850描述的，处理单元110可执行动作检测模块1704，以通过分析图像将前车200b定位在步骤1910接收的图像内。在步骤1925，处理单元110可执行动作检测模块1704，以使用上面结合图18的步骤1860描述的技术来确定前车200b是否在路口处转弯。如果确定前车200b在路口处转弯(步骤1925，是)，则在步骤1930，处理单元110可致使主车辆200a拒绝模仿前车200b的转弯。否则(步骤1925，否)，过程1900结束。

[0294] 图20是示出与公开的实施方式相一致的用于致使主车辆200a模仿或拒绝前车200b的转弯的示例性过程2000的流程图。在步骤2010，如上面结合图18的步骤1810描述的，处理单元110可经由位于处理单元110与图像获取单元120之间的数据接口128接收多个图像。在步骤2020，如上面结合图18的步骤1850描述的，处理单元110可执行动作检测模块1704，以通过分析图像将前车200b定位在步骤2010接收的图像内。在步骤2025，处理单元110可执行动作检测模块1704，以使用上面结合图18的步骤1860描述的技术来确定前车200b是否在路口处转弯。如果确定前车200b在路口处转弯(步骤2025，是)，则在步骤2035，处理单元110可执行动作检测模块1704，以使用上面结合图18的步骤1860描述的技术来确定前车200b是否在路口内变道。否则(步骤2025，否)，过程2000结束。如果确定前车200b在路口内变道(步骤2035，是)，则在步骤2050，处理单元110可致使主车辆200a拒绝模仿前车200b的转弯。否则(步骤2035，否)，在步骤2040，处理单元110可致使主车辆200a模仿前车200b的转弯。

[0295] 图21是示出与公开的实施方式相一致的用于致使主车辆200a模仿第一前车的一个或多个动作的另一示例性过程2100的流程图。在步骤2110，如上面结合图18步骤1810描述的，处理单元110可经由位于处理单元110与图像获取单元120之间的数据接口128接收多个图像。在步骤2120和2130，如上面结合图18的步骤1850描述的，处理单元110可执行动作检测模块1704，以通过分析图像将第一和第二前车定位在步骤2110接收的图像内。在步骤2135，处理单元110可执行动作检测模块1704，以使用上面结合图18的步骤1860描述的技术来确定第一前车路径的转弯半径是否小于第二前车路径。如果确定第一前车路径的转弯半径小于第二前车路径(步骤2135，是)，则在步骤2140，处理单元110可致使主车辆200a模仿第一前车的转弯。否则(步骤2135，否)，过程2100结束。

[0296] 图22是示出与公开的实施方式相一致的用于基于导航历史来致使主车辆200a模

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仿前车200b的一个或多个动作的示例性过程2200的流程图。在步骤2210，如上面结合图18的步骤1810描述的，处理单元110可经由位于处理单元110与图像获取单元120之间的数据接口128接收多个图像。在步骤2220，如上面结合图18的步骤1850描述的，处理单元110可执行动作检测模块1704，以通过分析图像将前车200b定位在步骤2210接收的图像内。

[0297] 在步骤2230，处理单元110可通过分析在步骤2210接收的图像来确定前车200b的位置信息。前车200b的位置信息可指示前车200b相对于主车辆200a的位置。处理单元110可通过使用上面结合图5A至图5D描述的技术来分析图像以得到前车200b的位置信息以及前车200b采取的一个或多个动作。

[0298] 在步骤2240，处理单元110可将在步骤2230确定的前车200b的位置信息与预定地图数据(例如，存储在地图数据库160中的数据)比较。例如，通过将位置信息与预定地图数据比较，处理单元110可得到前车200b的位置坐标。另外，处理单元110可使用预定地图数据，作为与在步骤2230确定的位置信息关联的置信水平的指示器。

[0299] 在步骤2250，处理单元110可通过例如跟踪前车200b采取的动作来创建与前车200b关联的导航历史。处理单元110可将前车200b采取的动作(例如，在步骤2230根据分析图像而确定)与步骤2240的预定地图数据关联。由此，导航历史可指示执行某些动作(例如，转弯、车道移位，等等)的前车200b处于某一位置坐标。

[0300] 在步骤2260，处理单元110可执行动作响应模块1706，以基于在步骤2250创建的导航历史并且使用上面结合图18的步骤1870描述的技术来确定是否致使主车辆200a模仿前车200b的一个或多个动作。例如，甚至在根据分析图像(例如，在步骤2230)没有检测到转弯的情况下，当导航历史指示前车200b已成功导航至少一先个前转弯时，处理单元110(例如，经由动作响应模块1706)可致使主车辆200a模仿前车200b的转弯。更一般地，在导航历史指示前车200b已成功执行这样的动作的情况下，处理单元110可致使主车辆200a模仿前车200b采取的动作。

[0301] 导航车辆以超越另一车辆

[0302] 系统100可提供驾驶员辅助功能性，用于监测车辆200附近并且倘若变道被认为置于致使诸如与另一车辆(例如，目标车辆)碰撞的风险下则中止变道。例如，如果确定目标车辆位于与车辆200不同的车道中，则系统100可使车辆200能够完成对目标车辆的超越。如果，在完成超越之前，系统100确定目标车辆正进入车辆200的行进车道，系统100可致使车辆200中止超越。例如，中止超越可包括致使车辆200制动或致使车辆200停止加速。

[0303] 如图23中图示的，车辆200可行进在道路2300上。车辆200可配备有系统100并且可实施任何公开的实施方式来识别车道约束以及在车道约束内操作车辆200。系统100还可促进车辆200做出的变道。例如，系统100可确定情形是否允许车辆200安全地变道，如果在变道期间情形改变，则致使车辆200中止变道。

[0304] 如图23所示并且如先前相对于图8A至图8D讨论的，车辆200可包括第一车辆侧802，第一车辆侧802距第一车道约束2302可以是第一距离805。类似地，车辆200可包括与第一车辆侧802相反的第二车辆侧812，并且第二车辆侧812距第二车道约束2304可以是第二距离815。以这种方式，第一车道约束810和第二车道约束2304可限定车辆200可行进的车道2330。

[0305] 系统100可基于由图像捕获装置122-126中的一个或多个获取的多个图像来确定

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第一车道约束2302和第二车道约束2304。根据一些实施方式，第一车道约束2302和/或第二车道约束2304可由可见的车道边界(包括标记在路面上的线)识别。另外地或替代地，第一车道约束2302和/或第二车道约束2304可包括路面的路边。根据一些实施方式，系统100可通过识别路面宽度2320的中点(或者车辆200可用作导航基准的任何其它合适的道路特征)来确定第一车道约束2302和/或第二车道约束2304。例如，当指定道路车道的线未被喷涂或以其它方式贴标签时，系统100可采取这种方式识别车道约束。

[0306] 当超越目标车辆2310时，车辆200的变道可能由于目标车辆2330的轨迹改变而复杂化。由此，系统100可基于对图像捕获装置122-126中的一个或多个获取的多个图像的分析来识别目标车辆2310。系统100还可识别目标车辆2310行进的第二车道2340。进一步，系统100可确定第二车道2340是否不同于车辆200行进的车道2330。如果第二车道2340不同于车道2330，则系统100可构造成使车辆200能够超越目标车辆2310。

[0307] 系统100还可基于多个图像来监测目标车辆2310。例如，系统100可监测目标车辆2310的位置，诸如监测目标车辆2310相对于车辆200、相对于第一车道约束2302和/或第二车道约束2304的位置、绝对位置或相对于另一基准点的位置。另外地或替代地，监测目标车辆2310的位置可包括估算目标车辆2310的速度。

[0308] 如果系统100确定目标车辆2310正进入车辆200行进的车道2330，则系统100可致使车辆200中止对目标车辆2310的超越。例如，系统100可致使车辆200停止加速或进行制动。另外地或替代地，系统100可发布语音通知，诸如通知车辆200的驾驶员中止变道。

[0309] 图24A是与公开的实施方式相一致的存储器140的示例性框图，该存储器140可存储用于执行一个或多个操作的指令。如图24A中图示的，存储器140可存储用于识别目标车辆的一个或多个模块和本文中描述的响应。例如，存储器140可存储车道约束模块2400、目标车辆获取模块2410和动作模块2415。

[0310] 在一个实施方式中，车道约束模块2400可存储指令，当由处理单元110执行时，该指令可检测并且限定第一车道约束2302和第二车道约束2304。例如，处理单元110可执行车道偏移模块2400，以处理从至少一个图像捕获装置122-124接收的多个图像并且检测第一车道约束2302和第二车道约束2304。如上面讨论的，这可包括识别喷涂的车道线或标记物和/或测量路面的中点。处理单元110可基于上面结合图5A至图5D描述的技术来执行这种分析。

[0311] 在一些实施方式中，目标获取模块2410可存储指令，当由处理单元110执行时，该指令可检测目标车辆2310的存在并且监测目标车辆2310的位置。例如，目标获取模块2410可处理多个图像，以检测并监测目标车辆2310。另外地或替代地，当执行目标获取模块2410时，处理单元110可接收来自指示目标车辆2310的存在和/或地点的另一模块或其它系统的信息。处理单元110可基于上面结合图5A至图5D描述的技术来执行这种分析。

[0312] 处理单元110可构造成确定一个或多个对象(诸如车辆200附近的目标车辆2310)的存在。例如目标车辆2310可包括在车辆200附近行进的另一车辆，诸如汽车、卡车或摩托车。对于每个目标车辆2310，处理单元110可确定偏移轮廓。偏移轮廓可包括确定在其当前预测位置中目标车辆2310是否将位于车辆200的预定范围内。如果处理单元110确定目标车辆2310位于或将位于车辆200的预定范围内，则处理单元可确定：为使车辆200绕过目标车辆2310，在第一车道约束810和第二车道约束820内是否有足够的空间。如果没有足够的空

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间，则处理单元110可执行变道。如果有足够的空间，则处理单元110可确定在车辆200与目标车辆2310之间距离缩短之前是否有足够的时间绕过目标车辆2310。如果有足够的时间，则处理单元110可启动或激活偏移机动以绕过目标车辆2310。偏移机动可由处理单元110执行，使得车辆200的移动对驾驶员而言平稳而舒适。例如，偏移摆率可大约为0.15米/秒到0.75米/秒。偏移机动可执行为使得偏移机动的最大振幅将发生在车辆200与对象825之间的间距缩短的时候。如果没有足够的时间，则处理单元110可启动制动，然后启动偏移机动。

[0313] 进一步，处理单元110可执行动作模块2415，以中止车辆200超越目标车辆2310的计划。如果目标车辆2310不在车辆200的车道2330中，则包括在动作模块1230中的指令可使车辆200能够超越目标车辆2330。然而，如果执行目标车辆获取模块2410指示目标车辆2310正变道进入车辆200的车道2330，则处理单元110可执行包括在动作模块2415中的指令以中止车辆200的变道。例如，处理单元110可向车辆200的节流系统220、制动系统230和/或转向系统240发送电子信号以中止变道。另外地或替代地，处理单元可致使语音通知发出。

[0314] 图24B图示了与公开的实施方式相一致的用于导航侵入车辆之中的车辆的示例性过程2420的流程图。过程2420可识别限定了车辆(例如，车辆200)行进的行进车道的车道约束，识别并监测目标车辆(例如，车辆2310)，并且使车辆能够超越目标车辆或者如果确定目标车辆正进入车辆的行进车道则中止超越。

[0315] 在步骤2430，图像捕获装置122、124和/或126中的至少一个可获取车辆200附近区域的多个图像。例如，包括在图像获取单元120中的相机(诸如图像捕获装置122)可捕获多个图像并且经数字连接(例如，USB、无线、蓝牙，等等)将图像发送到处理单元110。在一些实施方式中，处理单元110可经由多个数据接口接收多于一个的多个图像。例如，处理单元110可从图像捕获装置122、124、126中的每个接收多个图像，图像捕获装置122、124、126中的每个均可具有关联的数据接口用于与处理单元110通信数据。公开的实施方式并不限于任何特定的数据接口构造或协议。

[0316] 接下来，在步骤2440，处理单元110可使用经由数据接口128接收的多个图像来确定在第一车辆侧802上的第一车道约束和在第二车辆侧812上的第二车道约束。例如，作为实施步骤2440的一部分，处理单元110可执行车道约束模块910的指令。进一步，作为确定第一车道约束和第二车道约束的一部分，处理单元110可使用上面结合图5A至图5D讨论的过程中的一个或多个。

[0317] 在步骤2450，处理单元110可获取目标车辆2310。为了获取目标车辆2310，处理单元110可执行目标车辆获取模块2410。例如，处理单元110可执行指令来分析获取的图像，以识别目标车辆2310行进的第二车道2340并且确定目标车辆2310是否在车辆200行进的车道2330中行进。这种确定可基于上面结合图5A至图5D描述的技术。

[0318] 在步骤2455，处理单元110可确定目标车辆2310行进的第二车道2340是否不同于车辆200行进的车道2330。

[0319] 在步骤2460，如果第二车道2340不同于车辆200行进的车道2330，则处理单元110可使车辆200能够超越目标车辆2310。为了使车辆200能够超越目标车辆2310，处理单元可执行动作模块2415。

[0320] 接下来，在步骤2465，处理单元110可执行目标获取模块2410以监测目标车辆2310。这可包括估算目标车辆2310的速度并且确定目标车辆2310诸如相对于车辆200的地

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点。

[0321] 步骤2470可包括确定目标车辆2310是否已进入车道2330。如果处理单元110确定目标车辆2310尚未进入车道2330，则在步骤2480，处理单元110可允许车辆200完成超越。

[0322] 在步骤2490，如果处理单元110确定目标车辆2310已进入车道2330(或者正进入车道2330或以其它方式处于将要把车辆2310带入车道2330中的轨迹上)，则处理单元110可执行动作模块2415以中止超越。例如，这可包括经由扬声器360向车辆200的驾驶员发布语音通知。另外地或替代地，步骤2490可包括执行包括在动作模块2415中的指令，以致使处理单元110向车辆200的节流系统220、制动系统230和/或转向系统240发送电子信号，从而中止变道。

[0323] 导航车辆以避免侵入交通

[0324] 系统100可提供驾驶员辅助功能性，用于监测车辆200附近并且响应于侵入车辆200的另一车辆的存在。监测车辆200附近可包括监测碰撞阈值。例如碰撞阈值可包括将要碰撞的时间或车辆200与其它交通之间的最小预定距离。系统100可进一步致使车辆200采取躲避动作以避免侵入交通。例如，躲避动作可包括制动、变道或以其它方式变动车辆200的路线。

[0325] 如图25中图示的，车辆200可在道路2500上行进。车辆200可包括用于检测并响应于侵入交通的系统100。例如，车辆200可确定另一车辆正进入车辆200的行进车道，或者以其它方式确定另一车辆正越过碰撞阈值。车辆200可能通过诸如变动路线、制动或加速而对侵入车辆做出反应。

[0326] 如相对于图8A至图8D讨论的并且如图25所示，车辆200可包括第一车辆侧802，第一车辆侧802距第一车道约束2502可以是第一距离805。类似地，车辆200可包括与第一车辆侧802相反的第二车辆侧812，并且第二车辆侧812距第二车道约束2504可以是第二距离815。以这种方式，第一车道约束2502和第二车道约束2504可限定车辆200可行进的车道2505。

[0327] 系统100可基于由图像捕获装置122-126中的一个或多个获取的多个图像来确定第一车道约束2502和第二车道约束2504。根据一些实施方式，第一车道约束2502和/或第二车道约束2504可由可见的车道边界(诸如标记在路面上的线)识别。另外地或替代地，第一车道约束2502和/或第二车道约束2504可包括路面的路边。根据一些实施方式，系统100可通过识别路面宽度的中点2520(或者任何其它合适的道路特征车辆200可用作导航基准)来确定第一车道约束2502和/或第二车道约束2502。当例如指定道路车道的线未被喷涂或以其它方式贴标签时，系统100可采取这种方式识别车道约束。

[0328] 检测第一车道约束2502和/或第二车道约束2504可包括处理单元110确定它们在相机坐标系统中的三维模型。例如，第一车道约束2502和/或第二车道约束2504的三维模型可由第三多项式描述。除了第一车道约束2502和/或第二车道约束2504的三维建模，处理单元110可估算运动参数，诸如车辆200的速度、偏航和俯仰速率以及加速度。可选地，处理单元可检测静态和移动车辆及其位置、航向、速度和加速度(都相对于车辆200)。处理单元110可确定道路标高模型以将从多个图像获取的信息转换为三维空间。

[0329] 车辆200的驾驶员无法假设的是，如果使交通移位到车辆200所行驶的车道2505中是安全的，则在相邻或附近相邻车道中行进的其它交通将仅变道。由此，可期望考虑并监测

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在近旁车道中行进的交通，以检测对于车辆200的车道2505的侧向侵入，使得车辆200可对侧向侵入做出反应以避免碰撞。系统100可基于多个图像来识别侵入车辆2510并且确定侵入车辆2510正接近车辆200。然后，系统100可产生动作来考虑侵入车辆。例如，系统100可致使车辆200维持当前速度并且在第一车道约束2502和第二车道约束2504内行进，使得在侵入车辆2510接近的第一车辆侧802上的第一距离2530大于第二距离2540。

[0330] 处理单元110可构造成确定车辆200附近的一个或多个侵入车辆2510的存在。对于每个侵入车辆2510，处理单元110可确定偏移轮廓。偏移轮廓可包括确定在其当前预测位置中侵入车辆2510是否将位于车辆200的预定范围内。如果处理单元110确定侵入车辆2510位于或将位于车辆200的预定范围内，则处理单元可确定：为使车辆200绕过侵入车辆2510，在第一车道约束2502和第二车道约束2504内是否有足够的空间。如果没有足够的空间，则处理单元110可执行变道。如果有足够的空间，则处理单元110可确定在车辆200与侵入车辆2510之间距离缩短之前是否有足够的时间绕过侵入车辆2510。

[0331] 例如，如果有足够的时间，则处理单元110可启动或激活偏移机动以绕过侵入车辆2510。偏移机动可由处理单元110执行，使得车辆200的移动对驾驶员而言平稳而舒适。例如，偏移摆率可大约为0.15米/秒到0.75米/秒。偏移机动可执行为使得偏移机动的最大振幅将发生在车辆200与侵入车辆2510之间的间距缩短的时候。如果没有足够的时间，则处理单元110可启动制动(例如，经由向制动系统230发送电子信号)，然后启动偏移机动(例如，通过向节流系统220和/或转向系统240发送电子信号)。

[0332] 系统100可基于由图像捕获装置122-126中的一个或多个获取的多个图像来确定：侵入车辆2510已越过至少一个碰撞阈值。例如，至少一个碰撞阈值可包括车辆200与侵入车辆2510之间的最小预定距离2550。例如，如图25中图示的，侵入车辆2510示出为超过最小预定距离2550。另外地或替代地，至少一个碰撞阈值可包括车辆200与侵入车辆2510将要碰撞的时间。基于时间的碰撞阈值可基于下列来确定：车辆200与侵入车辆2510之间的距离、车辆200和/或侵入车辆2510的速度、车辆200和/或侵入车辆2510的侧向速度和/或车辆200和/或侵入车辆2510的加速度。基于碰撞时间的碰撞阈值可设定为允许系统100有足够的时间来有效进行躲避动作以避免碰撞。

[0333] 如果系统100确定至少一个碰撞阈值已被越过，则系统100可致使车辆200采取躲避动作。例如，这可包括致使车辆200的其它子系统操作。由此，系统100可操作成通过与节流系统220、制动系统230和/或转向系统240通信来致使车辆200的速度增加，以改变车辆200的速度和/或方向。

[0334] 躲避动作可包括致使车辆200变道。可期望在例如车辆200在多车道高速公路上行进的情况下响应，并且系统100确定：变道远离侵入车辆2510将避免碰撞。躲避动作可包括使车辆200变动其路线。另外地或替代地，躲避动作可包括变动车辆200的路线。例如，为了采取躲避动作，处理单元110可向节流系统220、制动系统230和/或转向系统240发送电子信号。

[0335] 系统100还可构造成在躲避动作已完成之后致使车辆200采取动作。例如，系统100可致使车辆200返回到车辆200行进的车道2505的中点2520。另外地或替代地，系统100可在响应于侵入车辆2510制动之后致使车辆200恢复预设速度。

[0336] 图26是与公开的实施方式相一致的存储器140的示例性框图，该存储器140可存储

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用于检测并且响应于车辆的交通侧向侵入的指令。如图26中图示的，存储器140可存储车道约束模块2610、侵入车辆获取模块2620和动作模块2630。

[0337] 在一个实施方式中，车道约束模块2610可存储指令，当由处理单元110执行时，该指令可检测并且限定第一车道约束2502和第二车道约束2504。例如，处理单元110可执行车道偏移约束模块2610，以处理从至少一个图像捕获装置122-126接收的多个图像并且检测第一车道约束2502和第二车道约束2504。如上面讨论的，这可包括识别喷涂的车道线和/或测量路面的中点。处理单元110可基于上面结合图5A至图5D描述的技术来执行这种分析。

[0338] 在一个实施方式中，侵入车辆获取模块2620可存储指令，当由处理单元110执行时，该指令可检测侵入车辆2510的存在并且监测侵入车辆2510。例如，侵入车辆获取模块2620可包括用于确定侵入车辆2510关于车辆200的相对地点的指令。在一些实施方式中，这可包括监测侵入车辆200的速度。根据一些实施方式，侵入车辆获取模块2620可确定侵入车辆2510是否已超过碰撞阈值。例如，碰撞阈值可以是车辆200与侵入车辆2510之间的最小预定距离。如果侵入车辆2510比最小预定距离更接近车辆200，则处理单元110可确定侵入车辆2510的确在侵入并且执行指令以避免与侵入车辆2510碰撞。

[0339] 另外地或替代地，碰撞阈值可包括碰撞时间。基于时间的碰撞阈值可基于下列来确定：车辆200与侵入车辆2510之间的距离、车辆200和/或侵入车辆2510的速度、车辆200和/或侵入车辆2510的侧向速度和/或车辆200和/或侵入车辆2510的加速度。基于碰撞时间的碰撞阈值可设定为允许处理单元110和系统100有足够的时间来有效进行躲避动作以避免碰撞。

[0340] 进一步，处理单元110可执行动作模块2630，以响应于侵入车辆2510的检测和/或越过碰撞阈值。例如，动作模块2630可包括这样的指令，该指令用于致使车辆200维持当前速度并且在第一车道约束2502和第二车道约束2504内行进，使得第一距离2530大于第二距离2540。第一距离2530可位于车辆200的与侵入车辆2510相同的那一侧上，使得车辆200在仍位于第一车道约束2502和第二车道约束2504内的同时更远离侵入车辆2510。如果处理单元110确定碰撞阈值已被越过，则处理单元110可执行动作模块2630，以致使车辆200采取躲避动作，诸如变动路线、制动和/或变道。动作模块2630还可包括这样的指令，在完成躲避动作之后，该指令致使车辆200恢复路线。例如，在制动或返回到车道2505的中央之后，处理单元110可致使车辆200恢复预设速度。

[0341] 图27图示了与公开的实施方式相一致的检测并且响应于车辆的交通侧向侵入的示例性过程2720的流程图。过程2720可识别限定车辆行进的行进车道的车道约束，确定侵入车辆2510是否接近，并且致使车辆200维持当前速度并在第一车道约束2501和第二车道约束2504内行进，使得在车辆200的侵入车辆2510接近的那一侧上的第一距离2530大于第二距离2540。

[0342] 在步骤2730，至少一个图像捕获装置122、124和/或126可获取车辆200附近区域的多个图像。例如，包括在图像获取单元120中的相机(诸如图像捕获装置122)可捕获多个图像并且经数字连接(例如，USB、无线、蓝牙，等等)将图像发送到处理单元110。在一些实施方式中，处理单元110可经由多个数据接口接收多于一个的多个图像。例如，处理单元110可从图像捕获装置122、124、126中的每个接收多个图像，图像捕获装置122、124、126中的每个均可具有关联的数据接口用于与处理单元110通信数据。公开的实施方式并不限于任何特定

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的数据接口构造或协议。

[0343] 接下来，在步骤2740，处理单元110可使用经由数据接口128接收的多个图像来确定在第一车辆侧802上的第一车道约束和在第二车辆侧812上的第二车道约束。例如，作为实施步骤2740的一部分，处理单元110可执行车道约束模块2610的指令。进一步，作为确定第一车道约束和第二车道约束的一部分，处理单元110可使用上面结合图5A至图5D讨论的过程中的一个或多个。

[0344] 在步骤2750，处理单元110可确定侵入车辆2510是否接近。为了做出这种确定，处理单元110可执行侵入车辆获取模块2620。侵入车辆获取模块2620可包括处理图像以检测其它交通的指令。这可包括在车辆200的特定范围内识别车辆，诸如邻近车辆200的那些车辆。这些邻近车辆可能是侵入车辆2510。

[0345] 一旦侵入车辆2510被识别，处理单元就可确定关于车辆2510的更多信息。例如，在步骤2555，处理单元110可确定目标车辆2330是否已超过碰撞阈值。例如，碰撞阈值可以是车辆200与侵入车辆2510之间的最小预定距离。如果侵入车辆2510比最小预定距离更接近车辆200，则处理单元110可确定侵入车辆2510的确在侵入并且执行指令以避免与侵入车辆2510碰撞。

[0346] 另外地或替代地，碰撞阈值可以是碰撞时间。基于时间的碰撞阈值可基于下列来确定：车辆200与侵入车辆2510之间的距离、车辆200和/或侵入车辆2510的速度、车辆200和/或侵入车辆2510的侧向速度和/或车辆200和/或侵入车辆2510的加速度。基于碰撞时间的碰撞阈值可设定为允许处理单元110和系统100有足够的时间来有效进行躲避动作以避免碰撞。

[0347] 在步骤2760，处理单元110可致使车辆200维持当前速度并且在第一车道约束2502和第二车道约束2504内行进。为了致使车辆200以这种方式操作，处理单元110可执行动作模块2630。另外地或替代地，步骤2760可包括执行动作模块1230上的指令，以致使处理单元110向车辆200的加速器2610、制动器2620和/或转向系统发送电子信号，致使车辆200维持当前速度并且在第一车道约束810和第二车道约束820内行进。

[0348] 在步骤2755，如果处理单元110确定碰撞阈值已被超过，则处理单元110可采取躲避动作。躲避动作可包括致使车辆200变道。可期望响应的是，例如，车辆200在多车道高速公路上行进，并且系统100确定变道远离侵入车辆2510将避免碰撞。躲避动作可包括使车辆200变动其路线。另外地或替代地，躲避动作可包括变动车辆200的路线。例如，处理单元110可通过向车辆200的节流系统220、制动系统230和/或转向系统240发送电子信号来采取躲避动作。在完成躲避动作之后，在步骤2780，处理单元110可控制车辆200恢复其原先的导航(例如，恢复导航至期望的地点)。

[0349] 车辆导航的多阈值反应区

[0350] 系统100可提供驾驶员辅助功能性，用于产生车辆200的响应，诸如制动、加速、切换车道、转弯和/或其它导航响应。例如，如果系统100检测存在着位于车辆200之前以慢于车辆200的速度行进的另一车辆，系统100可通过制动致使车辆200以减小其速度。系统100可施加制动轮廓，该制动轮廓考虑到风险(例如，碰撞的风险)的即时性，为驾驶员提供自然驾驶感觉。

[0351] 例如，取决于与另一车辆碰撞的情形和确定性风险，系统100可产生各种不同响

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应。如果目标车辆在前面足够远并且碰撞的确定性风险较低，则系统100响应于前面目标车辆的速度或方向改变可不采取动作。当目标车辆可能更近时或者当碰撞的风险上升超过预定水平时，系统100可产生响应，诸如制动，等等。当碰撞风险甚至更高时（例如，系统100确定碰撞将迫在眉睫而无躲避动作），系统100可致使车辆100采取躲避动作，诸如最大或近乎最大制动、方向改变，等等。

[0352] 图28A和图28B是与公开的实施方式相一致的主车辆200a在道路2800上的概略表示。在一些实例中，道路2800可分为两个车道，车道2810和车道2820。诸如目标车辆200b的目标对象可在同一车道（例如，如图28A和图28B所示的车道2820）的主车辆200a之前行进或在不同车道中。如图28A描绘的示例所示，主车辆200a和目标车辆200b可分离距离d_1。在图28A描绘场景之后的给定时间里，如图28B所示，主车辆200a和目标车辆200b可分离距离d_2，其中d_2小于d_1。例如，主车辆200a能以大于目标车辆200b的速度行进，致使车辆之间的距离从d_1降至d_2。

[0353] 作为另一示例，主车辆200a和目标车辆200b能以相同的速度行进，直到目标车辆200b通过制动减少其速度，或者主车辆200a通过加速增加其速度，致使车辆之间距离从d_1降至d_2。作为另一示例，目标车辆200b可从主车辆200a的一侧侵入。在一些情形下，如果目标车辆200b在主车辆200a之前或者远离主车辆200a足够距离（例如，五米以上，10米以上，等等）并且移向主车辆200a，系统100可不采取任何动作。然而，如果目标车辆200b继续移动而更接近主车辆200a，则系统100可致使主车辆200a制动、改变速度和/或变道。例如，如果目标车辆200b在预定阈值（例如，五米内）内，则主车辆200a可采取动作。涉及主车辆200a和目标车辆200b的相对速度和位置可以有不同的场景，并且公开的实施方式并不限于任何特定情景。

[0354] 在一些实施方式中，多阈值反应区可向用户提供自然感觉驾驶经历。例如，如上面讨论的，如果碰撞风险较低，则系统100可忽略目标车辆200b的移动。结果是，当不存在碰撞风险时（例如，当目标车辆200b在100米之前时，主车辆200a将不需要模仿目标车辆200b的每个运动），主车辆200a可不响应于目标车辆200b的移动或动作。然而，如果目标车辆200b接近主车辆200a和/或如果系统100确定碰撞风险较高，则可采取响应式机动，通过增加主车辆200a与目标车辆200b之间的空间使得用户感觉更安全。如果系统100确定撞击可能迫在眉睫，则系统100可采取更激进的动作而不会致使用户感到惊讶，因为为避免碰撞该动作可能是必要的。

[0355] 因此，在一些实施方式中，系统100可将不同的反应区与不同程度的响应动作关联。例如，在一些实施方式中，当目标车辆200b在第一阈值内时（例如，当目标车辆200b远离主车辆200a时），系统100可不采取动作；当目标车辆200b在第二阈值内时（例如，当目标车辆200b更接近主车辆200a时），系统100可采取中等动作；并且当目标车辆200在第三阈值内时（例如，当目标车辆200b足够接近主车辆200a存在碰撞风险时），系统100可采取更激进的动作。在与第一阈值关联的第一反应区中，当与目标车辆200b关联的距目标的估算距离比预定安全距离大两倍时，系统100可不采取动作。在一些实施方式中，在与目标车辆200b关联的距目标的估算距离落入预定安全距离的1.5倍到2.5倍的范围内的情况下，可应用第一反应区。

[0356] 距目标的估算距离可以是主车辆200a与目标车辆200b之间的当前距离加上该距

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离经预测时间(例如,在0.1秒到1.0秒的范围内,取决于与系统100关联的因素,诸如速度跟踪控制环、致动器和车辆动态)后的预期改变。预期距离改变可计算为:$(v_{目标}-v_{主})*t_{预测}+((a_{目标}-a_{主})*t_{预测}^{1/2})$,其中$v_{目标}$和$v_{主}$分别对应于目标车辆200b和主车辆200a的速度,$a_{目标}$和$a_{主}$分别对应于目标车辆200b和主车辆200a的加速度,并且$t_{预测}$对应于预测时间。选择逼近系统100的整体反应时间的预测时间可考虑以下事实,即主车辆200a的期望导航响应可不立即实施,从而可为主车辆200a的驾驶员和/或乘客提供平稳的自然驾驶经历。

[0357] 预定安全距离可定义为:最大$\{d_{静态},d_{动态}\}$。可落入2米到10米范围内的$d_{静态}$可表示车辆停止和/或低速移动时主车辆200a与另一车辆(诸如目标车辆200b)之间的期望安全距离。$d_{动态}$可表示车辆以大于低速的速度移动时的期望安全距离,并且可计算为:$t_{安全}$*最小$(v_{目标},v_{主})$,其中$v_{目标}$和$v_{主}$分别对应于目标车辆200b和主车辆200a的速度。$t_{安全}$可落入0.5秒到2.5秒的范围内,并且可根据驾驶员的喜好由主车辆200a的驾驶员经由用户接口170调整。由此,驾驶员能够控制主车辆200a与其它车辆之间系统100维持的距离。

[0358] 在与第二阈值关联的第二反应区中,系统100可将目标车辆200b放置在安全区中并且向由目标车辆200b执行的不同机动施加不同的权重。例如,在目标车辆200b可接近安全区的下边界时,例如,与目标车辆200b关联的距目标的估算距离可接近预定安全距离(上面结合第一反应区讨论过),系统100可以向机动减速分配更大的权重(例如,模仿更多)并且向机动加速分配更小的权重(例如,模仿更少)。在一些实施方式中,下边界可落入预定安全距离的0.5倍到1.5倍的范围内(取决于驾驶员的喜好)。反过来,在目标车辆200b接近安全区的上边界时,例如,与目标车辆200b关联的距目标的估算距离可接近预定安全距离的两倍,系统100可以向机动减速分配更小的权重(例如,模仿更少)并且向机动加速分配更大的权重(例如,模仿更多)。在一些实施方式中,下边界可落入预定安全距离的1.5倍到2.5倍的范围内(取决于驾驶员的喜好)。

[0359] 在与第三阈值关联的第三反应区中,当与目标车辆200b关联的距目标的估算距离小于预定安全距离时,系统100可将目标车辆200b放置在危险区中。在该情景下,系统100可致使主车辆200a模仿(例如,立即模仿)目标车辆200b执行的任何减速机动(同时不考虑任何加速机动)。在一些实施方式中,在与目标车辆200b关联的距目标的估算距离落入预定安全距离的0.5倍到1.5倍的范围内(取决于驾驶员的喜好)的情况下,可应用第一反应区。

[0360] 在一些实施方式中,系统100可产生主车辆200a的响应,诸如制动。如图28B中指示的,例如,主车辆200a与目标车辆200b之间的距离可从d_1降至d_2。取决于距离d_2并且延伸至在碰撞之前的时间,系统100可致使主车辆200a减少其速度以避免与目标车辆200b碰撞。另外,还基于例如在碰撞之前的时间,当致使主车辆200a减少其速度时,系统100可施加一个或多个制动轮廓。由此,如果在碰撞之前的时间(和/或距离d_2)超过第一预定阈值,则系统100可致使主车辆200a以渐进的方式制动、变道和/或改变速度,而如果在碰撞之前的时间(和/或距离d_2)低于第二预定阈值,则系统100可致使主车辆200a制动、变道和/或以更快速的方式改变速度。

[0361] 图29是与公开的实施方式相一致的存储器的示例性框图,该存储器被构造成存储用于执行一个或多个操作的指令。如图29所示,存储器140可存储目标监测模块2902、拦截时间模块2904和动作响应模块2906。公开的实施方式并不限于任何特定构造的存储器140。进一步,处理单元110可执行存储在任何模块2902-2906(包括在存储器140中)中的指令。

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[0362] 在一个实施方式中，目标监测模块2902可存储软件指令(诸如计算机视觉软件)，当由处理单元110执行时，该软件指令识别并且监测出现在表示主车辆200附近环境的多个图像中的目标对象(诸如目标车辆200b)。出于本公开的目的，目标对象也可被称为目标车辆200b，但是目标对象可以是行人、道路危险(例如，大的碎片)，等。多个图像可由图像捕获装置122、124和126中的一个或多个获取。处理单元110可执行目标监测模块2902，以使用上面结合图5A至图5D描述的技术通过例如分析多个图像来识别并且监测目标车辆200b。由此，目标监测模块2902可跟踪不同的变量，诸如与目标车辆200b关联的运动(例如，行进方向和轨迹)、速度和加速度，以及主车辆200a与目标车辆200b之间的距离。这样的信息可不断地或者以预定的间隔跟踪。

[0363] 在一个实施方式中，拦截时间模块2904可存储软件指令，当由处理单元110执行时，该软件指令确定主车辆200a和目标车辆200b之间的拦截时间的指示器。拦截时间可指在主车辆200a与目标车辆200b接触(例如，碰撞)之前的时间量。处理单元110可执行拦截时间模块2904，以基于分析由图像捕获装置122、124和126中的一个或多个获取的图像来确定拦截时间的指示器。例如，拦截时间模块2904可使用例如目标车辆200b(相对于主车辆200a)的位置、速度和/或加速度的一系列基于时间的观察(诸如卡尔曼滤波器或线性二次估算(LQE))来做出确定。卡尔曼滤波器可基于目标车辆200b的尺度的测量结果，其中尺度测量结果与拦截时间成比例。

[0364] 在一个实施方式中，动作响应模块2906可存储软件指令(诸如计算机视觉软件)，当由处理单元110执行时，该软件指令在主车辆200a中产生一个或多个响应。所述响应可基于目标车辆200b的识别和监测(例如，经由执行目标监测模块2902来执行)和/或主车辆200a与目标车辆200b之间的拦截时间的指示器(例如，经由执行拦截时间模块2904确定)。处理单元110可通过例如(例如，经由CAN总线)向主车辆200a的节流系统220、制动系统230和/或转向系统240发送电子信号来在主车辆200a中产生一个或多个响应，以制动、加速或触发主车辆200a的转弯、车道移位和/或方向改变。处理单元110可使用扩展的卡尔曼滤波器来估算与目标车辆200b和主车辆200a关联的数据，诸如：速度、加速度、转弯率、俯仰角、俯仰速率、目标车辆200b相对于主车辆200a的位置和航向、目标车辆200b的大小、道路几何形状，等。例如，处理单元110可接收来自主车辆200a上的部件(诸如里程表、惯性测量单元(IMU)、图像处理器190，等)的测量结果。由此，处理单元110可使用从运动的运动学公式得到的状态公式、刚性约束和运动假设来计算与目标车辆200b和/或主车辆200a关联的数据，其中公式的输入可包括来自主车辆200a上的部件的测量结果。处理单元110还可使用上面结合图4至图7描述的技术，以产生主车辆200a的一个或多个响应。

[0365] 图30是示出与公开的实施方式相一致的用于产生主车辆的响应的示例性过程3000的流程图。在步骤3010，处理单元110可经由位于处理单元110与图像获取单元120之间的数据接口128接收多个图像。例如，包括在图像获取单元120中的一个或多个相机可捕获主车辆200a前方(例如，或车辆的侧方或后面)的区域的多个图像并且经数据连接(例如，数字、有线、USB、无线、蓝牙，等等)将图像发送到处理单元110。

[0366] 在步骤3020，处理单元110可执行目标监测模块2902，以识别多个图像内的目标对象(诸如目标车辆200b)。例如，目标监测模块2902可使用上面结合图5A和图5B描述的技术来检测图像中的车辆的存在。基于图像数据、位置数据(例如，GPS地点信息)、地图数据、主

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车辆200a的偏航率、车道或其它道路标记、速度数据和/或包括在主车辆200a中的传感器的数据，多个车辆(和/或对象)可在与主车辆200a相同的车道或不同的车道中被检测，并且距主车辆200a的距离是变化的。在检测多个车辆的情景下，目标监测模块2902可将目标车辆200b确定为在与主车辆200a相同的车道中行进和/或最接近主车辆200a的车辆。

[0367] 在步骤3030，处理单元110可执行目标监测模块2902，以监测在步骤3020识别的目标车辆200b。例如，目标监测模块2902可跟踪与目标车辆200b关联的信息，诸如运动(例如，行进方向和轨迹)、速度和加速度，以及主车辆200a与目标车辆200b之间的距离。目标监测模块2902可使用上面结合图5A至图5D描述的技术通过分析多个图像来不断地或者以预定的间隔跟踪这样的信息。在步骤3040，处理单元110可执行拦截时间模块2904，以确定主车辆200a与目标车辆200b之间的拦截时间的指示器。拦截时间模块2904可通过跟踪在一个或多个时间周期上目标车辆200b(相对于主车辆200a)的位置、速度和/或加速度来做出确定。拦截时间模块2904可使用上面结合图5A和图5B描述的技术来跟踪这样的信息。

[0368] 在步骤3050，处理单元110可执行动作响应模块2906，以产生主车辆200a的一个或多个响应。例如，处理单元110可(例如，经由CAN总线)向主车辆200a的节流系统220、制动系统230和/或转向系统240发送电子信号，以制动、加速或触发主车辆200a的转弯、车道移位和/或方向改变。进一步，一个或多个致动器可控制节流系统220、制动系统230和/或转向系统240。例如，处理单元110可发送电子信号，致使系统100物理地踩下制动器达预定的量或者部分地松开车辆200的加速器。进一步，处理单元110可发送致使系统100车辆200沿特定方向转向的电子信号。这样的响应可基于(在步骤3030执行的)目标车辆200b的监测和/或(在步骤3040确定的)主车辆200a与目标车辆200b之间的拦截时间的指示器。在一些实施方式中，拦截时间可与一个或多个预定阈值(例如，第一和第二拦截阈值)比较。例如，如果拦截时间的指示器指示目标对象在特定拦截阈值内(例如，在第二拦截阈值内)，则所述响应可包括紧急避让动作。紧急避让动作可包括变道和/或紧急制动。

[0369] 阈值可表达为时间的单位。由此，例如，如果拦截时间的指示器指示目标车辆200b在第一阈值之外(例如，在主车辆200a与目标车辆200b之间的碰撞之前的时间超过第一阈值)，则动作响应模块2906可基于与目标车辆200b关联的平均运动轮廓来在主车辆200a中产生响应。与目标车辆200b关联的平均运动轮廓可表示目标车辆200b针对特定阈值的平均位置和/或平均速度。在一些实施方式中，如果目标车辆200b为某一距离和/或以某一速度行进，则系统100可不采取动作。例如，如果目标车辆200b在主车辆200a之前或者距离足够远离主车辆200a(例如，五米、10米，等等)，则系统100可不采取任何动作，除非目标车辆200b更接近主车辆200。

[0370] 如果拦截时间的指示器指示目标车辆200b在第一阈值与第二阈值之间(例如，在主车辆200a与目标车辆200b之间的碰撞之前的时间落入第一阈值与第二阈值之间)，则动作响应模块2906可基于与目标车辆200b关联的实际运动来产生主车辆200a的响应。实际运动可表示目标车辆200b的位置和/或速度(例如，并未平均或延迟)，如果拦截时间的指示器指示目标车辆200b在第二阈值内(例如，在主车辆200a与目标车辆200b之间的碰撞之前的时间低于第二阈值)，则动作响应模块2906可产生主车辆200a的紧急动作(诸如变道或紧急制动)。

[0371] 图31是示出与公开的实施方式相一致的用于拒绝在主车辆中产生响应的示例性

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过程3100的流程图。在步骤3110，如上面结合图30的步骤3010描述的，处理单元110可经由位于处理单元110与图像获取单元120之间的数据接口128接收多个图像。

[0372] 在步骤3120，如上面结合图30的步骤3020描述的，处理单元110可执行目标监测模块2902，以通过分析图像将目标对象(例如，目标车辆200b)定位在步骤3010接收的图像内。在步骤3125，处理单元110可执行目标监测模块2902，以使用上面结合图30的步骤3030描述的技术来确定目标对象(例如，目标车辆200b)是否在不同于主车辆200a的车道中行进。如果确定目标车辆200b在不同于主车辆200a的车道中行进(步骤3125，是)，则在步骤3130，处理单元110可拒绝在主车辆200a中产生响应。替代地，如果系统100确定目标车辆200b不构成迫在眉睫的碰撞风险(例如，目标车辆200b在与主车辆200a非相交的轨线上或者潜在的将要碰撞的时间超过阈值，使得目标对象在目前的时间里不构成迫在眉睫的风险)，在步骤3130，处理单元110可拒绝在主车辆200a中产生响应。否则(步骤3125，否)，过程3100可结束且不发生响应。

[0373] 使用多区段制动轮廓来停止自主驱动车辆

[0374] 系统100可提供驾驶员辅助功能性，用于监测并且响应于环境条件以控制车辆200的制动。例如，系统100可基于多个图像来检测触发车辆200停止的对象。例如，该对象可包括车辆200附近的另一车辆、交通灯和/或交通标志。系统100可使用制动轮廓来减速和/或停止车辆200。根据一些实施方式，制动轮廓可包括在不同阶段执行减速的多个区段。例如，制动轮廓可致使系统100以降速的减速度停止车辆200。

[0375] 通过提供包括多个区段的制动轮廓，系统100可致使车辆200以对驾驶员和/或乘客而言感觉自然的方式操作。例如，当驾驶员在交通灯处停止车辆时，从施加的时刻直到车辆停止的时刻，制动器通常不以恒速来施加。以这样的方式操作制动器导致终止时突然停止。相反，驾驶员可首先平缓地施加制动器，然后增加压力，进而在车辆到达其目标停止地点时，驾驶员可降低制动水平，直到在汽车停止的时刻到达零(或零附近)。以这种方式操作车辆可提供自然停止过程，即，驾驶员可首先致使逐步减速，所以车辆不会经历突然初始减速然后终止，使得车辆不会突然停止。

[0376] 系统100可提供可根据对车辆200的驾驶员和/或乘客而言感觉自然的方法来实施制动的自主车辆导航。例如，在一些实施方式中，系统100可致使图像捕获装置122-126中的一个或多个获取车辆200附近区域的多个图像。处理装置110可经由数据接口128接收多个图像，并且基于对多个图像的分析来识别用于停止车辆200的触发器(例如，对象、交通灯和/或交通标志)。基于被识别的触发器，系统100可根据制动轮廓致使车辆200停止。在一些实施方式中，如基于对多个图像的分析而确定的，制动轮廓可包括多个区段(例如，包括：与第一减速率关联的第一区段；包括小于第一减速率的第二减速率的第二区段；以及在接近目标停止地点时使制动水平降低的第三区段)。

[0377] 图32A图示了在包括对象3220的道路3210上行进的车辆200。系统100可识别触发器(例如，对象3220)以使车辆200相对于触发器的检测而停止。例如，在触发器被检测到之后系统100可首先使车辆200减速，并且在到达对象3220之前使车辆200停止。

[0378] 处理单元110可构造成基于由图像捕获装置122-126中的一个或多个获取的多个图像来确定用于停止车辆200的触发器。处理单元110可经由数据接口128从图像捕获装置122-126接收图像。根据一些实施方式，触发器可包括对象3220。例如，对象3220可以是道路

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2810上的另一车辆。根据一些实施方式，如果对象3220在车辆200的某一附近区域内，则处理单元110可识别触发器。例如，识别触发器可取决于对象3220与车辆200之间的相对距离。进一步，这种识别可选地考虑对象3220与车辆200之间的相对速度和/或相对加速度。

[0379] 另外地或替代地，触发器可包括交通标志，诸如图32A中示出的交通标志3240。例如，交通标志3240可以是停止标志和/或限速标志。根据一些实施方式，处理单元110可处理多个图像以确定交通标志3240的内容，作为确定触发器是否存在的一部分。例如，如果车辆200超过限速，则处理单元110可基于由交通标志3240规定的限速来确定触发器的存在。作为另一示例，如果黄灯亮和/或红灯亮，则处理单元110可基于交通灯2830来确定触发器的存在。

[0380] 基于多个图像，处理单元110可确定目标停止地点3250，一旦执行制动轮廓，车辆200就将停止在目标停止地点3250处。到达目标停止地点3250可伴随着车辆200的制动压力的释放。目标停止地点3250可基于交通灯3230和/或交通标志3240的地点，使得车辆200符合交通灯3230和/或交通标志3240。替代地，目标停止地点3250可基于对象3220，使得车辆200在到达对象3220之前停止。因此，目标停止地点3250可基于对象3220的地点，以避免车辆200与对象3220之间的碰撞。在一些实施方式中，目标停止地点3250的更新可基于从多个图像获得的新的信息，诸如新识别的目标、新的可见障碍、新的可见标志，等等。

[0381] 图32B图示了与公开的实施方式相一致的示例性制动轮廓。在图32B示出的示例中，制动轮廓包括四个区段。然而，区段的数目是示例性的，并且与公开的实施方式相一致的制动轮廓可包括任何适当数目的区段(例如，2个、3个、4个、5个、6个等等区段)。

[0382] 在区段1中，系统100可准备可能的制动情景。例如，在该区中，系统100可接收关于即将到来的路口(例如，具有交通灯的路口)的信息(例如，地图数据和/或图像数据)。系统100可逐渐减小车辆200的速度(例如，取决于路口的特性，车辆200的速度可逐渐减小至约70-50km/hr)。系统100可产生速度调整，例如，大约在枢纽之前的100-200米平均减速度约0.2-0.4米/秒^2(最大约0.5米/秒^2)。通过在区段1中降低车辆200的速度，系统100可为车辆200的驾驶员和/或乘客提供系统100知晓接近路口的置信度。

[0383] 在区段2中，系统100可施加强大的制动。在该区段中，系统100可基于对图像数据的分析来接收信息，例如，交通灯变红和/或在车辆200行进线中的路口处存在停止车辆。系统100可致使车辆200在该区中经历显著的速度减小，同时距停止线或停止车辆的距离仍较大。这样做可为车辆200的驾驶员和/或乘客提供舒适的感觉，系统100将具有足够多的空间来完成制动机动。该区可远离停止线大约30-100米，并且平均减速度可约为1.5-2.5米/秒^2(最大约为3.5米/秒^2)。

[0384] 在区段3中，系统100可做出适度制动调整。例如，在该区段中，系统100可根据距停止线或停止车辆的剩余距离并且基于车辆200的当前速度和减速度来调整车辆200的速度。通过做出这种调整，系统100可为车辆200的驾驶员和/或乘客提供如下指示：系统100正释放大部分制动功率，同时速度仍减小，但慢于之前。该区可远离停止线或停止车辆大约5-30米，并且平均减速度可约为0.5-1.5米/秒^2(最大约为2米/秒^2)。

[0385] 在区段4中，系统100可做出小幅制动调整。在该区段中，系统100能以逐渐变为零的非常低的速度缩短距停止线或停止车辆的剩余距离。在该区中，驾驶员和/或乘客可感觉车辆200缓缓地滑动到位(例如，在停止线处或在另一车辆后面)。该区可构成距停止线或停

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止车辆的大约最后5-7米，并且平均减速度可约为0.3-0.5米/秒^2(最大约为1米/秒^2)。

[0386] 图33是与公开的实施方式相一致的存储器140和/或150的示例性框图，该存储器140和/或150可存储用于执行一个或多个操作的指令。如图33中图示的，存储器140可存储用于执行本文中描述的触发器检测和响应的一个或多个模块。例如，存储器140可存储触发器识别模块3300和动作响应模块3310。

[0387] 触发器识别模块3300可存储指令，当由处理单元110执行时，该指令可检测用于停止车辆200的触发器的存在。例如，触发器识别模块3300可处理从至少一个图像捕获装置122-124接收的多个图像，以检测触发器的存在。如上面讨论的，这可包括识别对象3220、交通灯3230和/或交通标志3240。

[0388] 动作响应模块3310可存储指令，当由处理单元110执行时，该指令可响应于触发器的存在。例如，动作响应模块3310可执行控制，以减速和/或停止车辆200。例如，动作响应模块3310可执行制动轮廓，以减速和/或停止车辆200。动作响应模块3310可基于制动轮廓的数目并且基于例如环境因素、被检测触发器的类型和车辆200的速度来确定执行多个制动轮廓中的一个。为了基于被检测触发器将车辆200导航至停止，处理单元110可向车辆200的节流系统220、制动系统230和/或转向系统240中的一个或多个发送电子信号。进一步，一个或多个致动器可控制节流系统220、制动系统230和/或转向系统240。例如，处理单元110可发送电子信号，致使系统100物理地踩下制动器达预定的量。

[0389] 图34图示了与公开的实施方式相一致的用于导航车辆200的过程3400。过程3000可识别用于停止车辆200的触发器(例如，对象、车辆、交通灯、交通标志，等等)并且响应于触发器的检测来执行制动轮廓。过程3400可检测各种类型的触发器，以确定执行多个制动轮廓中的哪一个。

[0390] 制动轮廓可基于被检测触发器的类型和/或与被检测触发器相关的其它环境条件(例如，距对象的距离)。例如，在一些实施方式中，制动轮廓可包括多个区段(例如，三个区段)。在三区段制动轮廓中，制动轮廓的第一区段可与第一减速率关联，制动轮廓的第二区段可包括小于第一减速率的第二减速率，并且制动轮廓的第三区段可包括在接近目标停止地点时致使制动水平降低，这基于对由图像捕获装置122-126中的一个或多个获取的多个图像的分析来确定。例如，在一些实施方式中，第一区段可致使车辆200逐步增加减速度，第二区段可致使车辆200恒速减速，并且第三区段可致使车辆200将其减速率逐步降低至零(或附近零)。

[0391] 在步骤3410，过程3400可使用图像捕获装置122-126中的至少一个来获取车辆200附近区域的多个图像。例如，处理单元110可经由数据接口128接收多个图像。处理单元110可构造成基于获取的图像来确定存在一个或多个对象和/或位于道路3210之上或附近的标志。例如，处理单元110可构造成确定对象3220、交通灯3230和/或交通标志3240的存在。处理单元110可进一步构造成读取交通标志3240的内容。例如，处理单元110可构造成在限速标志与停止标志之间进行区分。进一步，处理单元110可构造成基于交通标志3240来处理图像以确定限速。

[0392] 在步骤3420，过程300可包括用于停止车辆200的触发器。例如，处理单元110可基于对象3220在车辆200附近区域内的存在来识别触发器。另外地或替代地，处理单元110可基于交通灯3230的当前信号状态来识别触发器。根据一些实施方式，如果不是绿灯，则处理

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单元110可确定交通灯3230构成触发器。根据一些实施方式，例如，如果交通标志3240是停止标志，则处理单元110可确定交通标志3240构成触发器。在一些实施方式中，如果交通标志3240是限速标志并且车辆200超过限速，则交通标志3240可构成触发器。进一步在一些实施方式中，处理单元110可致使系统100提供语音通知，识别触发器和/或指示车辆200正制动或正要开始制动。

[0393] 在处理单元110识别触发器之后，在步骤3430，处理单元110可根据制动轮廓来致使车辆200减速和/或停止。在一些实施方式中，制动轮廓可包括一定数目的轮廓区段。制动轮廓的不同轮廓区段可由时间周期和/或车辆速度限定。例如，处理单元110可依据持续预定时间段或直到车辆200的速度到达目标值的第一轮廓区段来执行车辆200的控制。目标值可以是预定速度，或者可以是车辆200过去在执行制动轮廓之前的行进的速度的百分比。为了实施制动轮廓，处理单元110可向车辆200的节流系统220、制动系统230和/或转向系统240中的一个或多个发送电子信号。进一步，一个或多个致动器可控制节流系统220、制动系统230和/或转向系统240。

[0394] 如上面讨论的，根据一些实施方式，制动轮廓的轮廓区段可对应于减速率。例如，制动轮廓可包括多个区段，并且第一区段可与第一减速率关联。制动轮廓可进一步包括与第二减速率关联的第二区段。第二减速率可小于第一减速率。

[0395] 进一步，如上面讨论的，根据一些实施方式，制动轮廓可包括第三轮廓区段，其中制动水平的降低是车辆200与产生触发器的潜在因素(例如，对象3220、交通灯3230、交通标志3240)之间的距离的函数。例如，制动轮廓可包括在车辆200接近目标停止地点3250时降低制动水平。进一步，到达目标停止地点3250可伴随着车辆200的制动压力的释放。

[0396] 出于图示的目的，前面的描述已呈现。并非穷尽且并不限于公开的具体形式或实施方式。考虑到说明书和公开的实施方式的实践，修改和改写对本领域技术人员将是明显的。另外，虽然公开的实施方式的各方面描述为存储在存储器中，但是本领域技术人员将了解到，这些方面也可以存储在其它类型的诸如二级存储装置的计算机可读介质上，例如，硬盘或CD ROM，或其它形式的RAM或ROM、USB介质、DVD、蓝光或其它光驱介质。

[0397] 基于书面描述和公开方法的计算机程序在有经验的开发人员的技术内。各种程序或程序模块可以使用本领域技术人员公知的任何技术来创建或者可以结合现有软件设计。例如，程序段或程序模块可以设计或借助.Net Framework、.Net Compact Framework(及相关语言，诸如Visual Basic、C，等等)、Java、C++、Objective-C、HTML、HTML/AJAX组合、XML或包括Java小程序的HTML。

[0398] 而且，虽然说明性实施方式已在本文中描述，具有等同元件、修改、省略、组合(例如，跨各实施方式的方面)、改写和/或变更的任何及所有实施方式的范围将基于本公开被本领域技术人员了解。权利要求书中的限制应解译宽泛地基于权利要求书中采用的语言，并不限于本说明书或本申请审查期间描述的示例。示例应被解释为非排他性的。此外，公开方法中的步骤能以任何方式修改，包括重新排序各步骤和/或插入或删除步骤。因此，预期说明书和示例考虑为仅是说明性的，真正的范围和精神由以下权利要求书及其完整的等同范围指示。

[0399] 相关申请的交叉引用

[0400] 本申请要求以下的优先权：2013年12月4日提交的美国临时专利申请号61/911，

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490;2014年5月14日提交的美国临时专利申请号61/993,084;2014年5月14日提交的美国临时专利申请号61/993,111;2014年6月23日提交的美国临时专利申请62/015,524;2014年7月9日提交的美国临时专利申请62/022,221;2014年8月21日提交的美国临时专利申请号62/040,224;以及2014年8月21日提交的美国临时专利申请62/040,269。所有前述申请的整体内容都通过引用并入本文。

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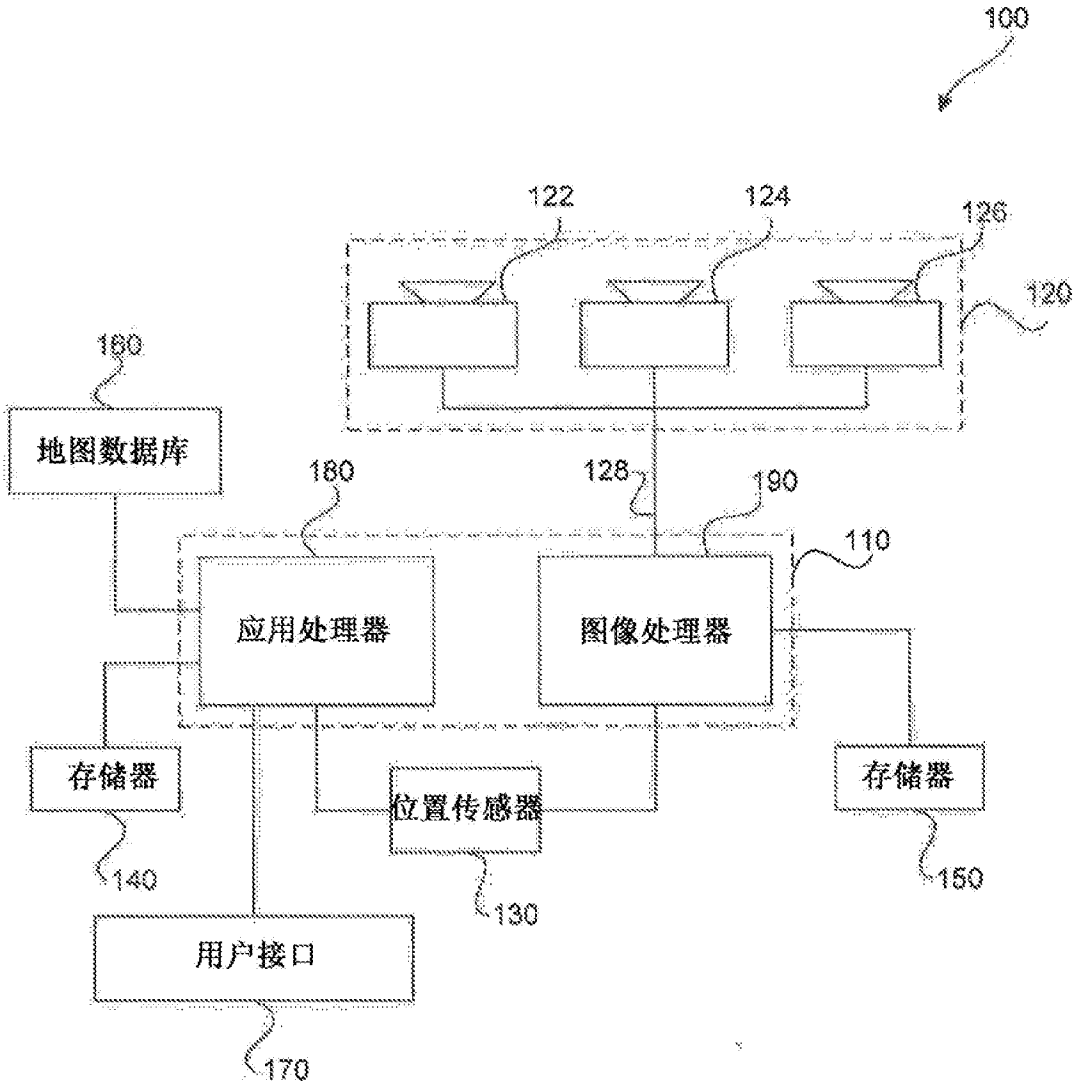


图1

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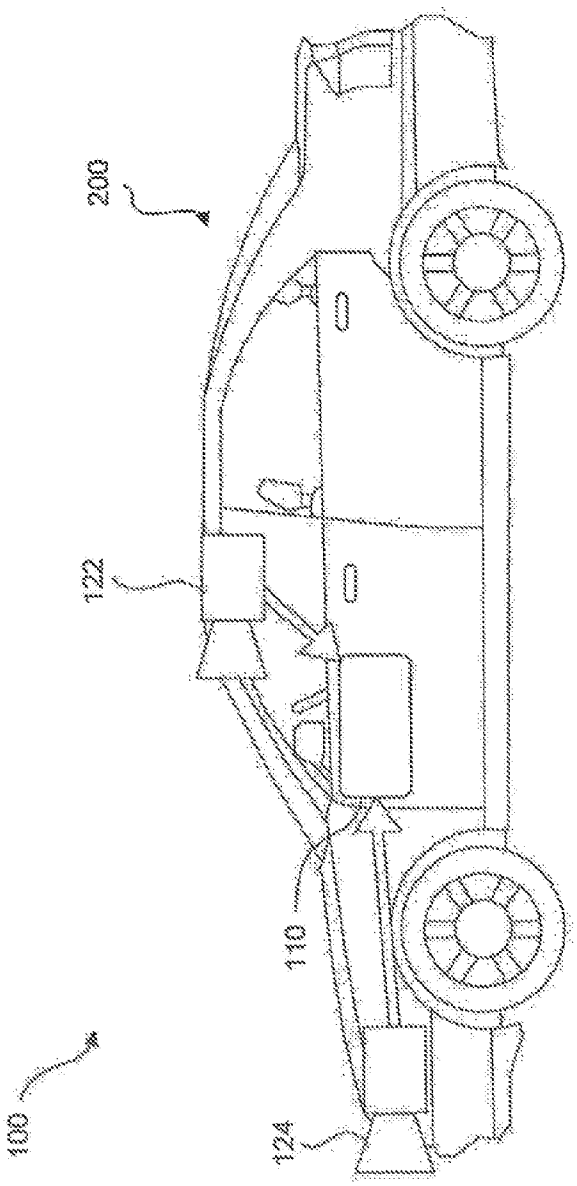


图2A

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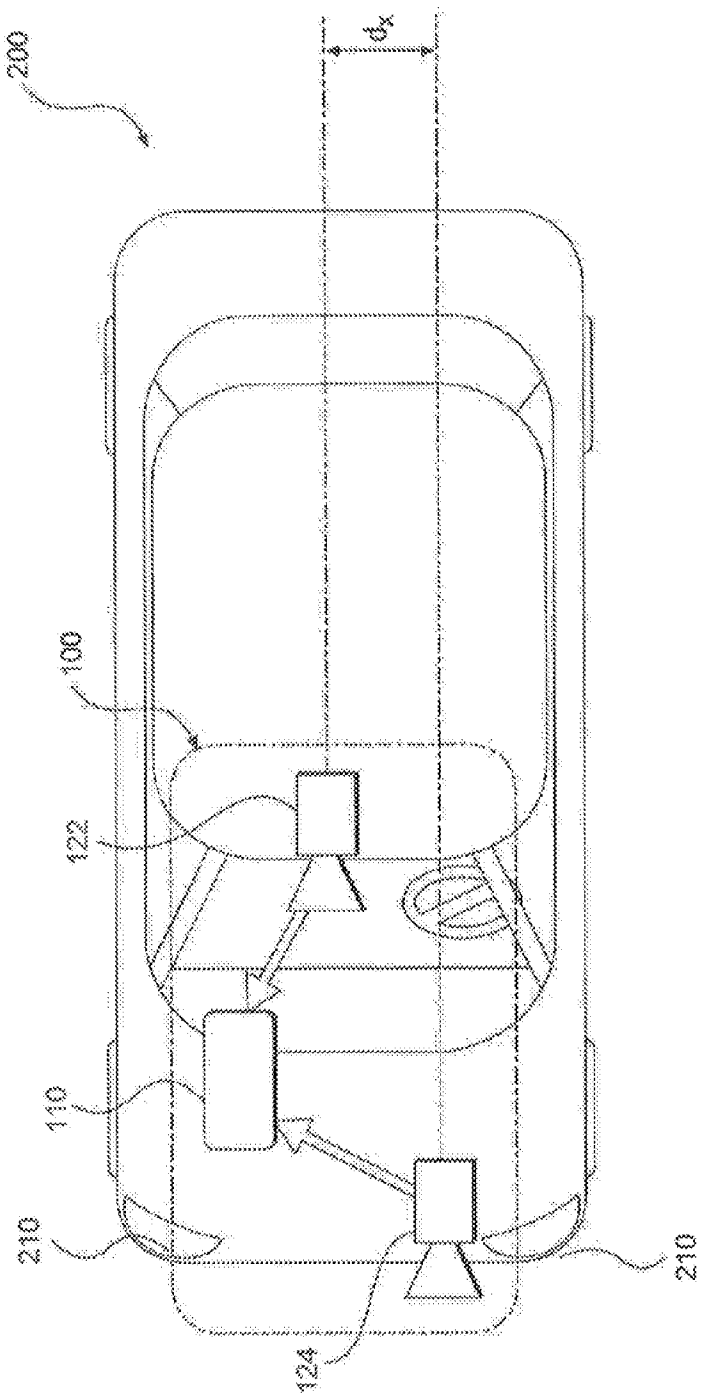


图2B

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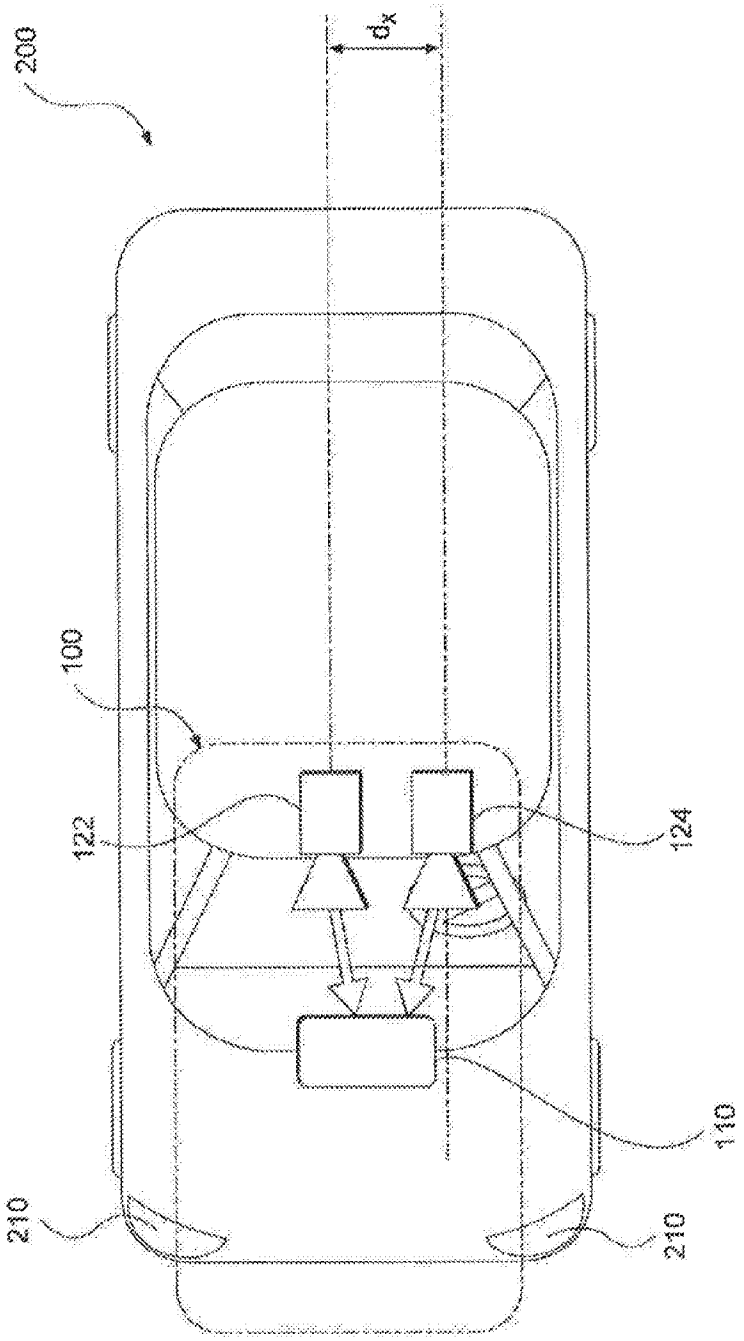


图2C

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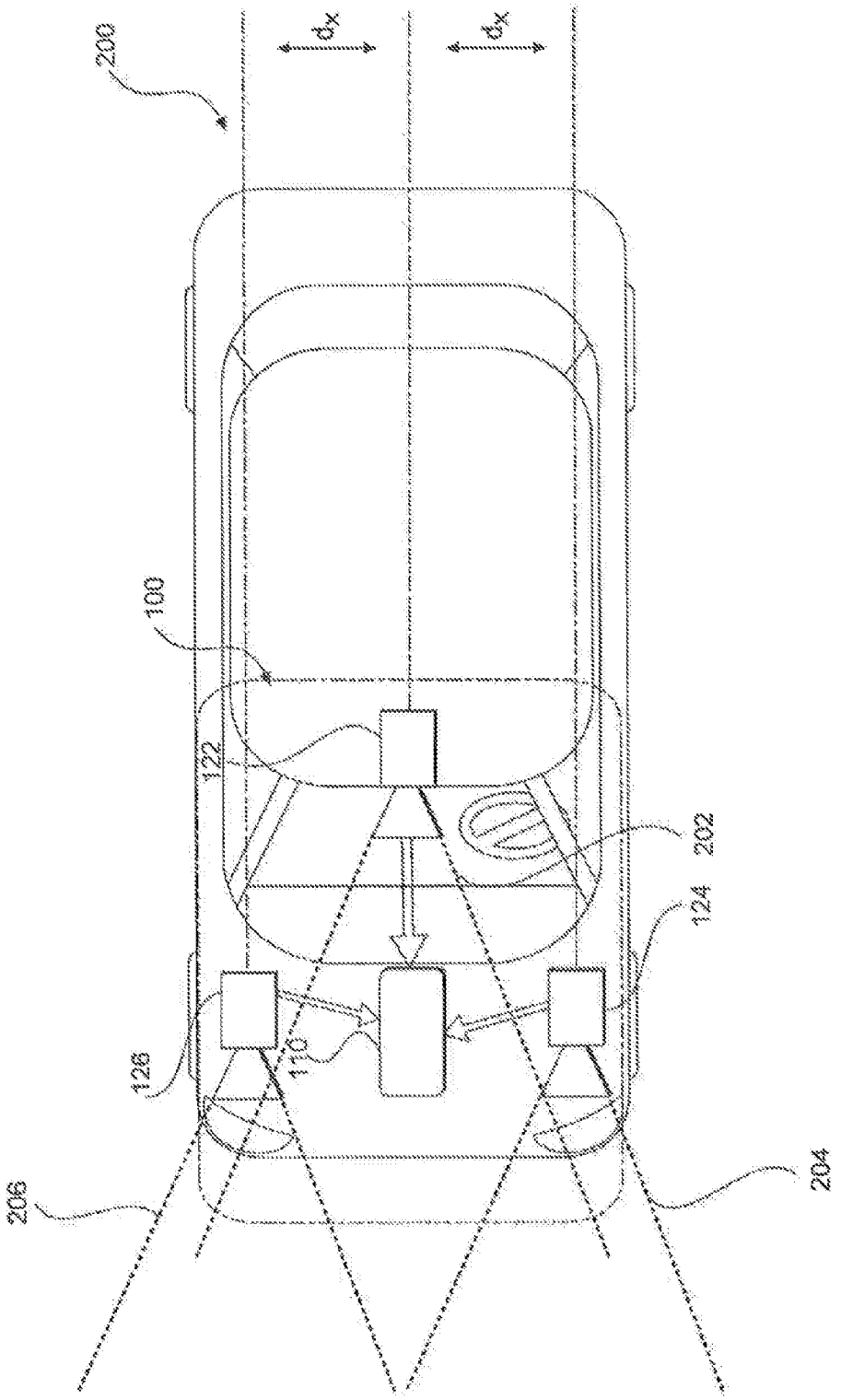


图2D

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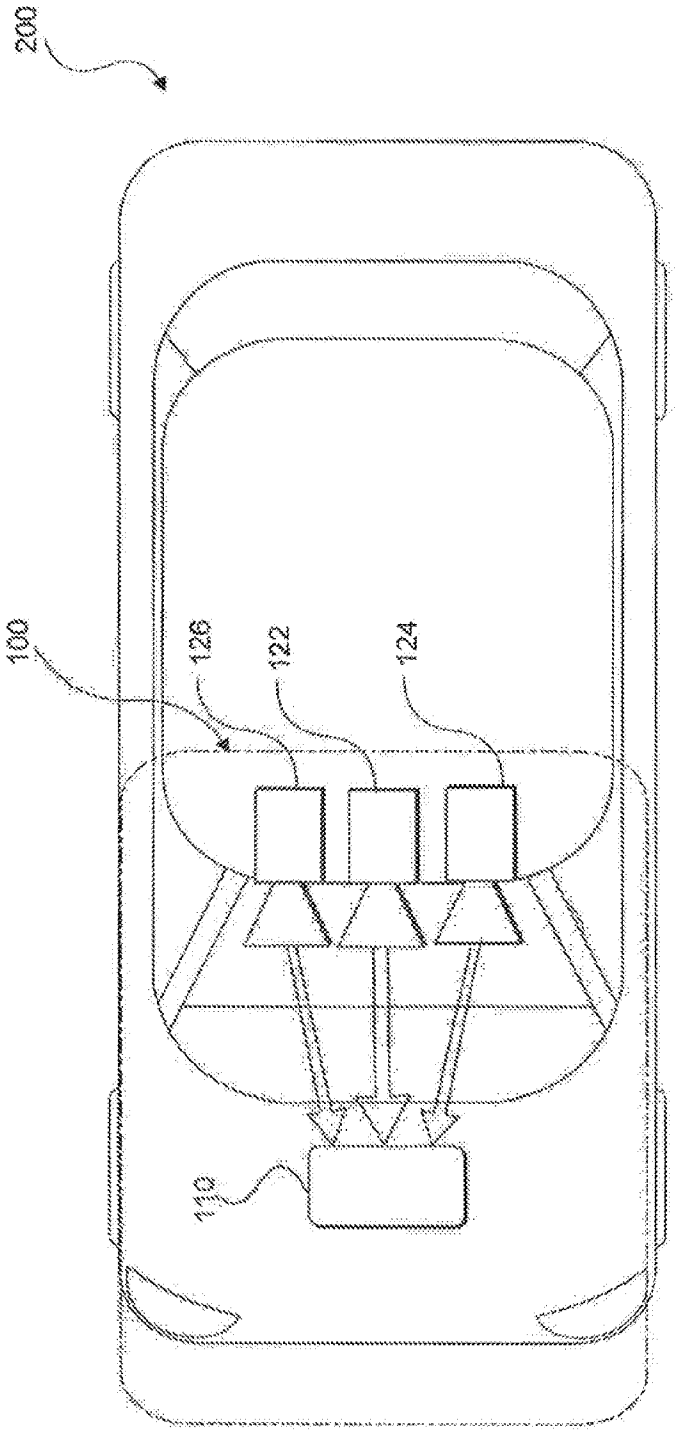


图2E

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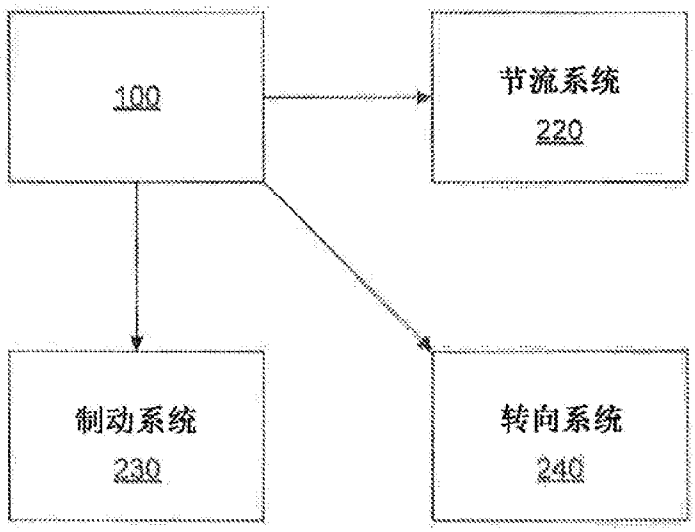


图2F

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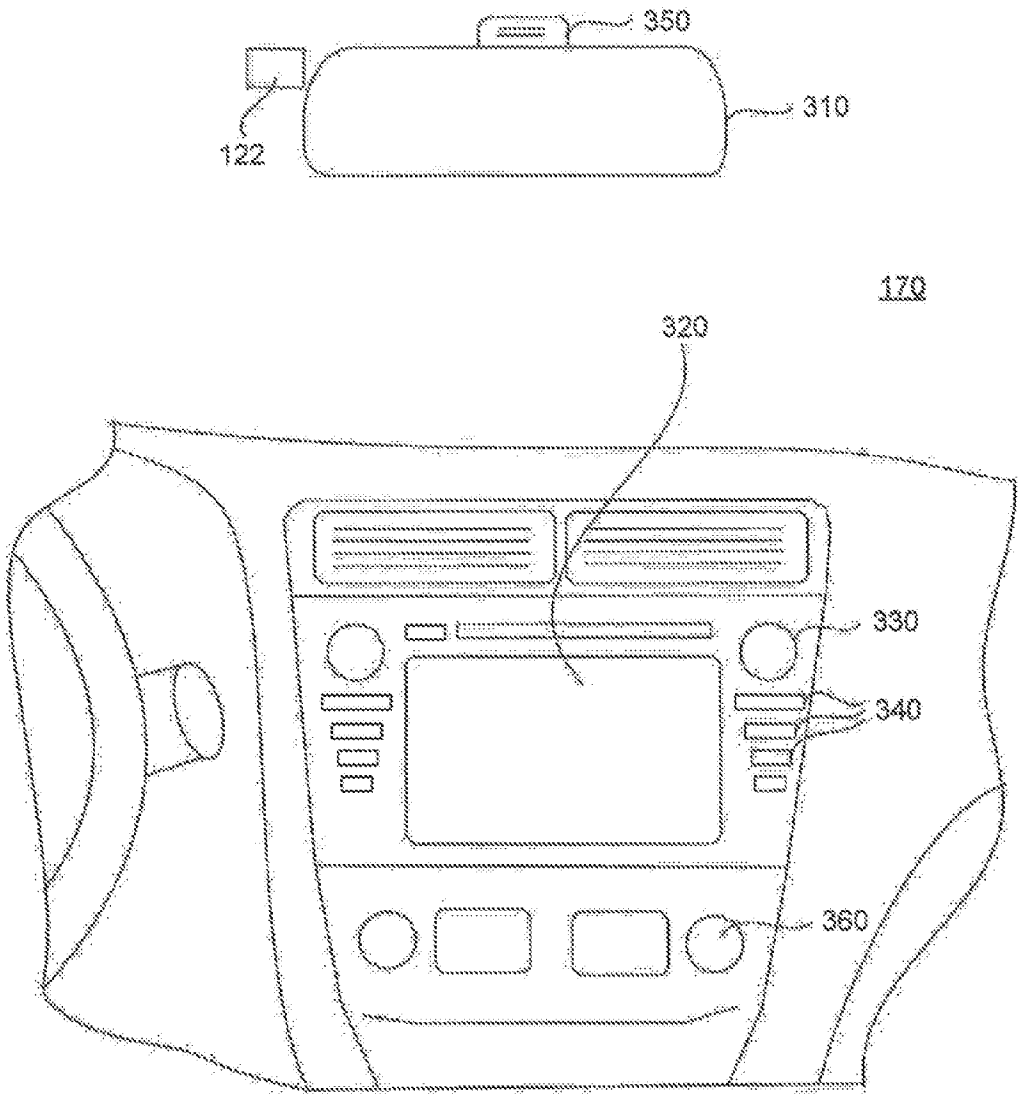


图3A

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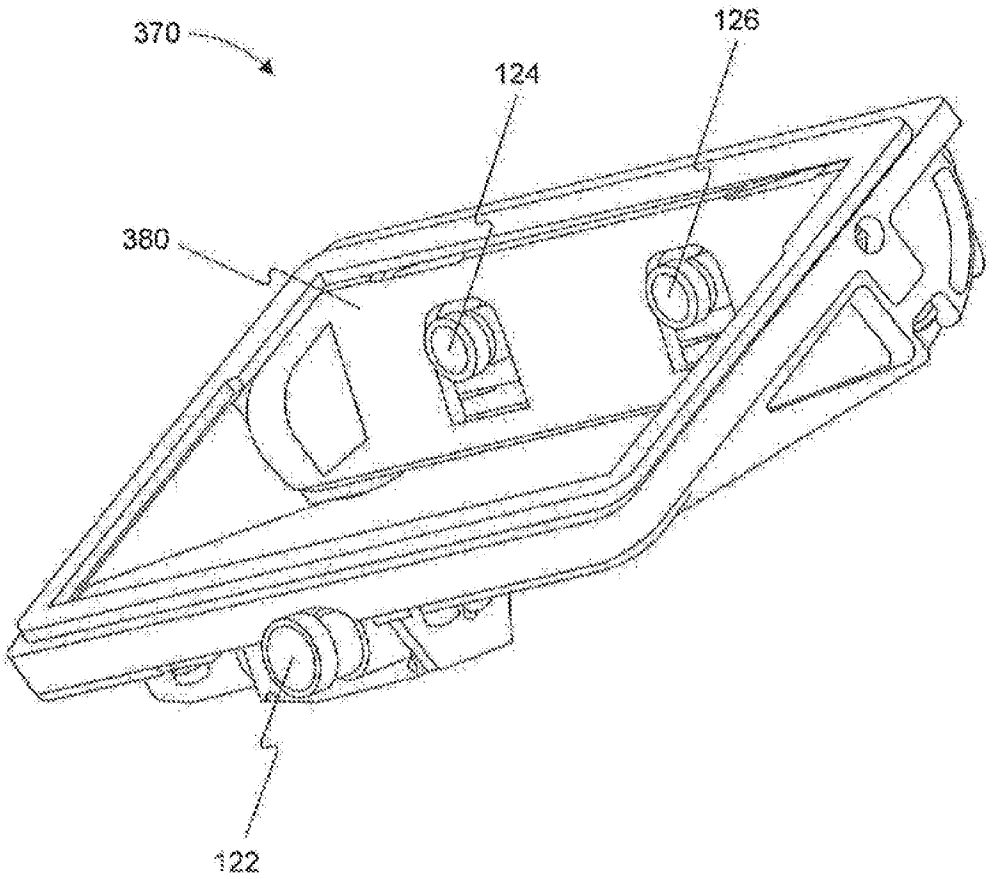


图3B

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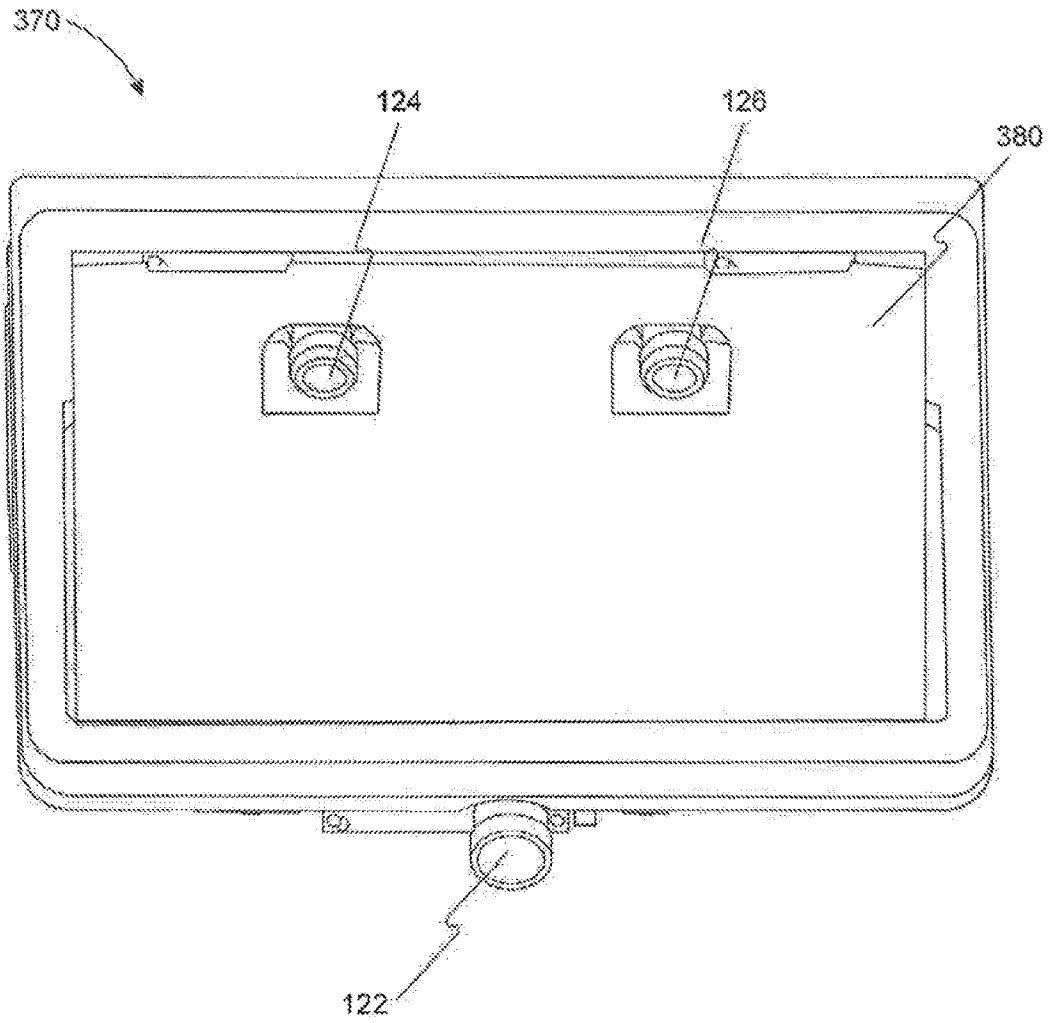


图3C

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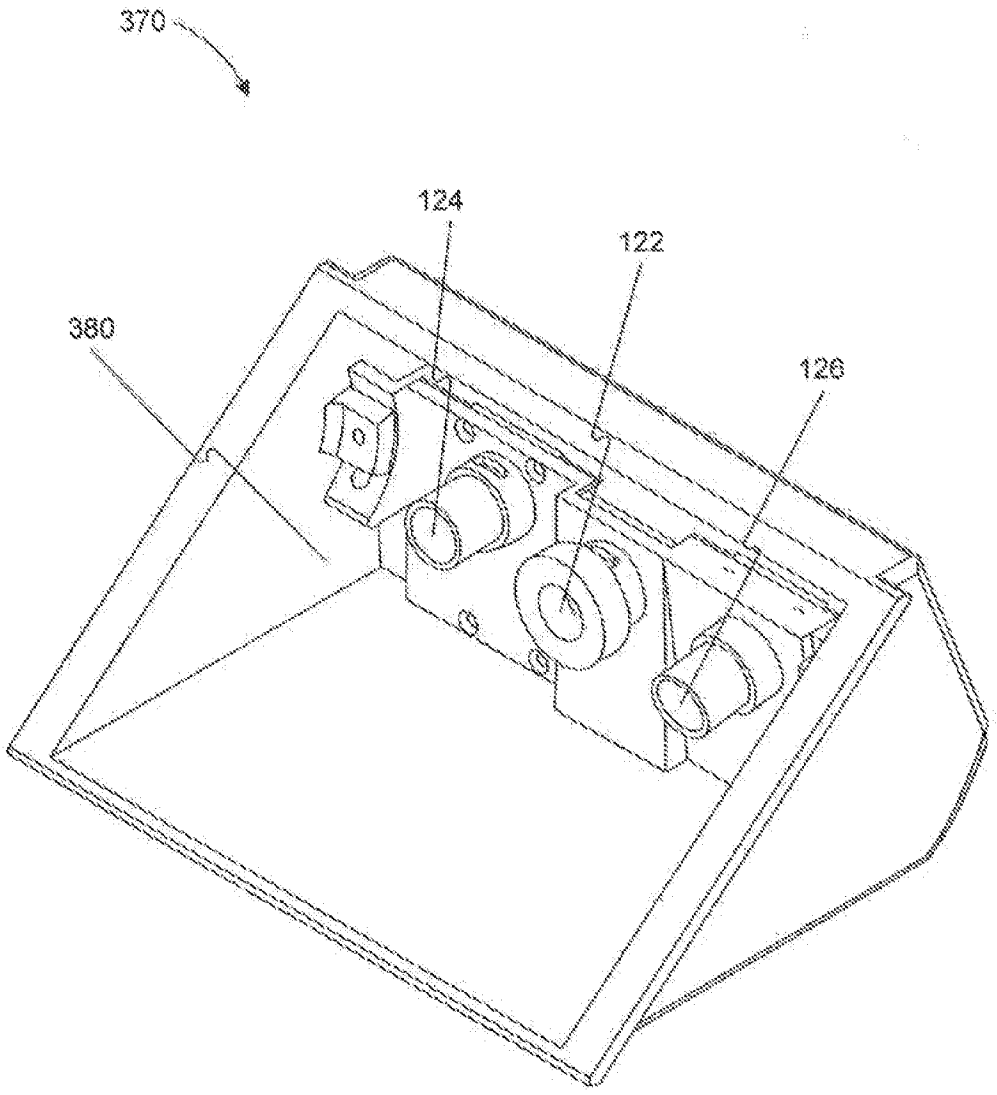


图3D

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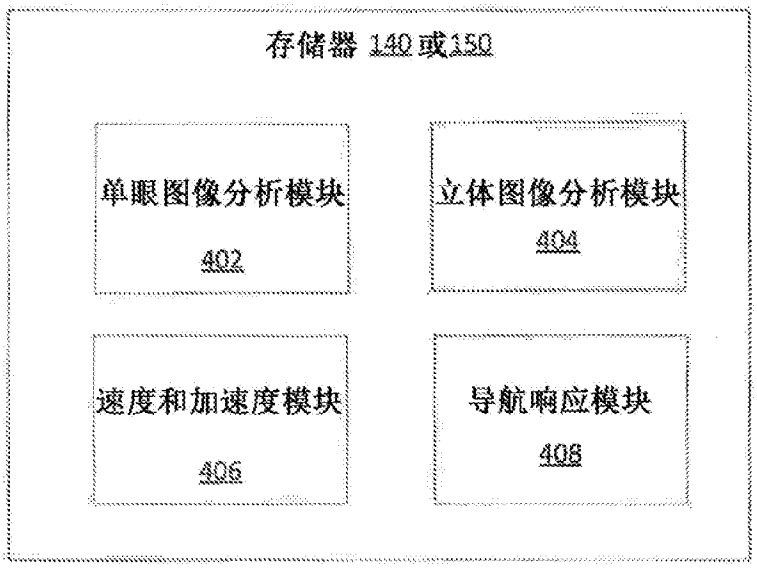


图4

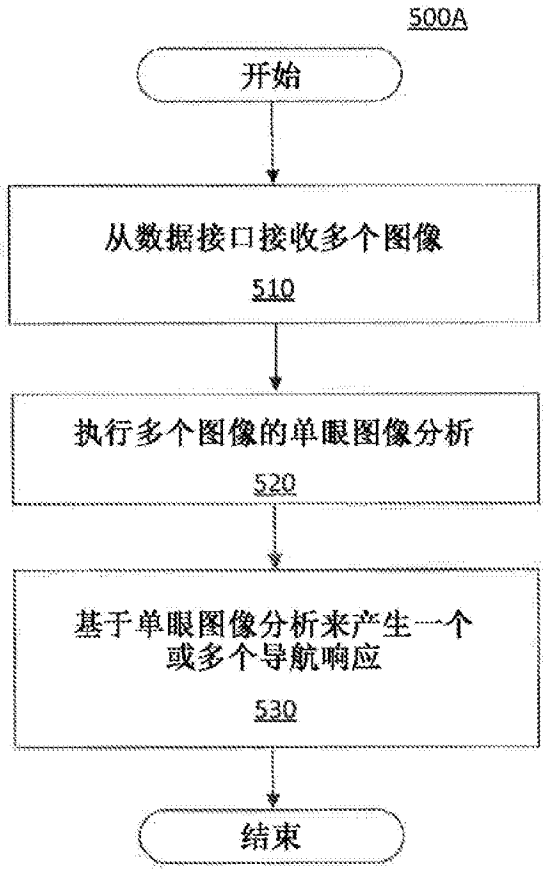


图5A

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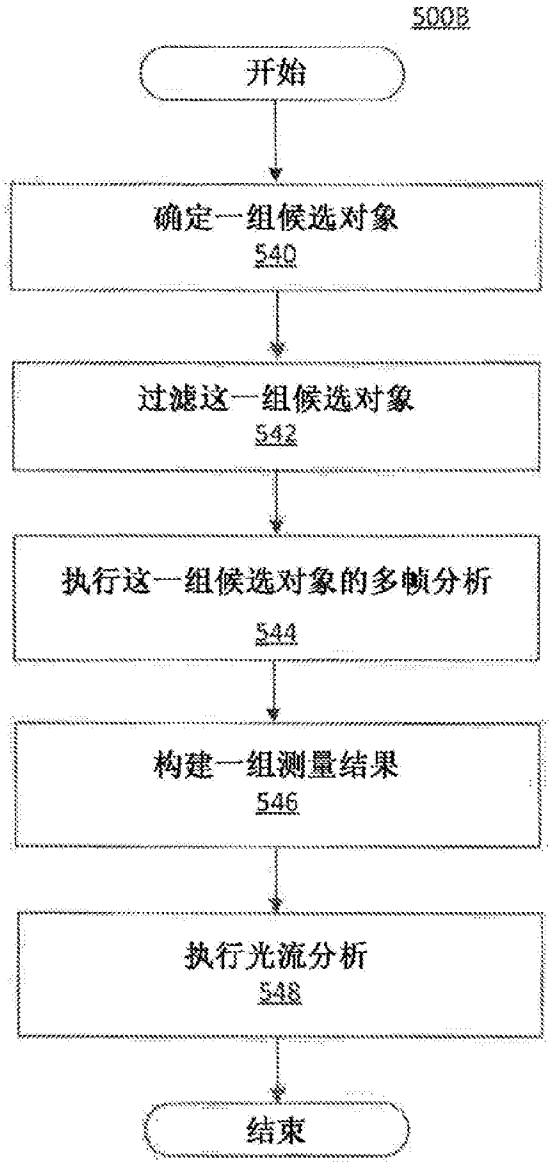


图5B

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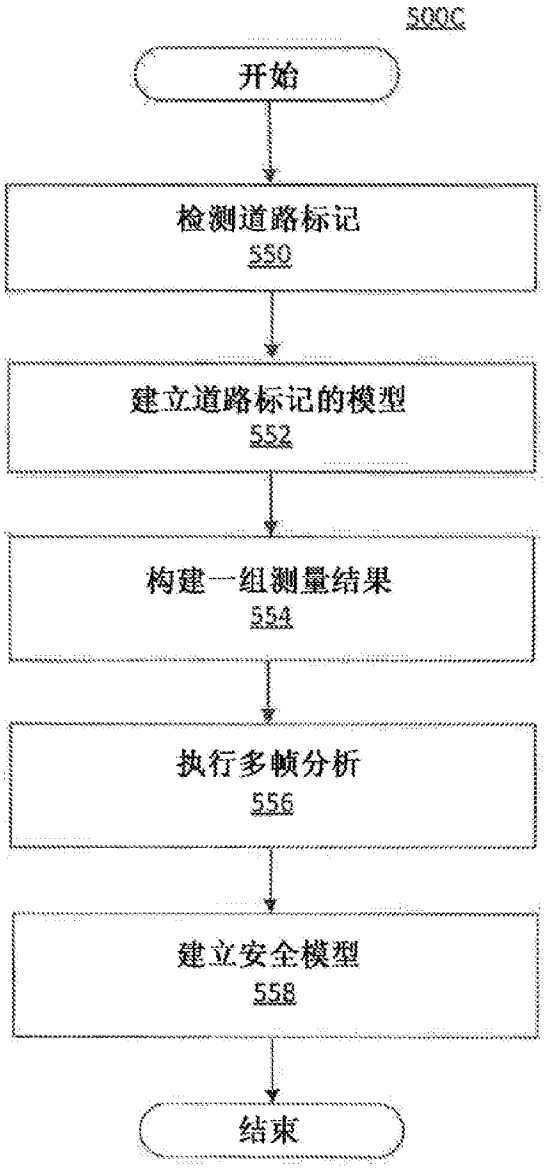


图5C

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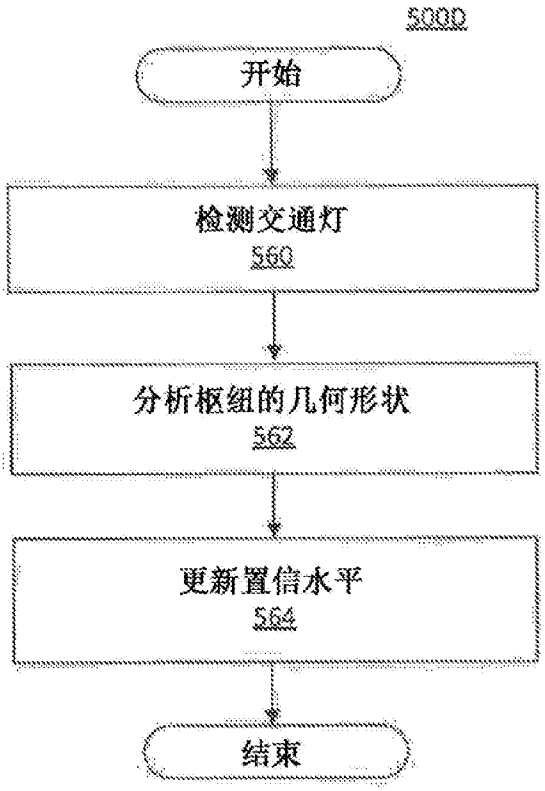


图5D

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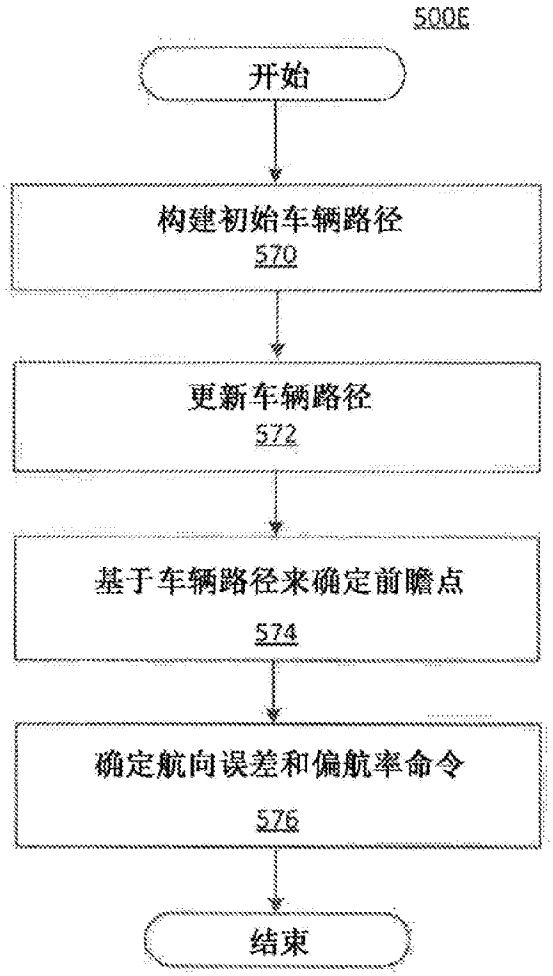


图5E

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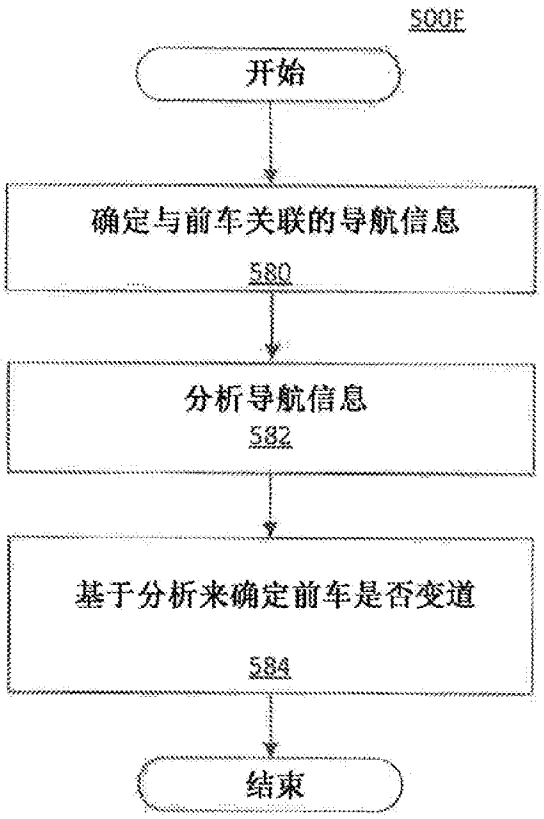


图5F

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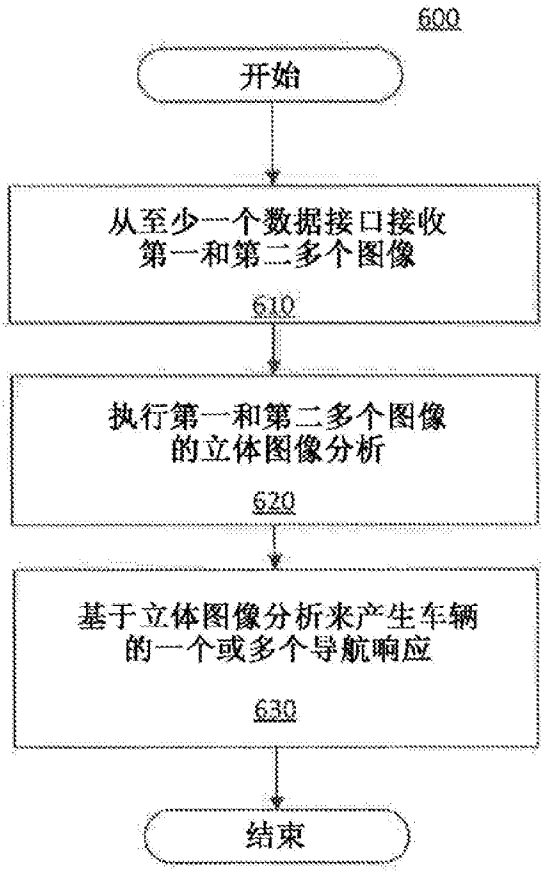


图6

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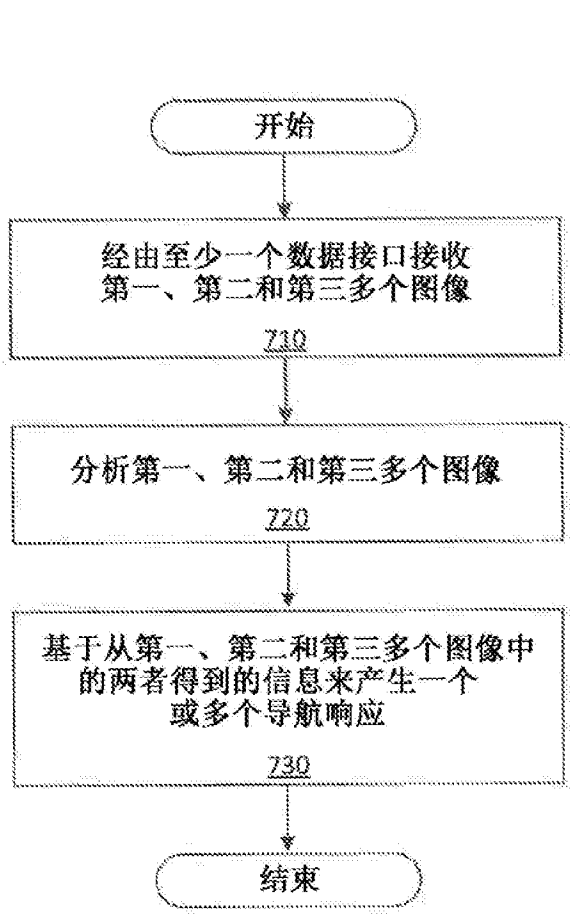


图7

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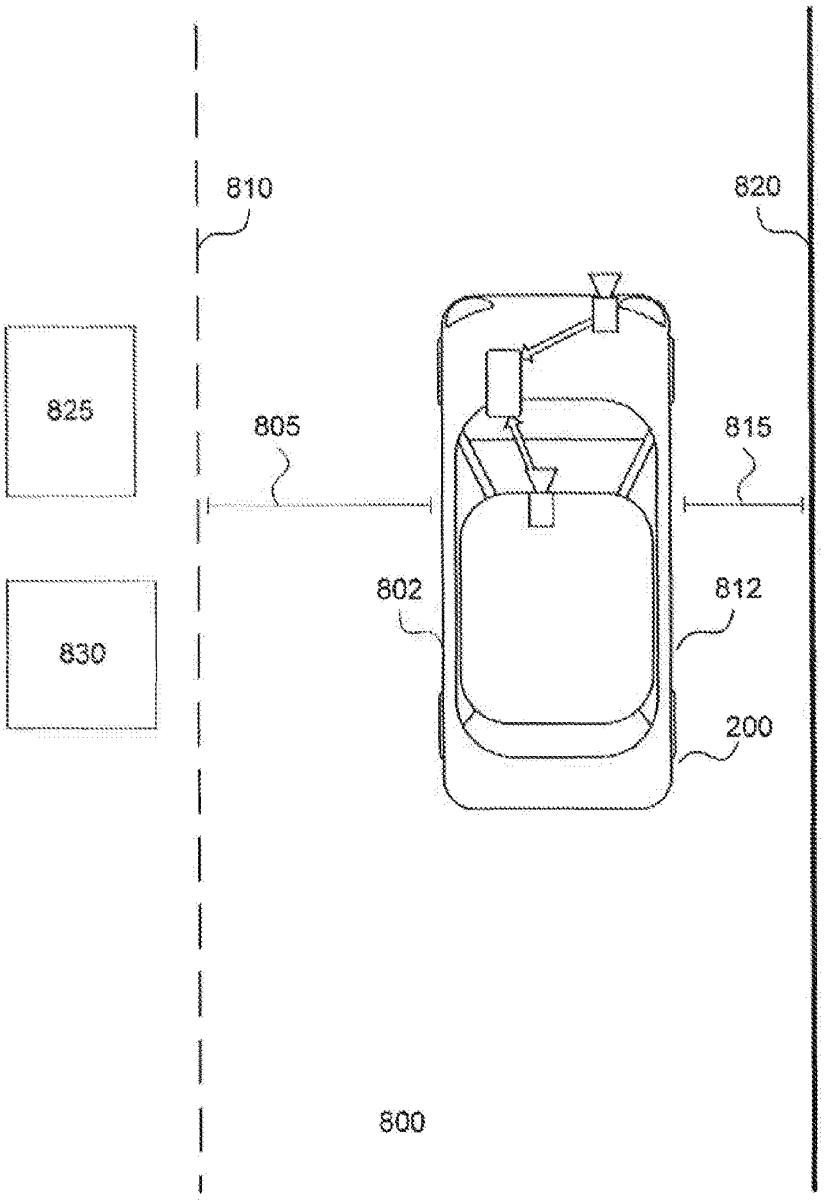


图8A

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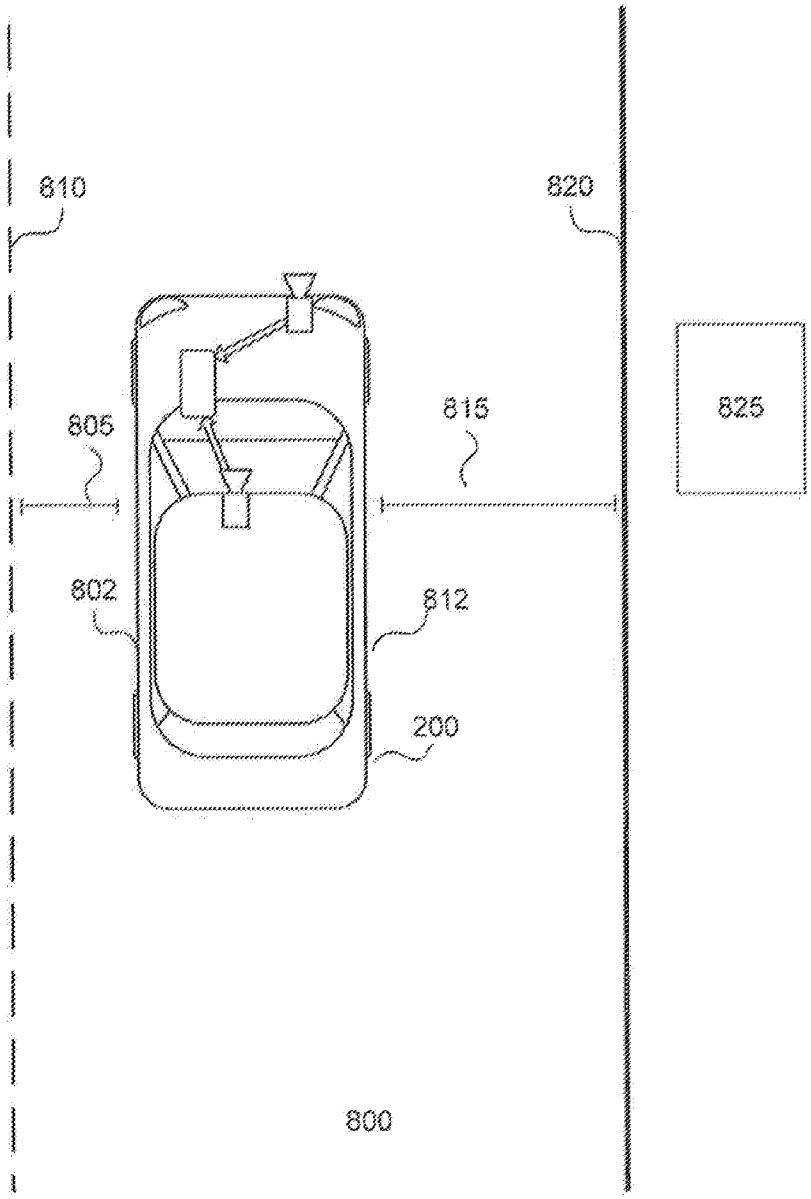


图8B

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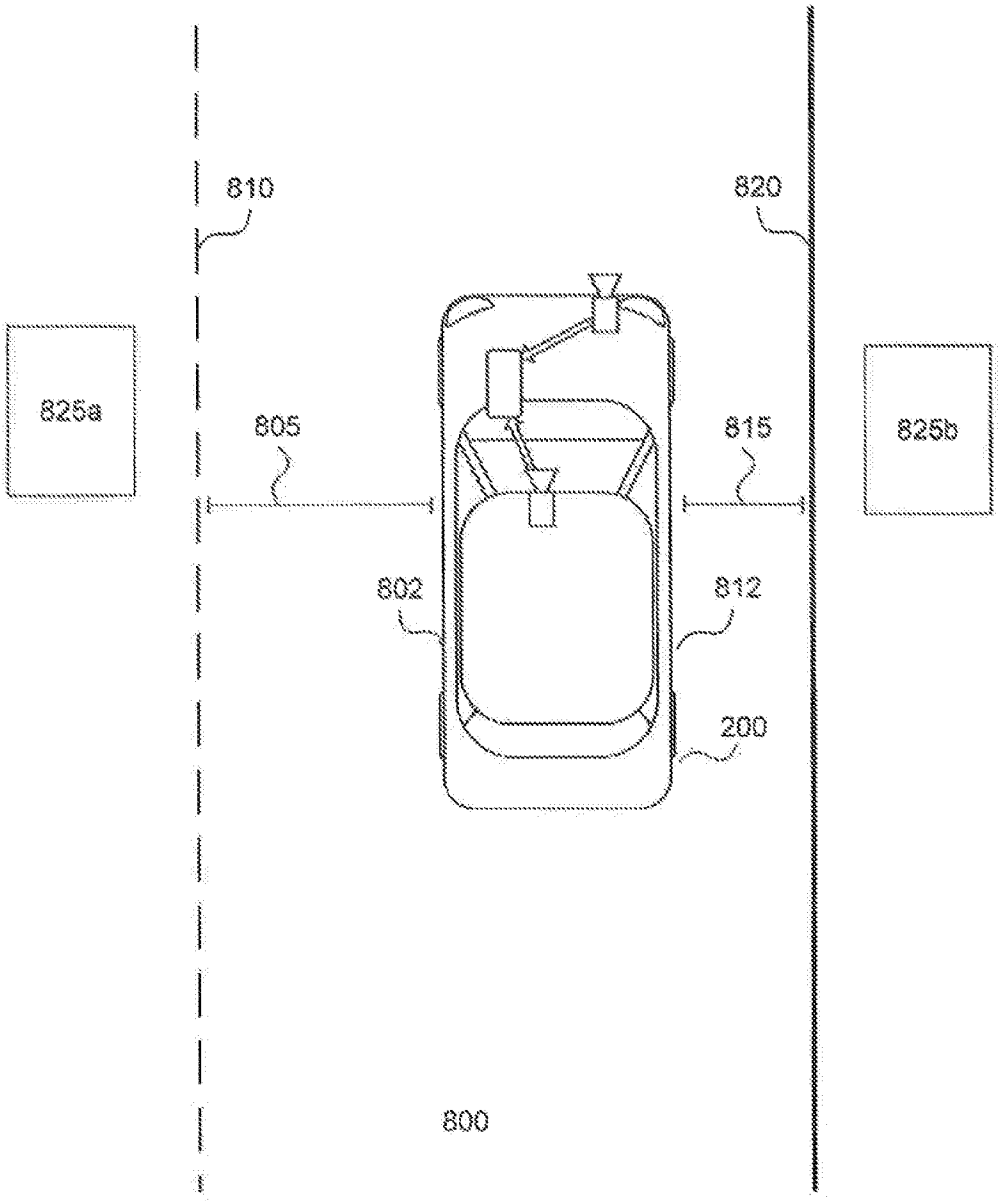


图8C

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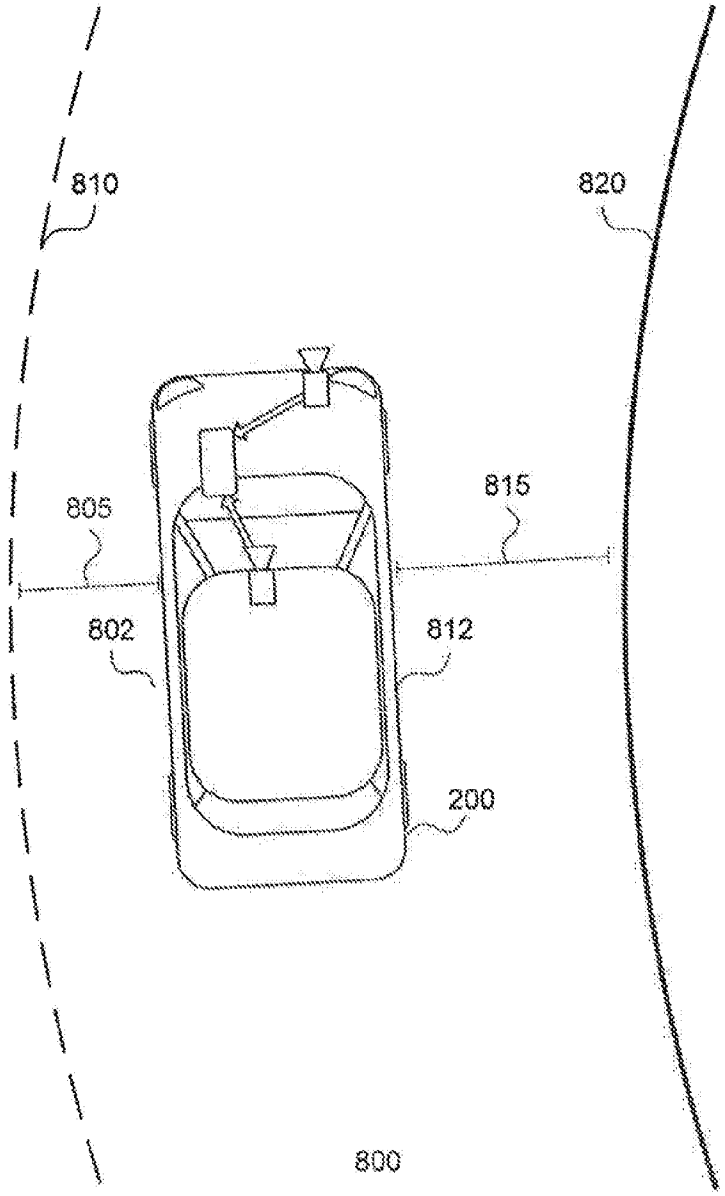


图8D

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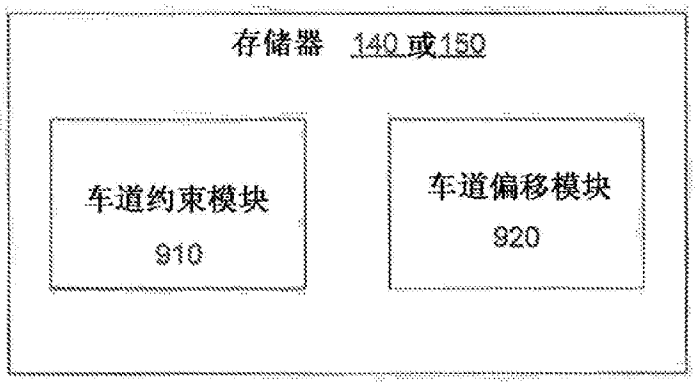


图9

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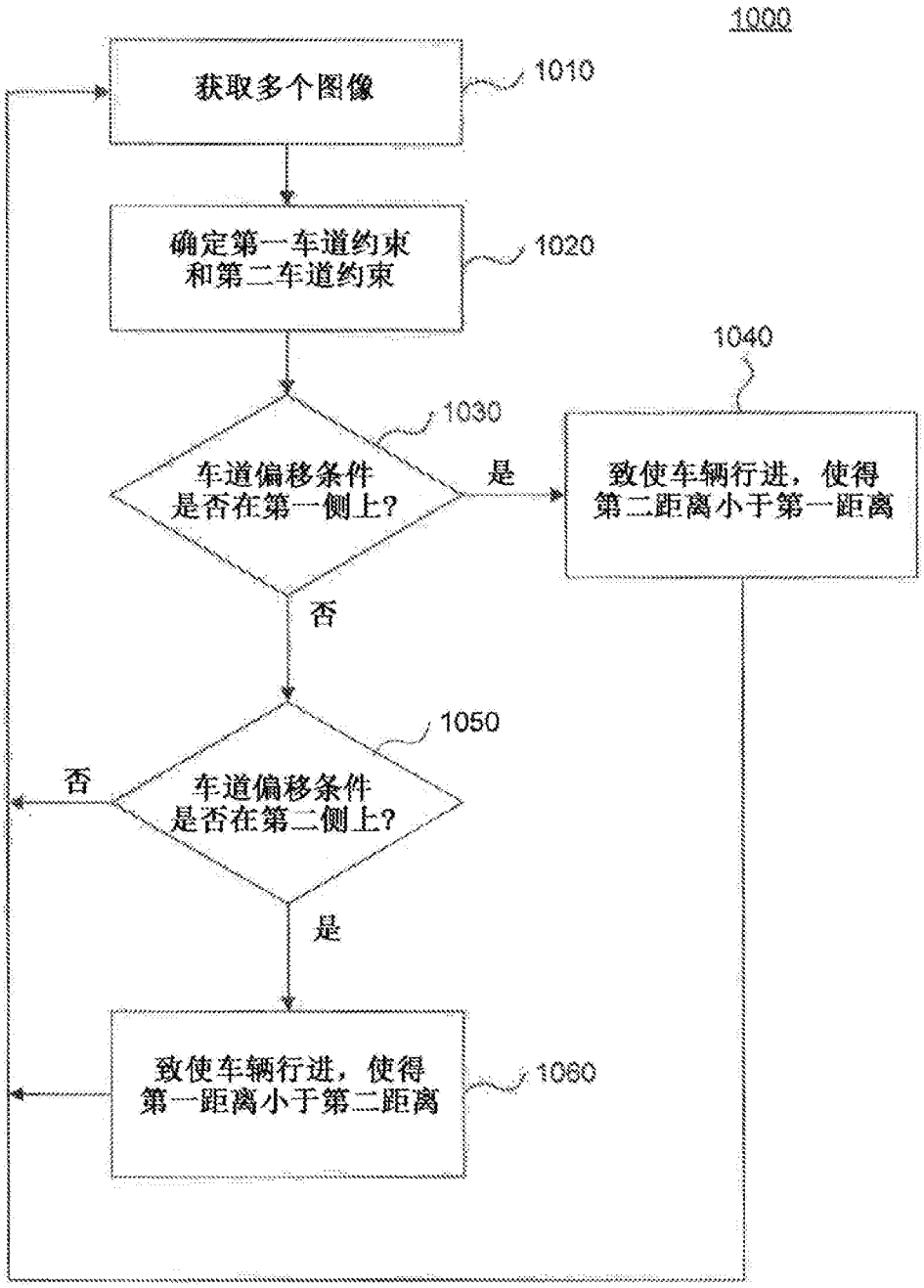


图10

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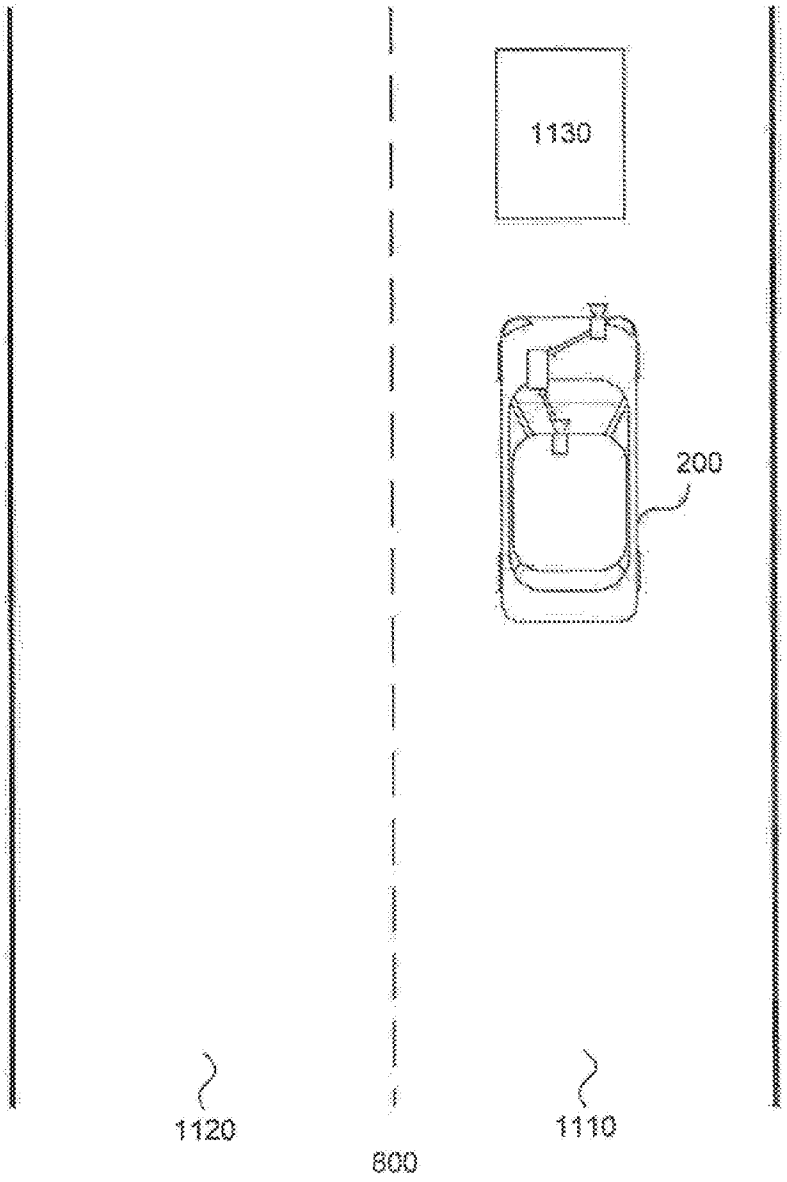


图11

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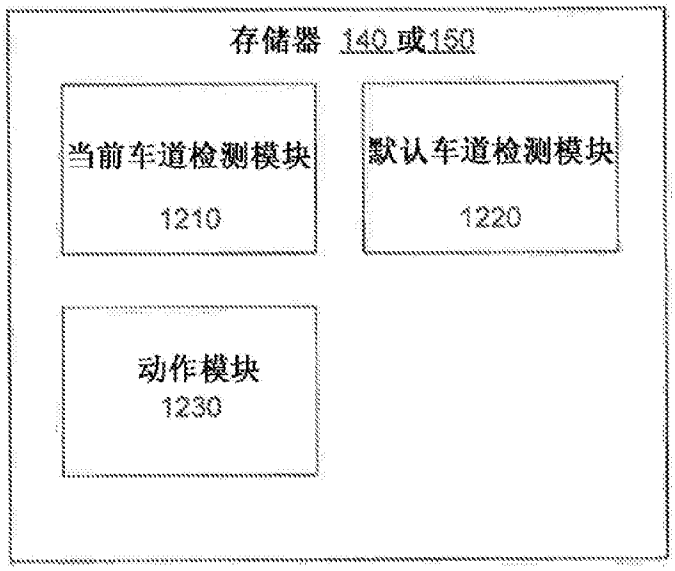


图12A

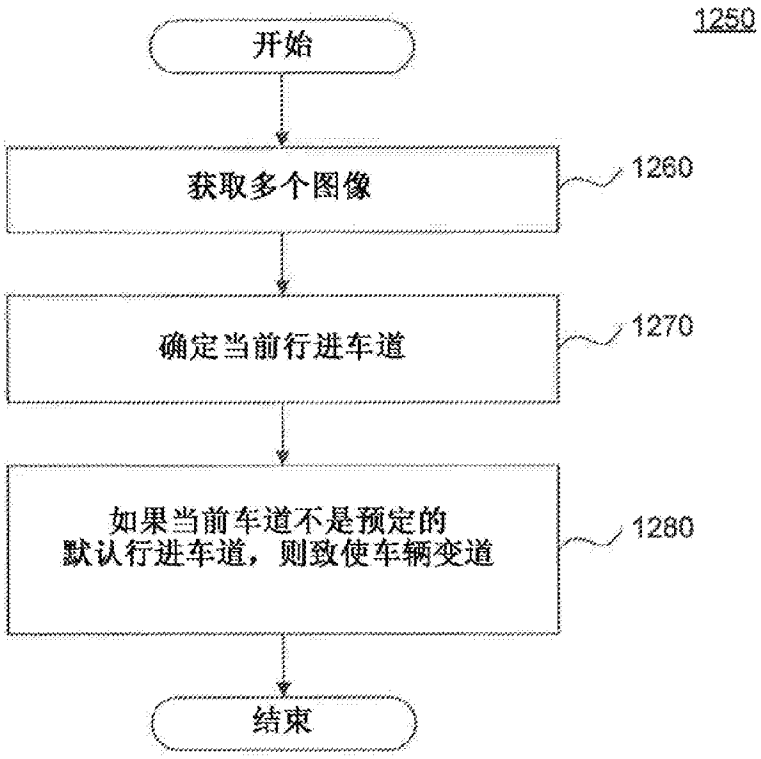


图12B

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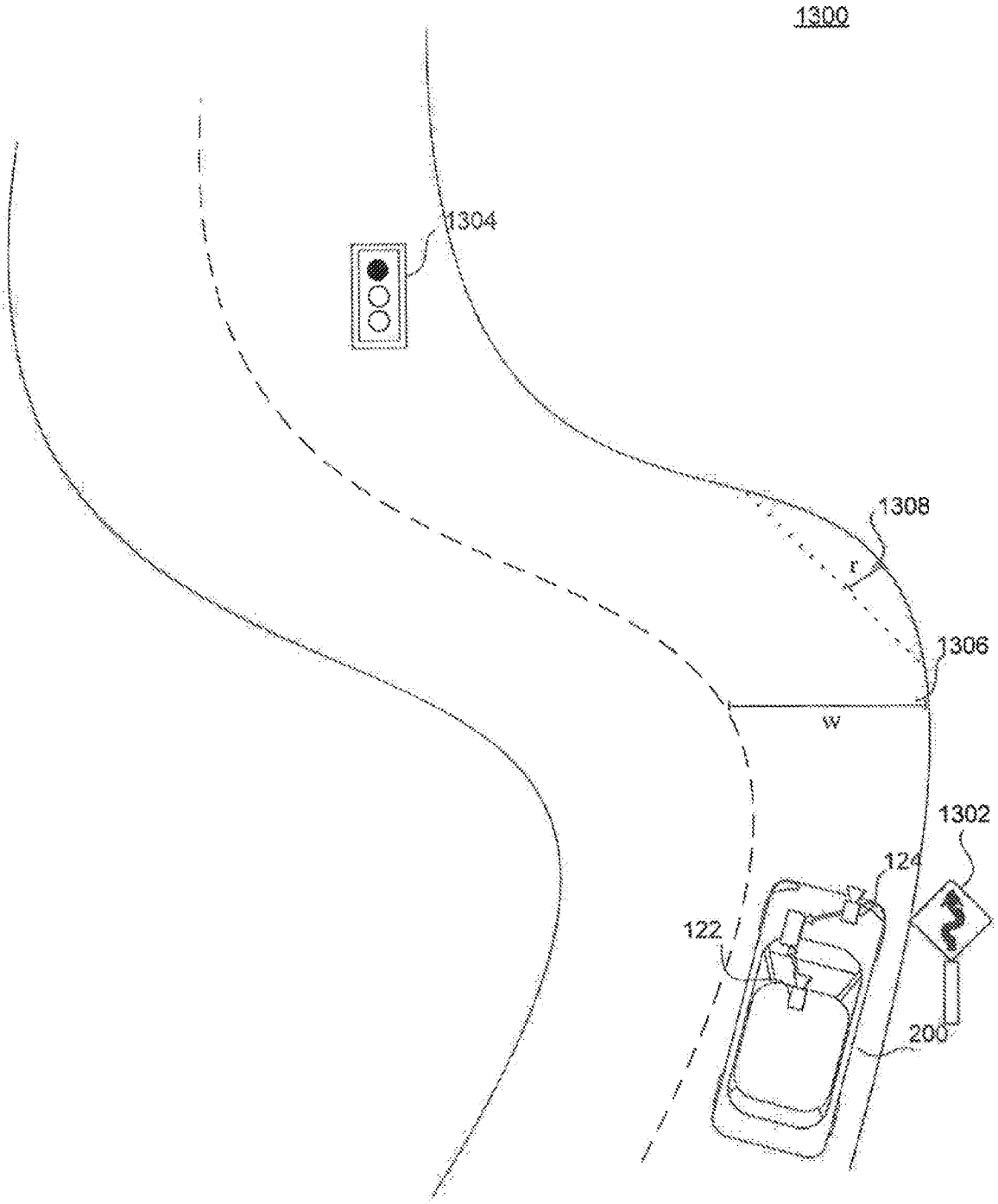


图13A

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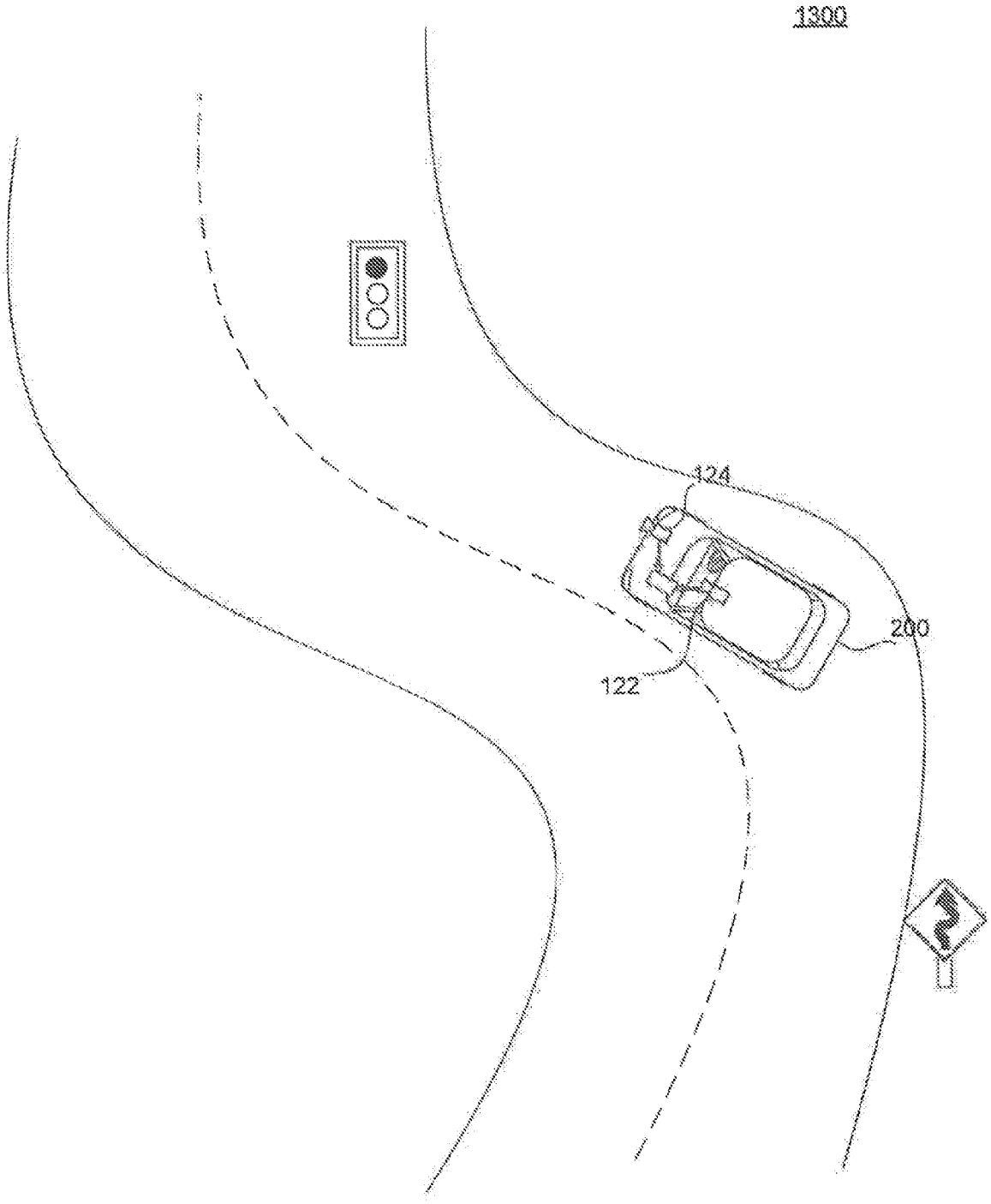


图13B

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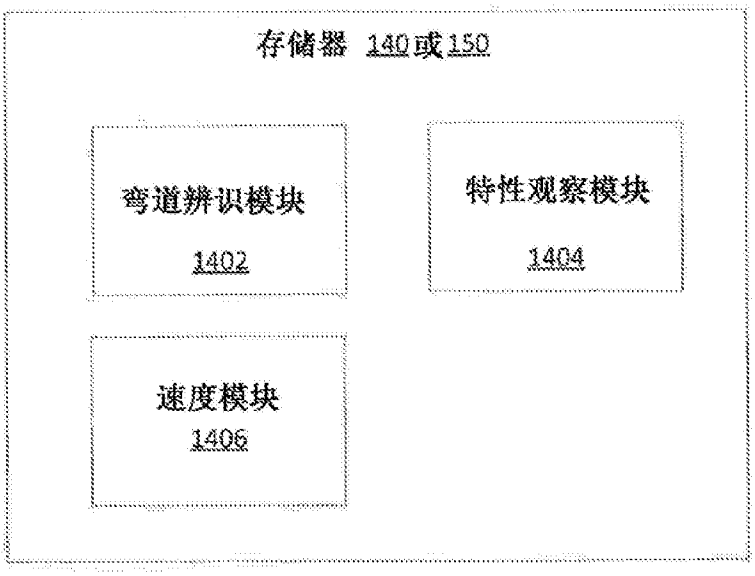


图14

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图15

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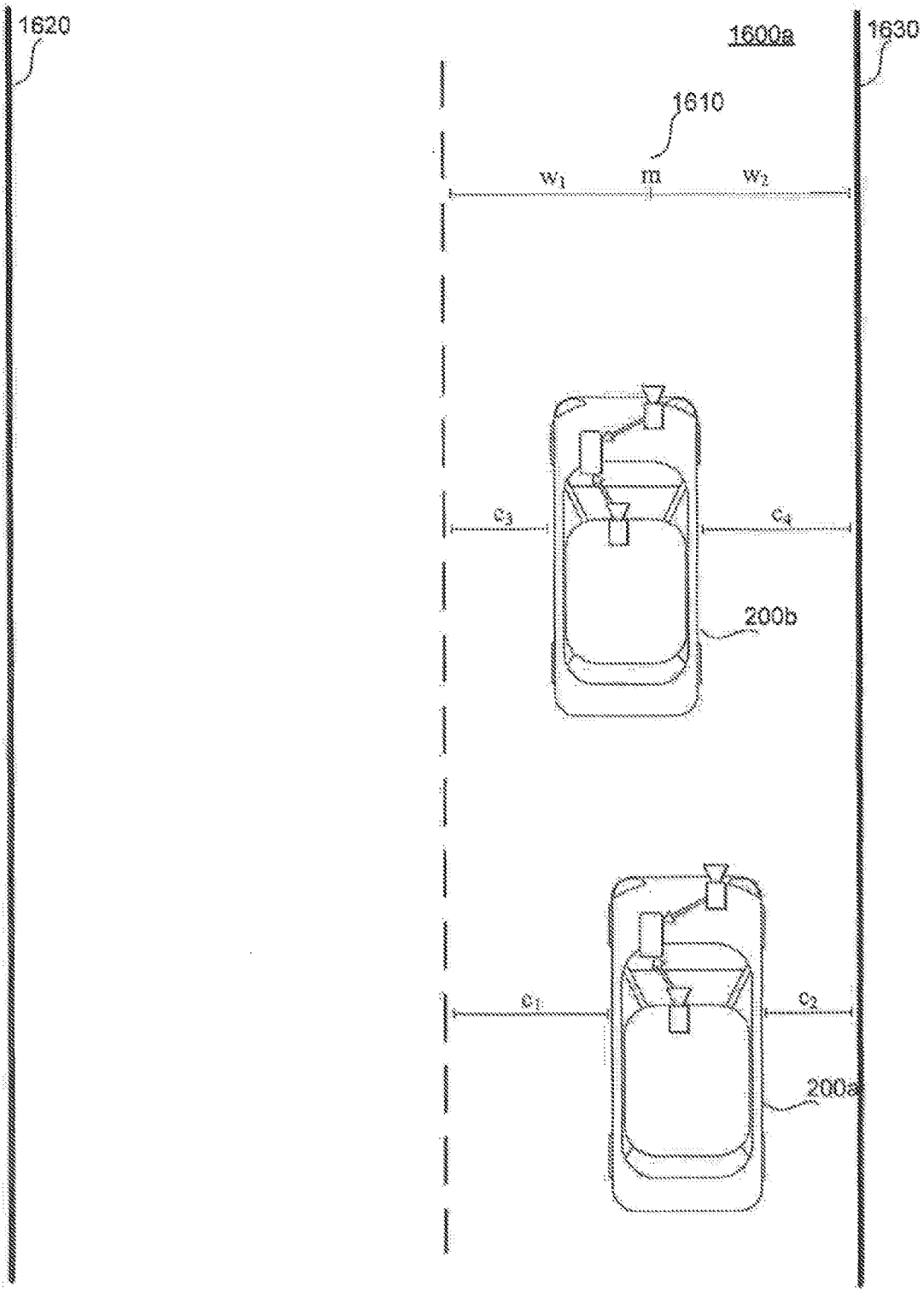


图16A

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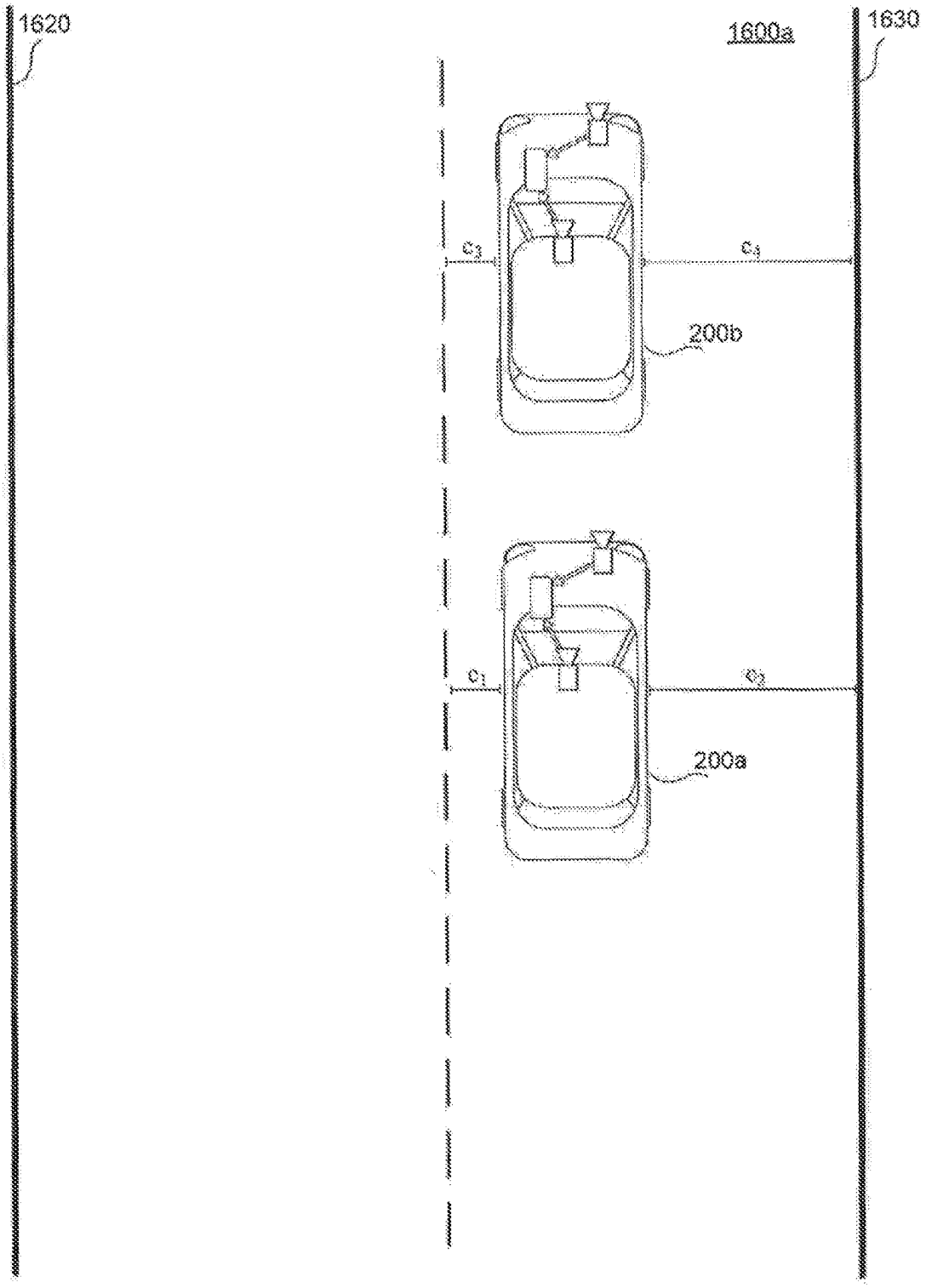


图16B

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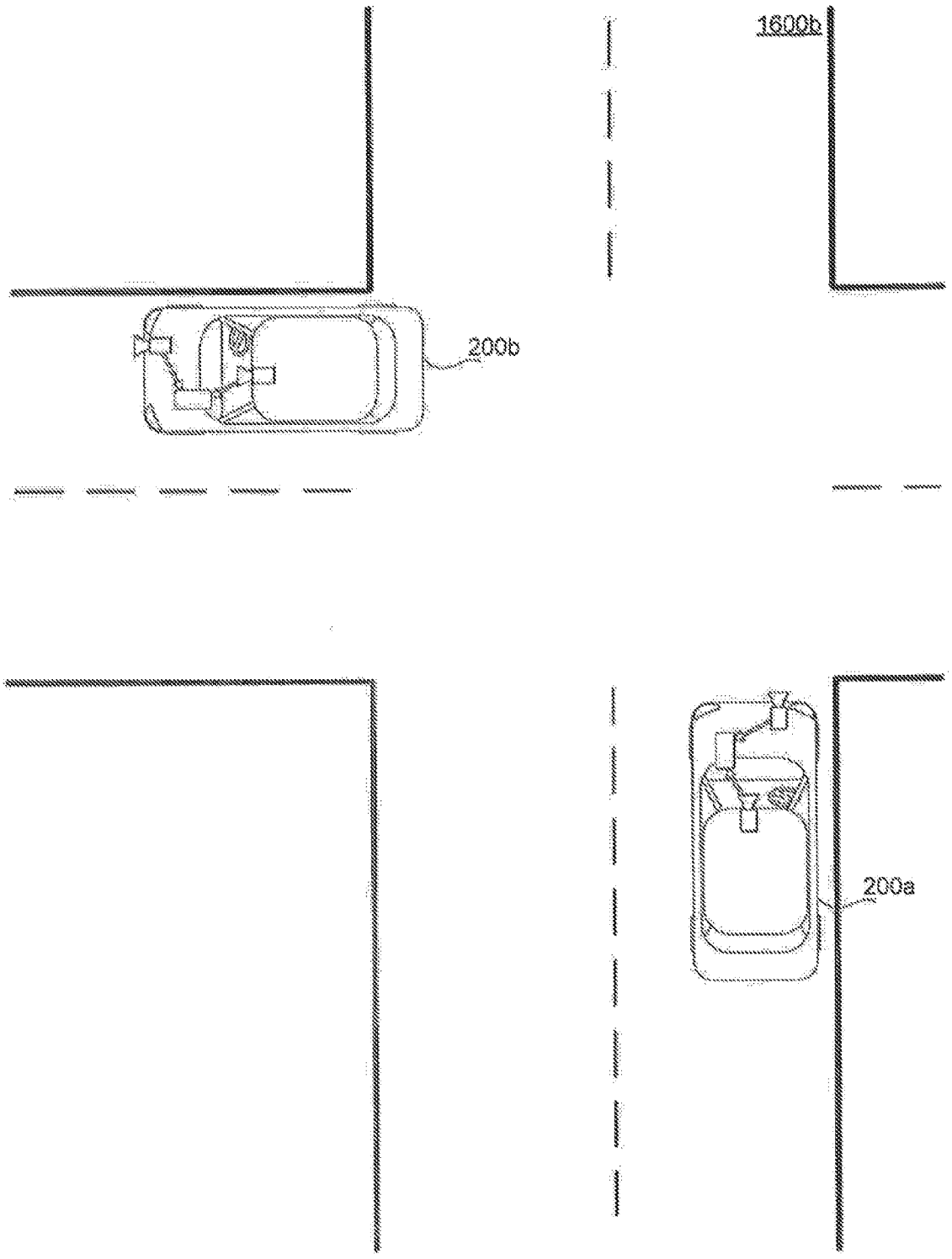


图16C

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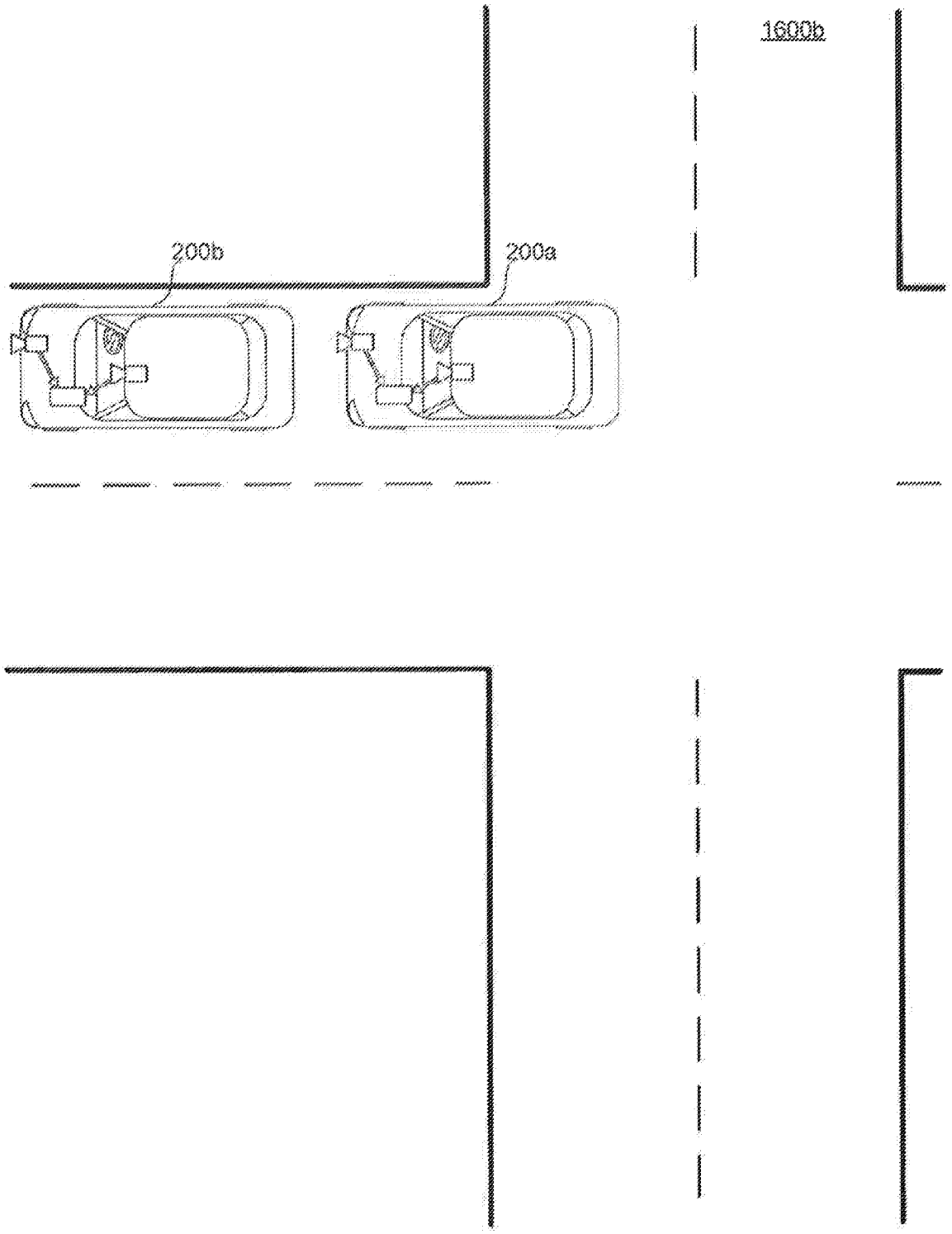


图16D

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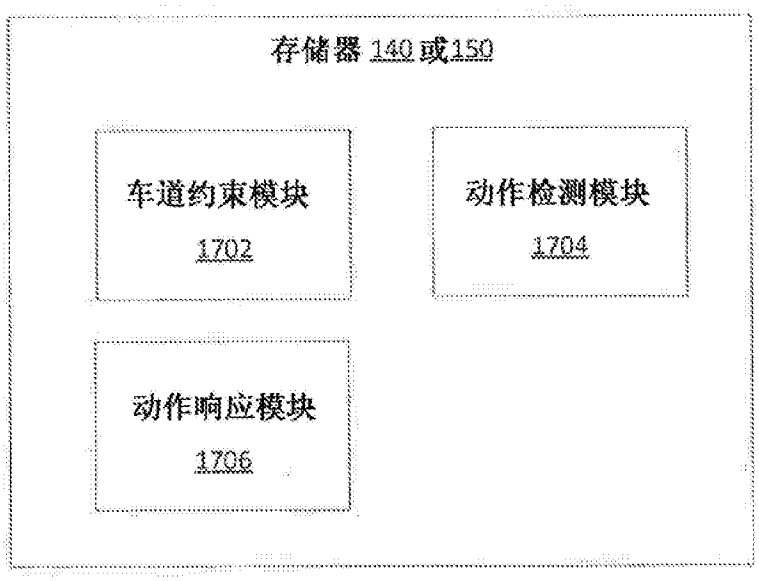


图17

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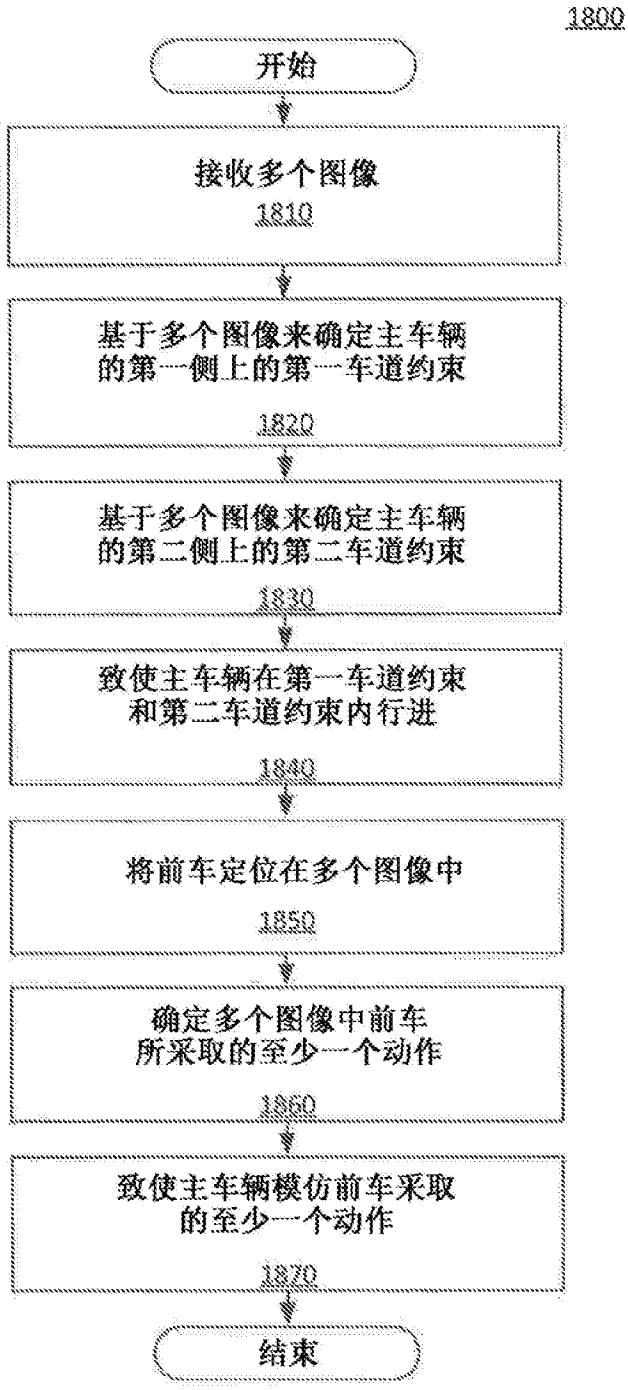


图18

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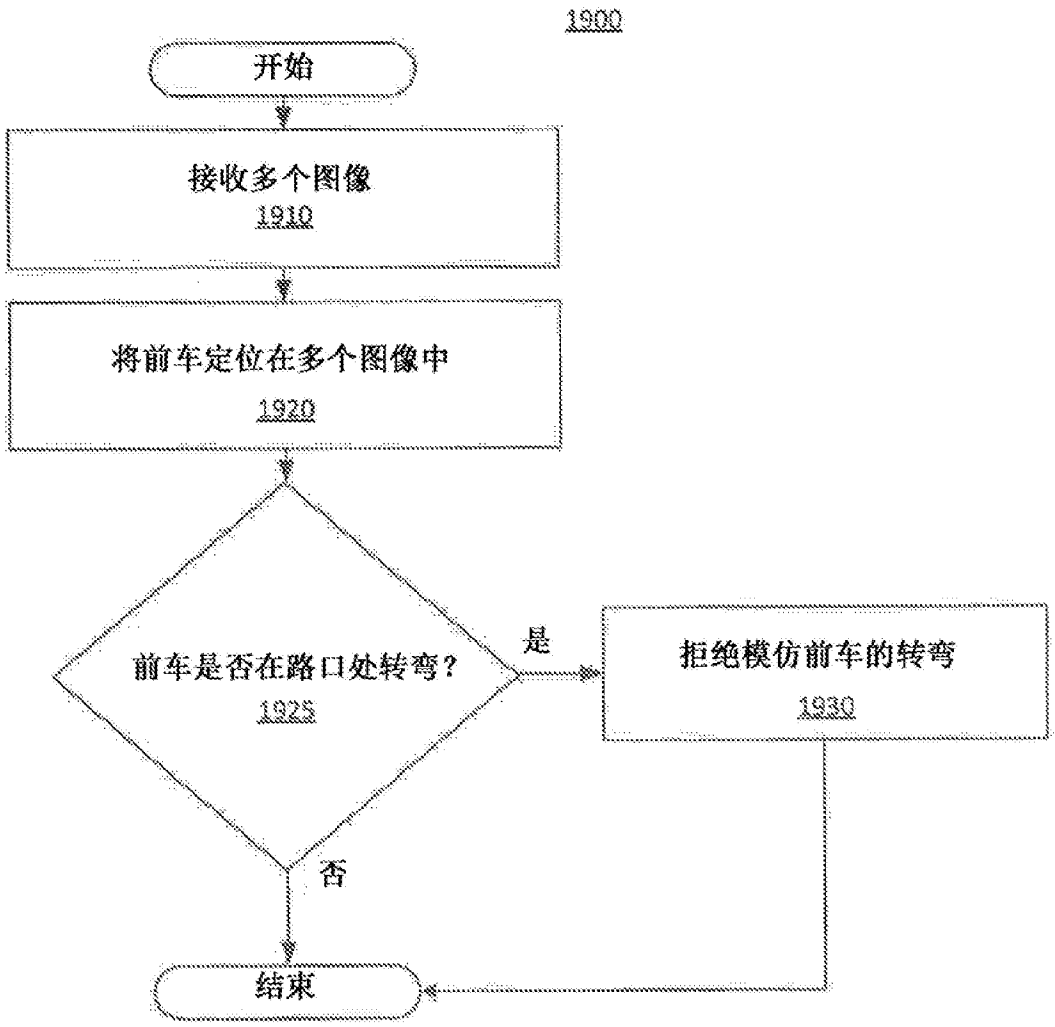


图19

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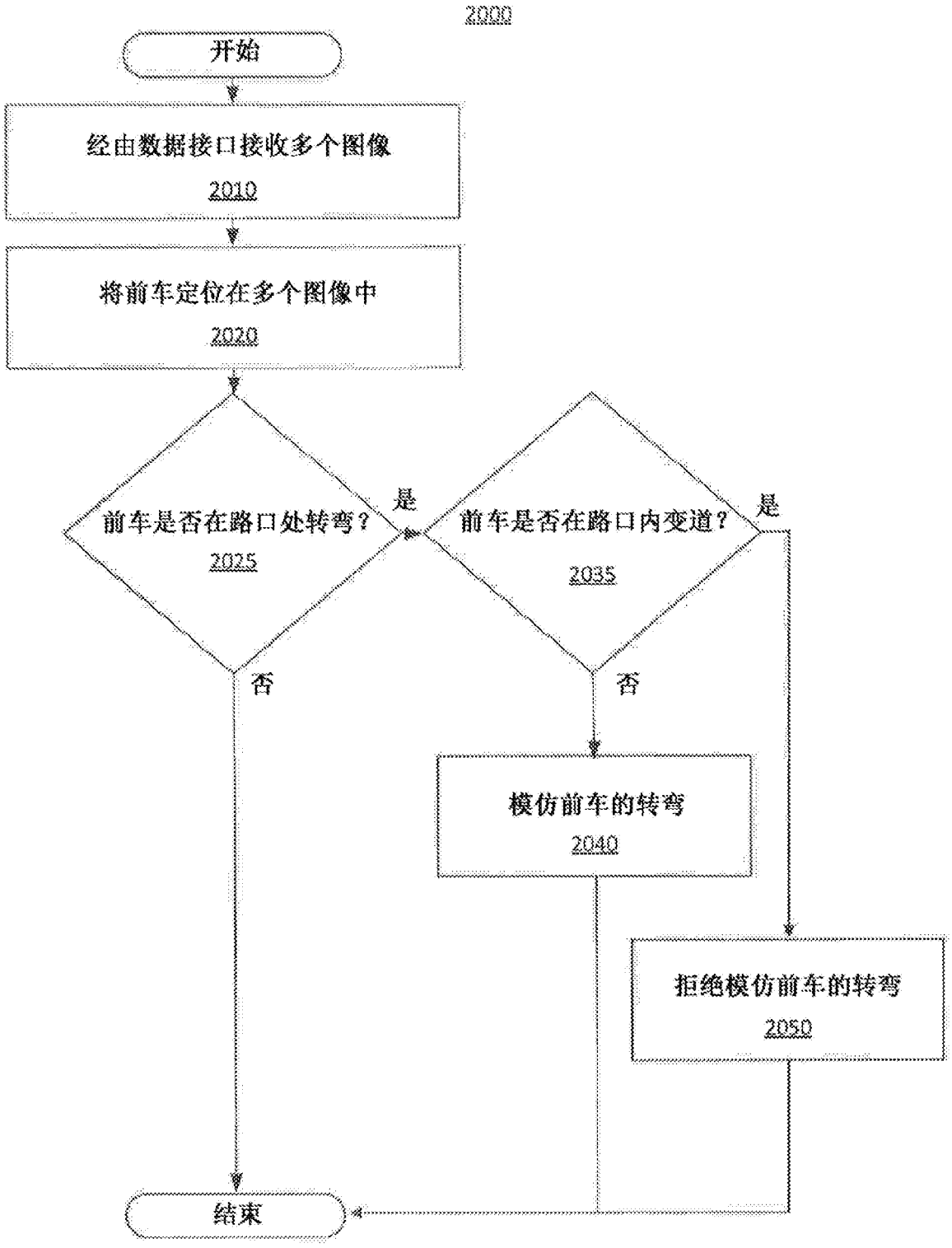


图20

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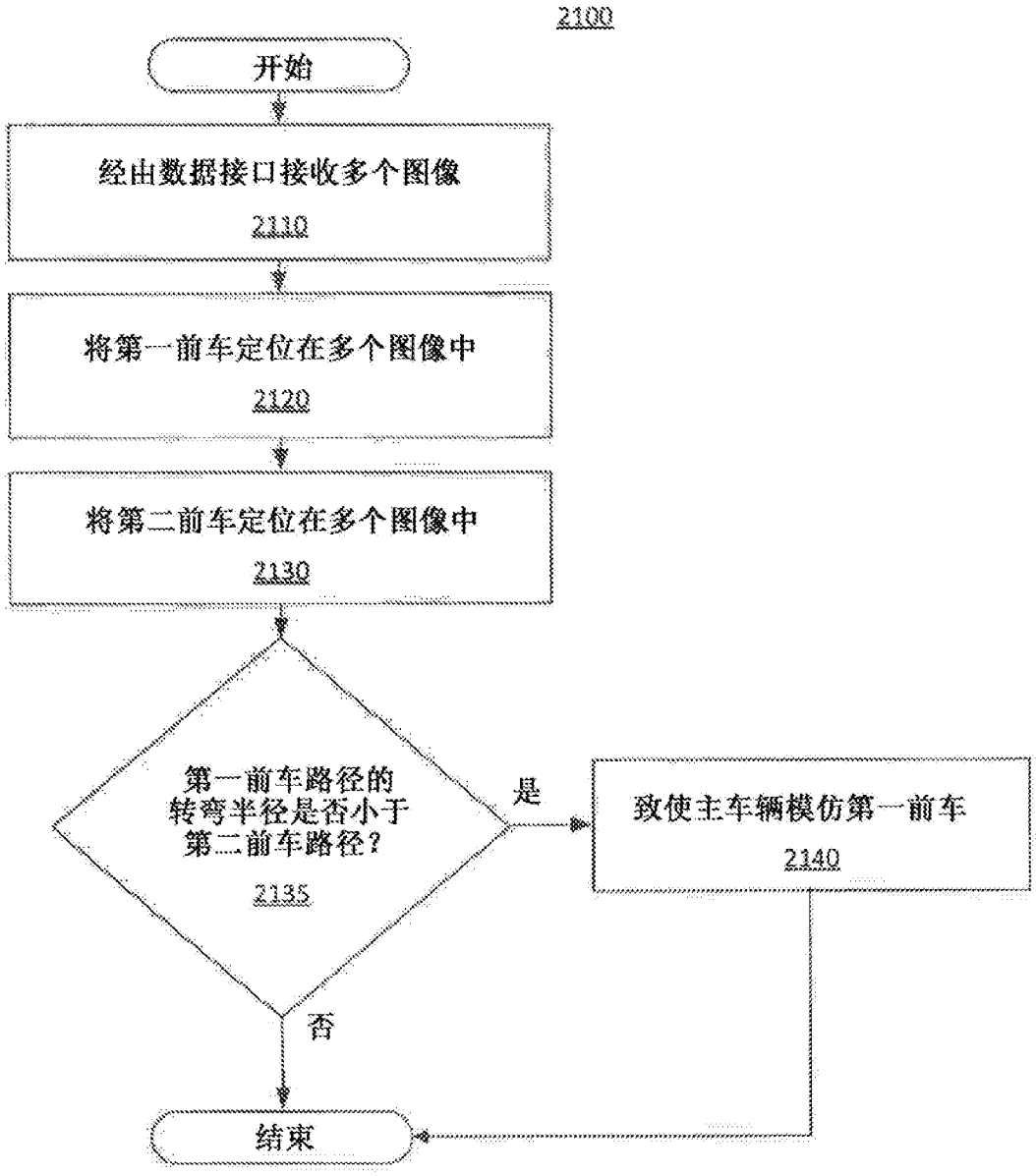


图21

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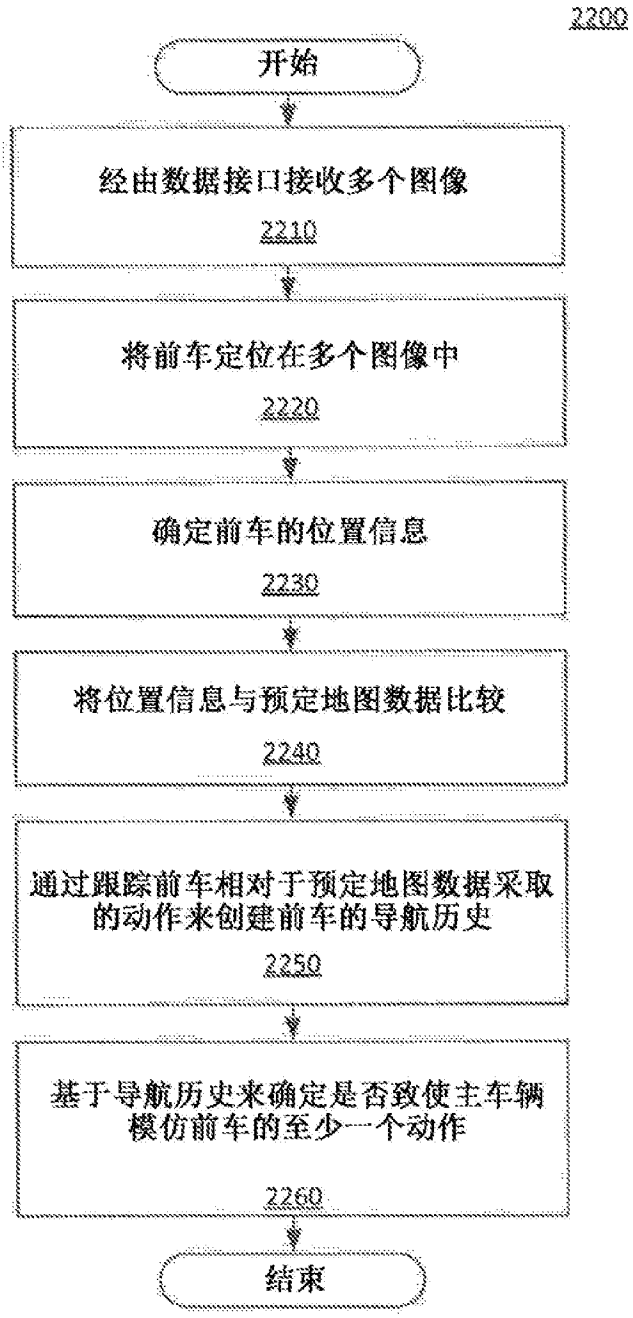


图22

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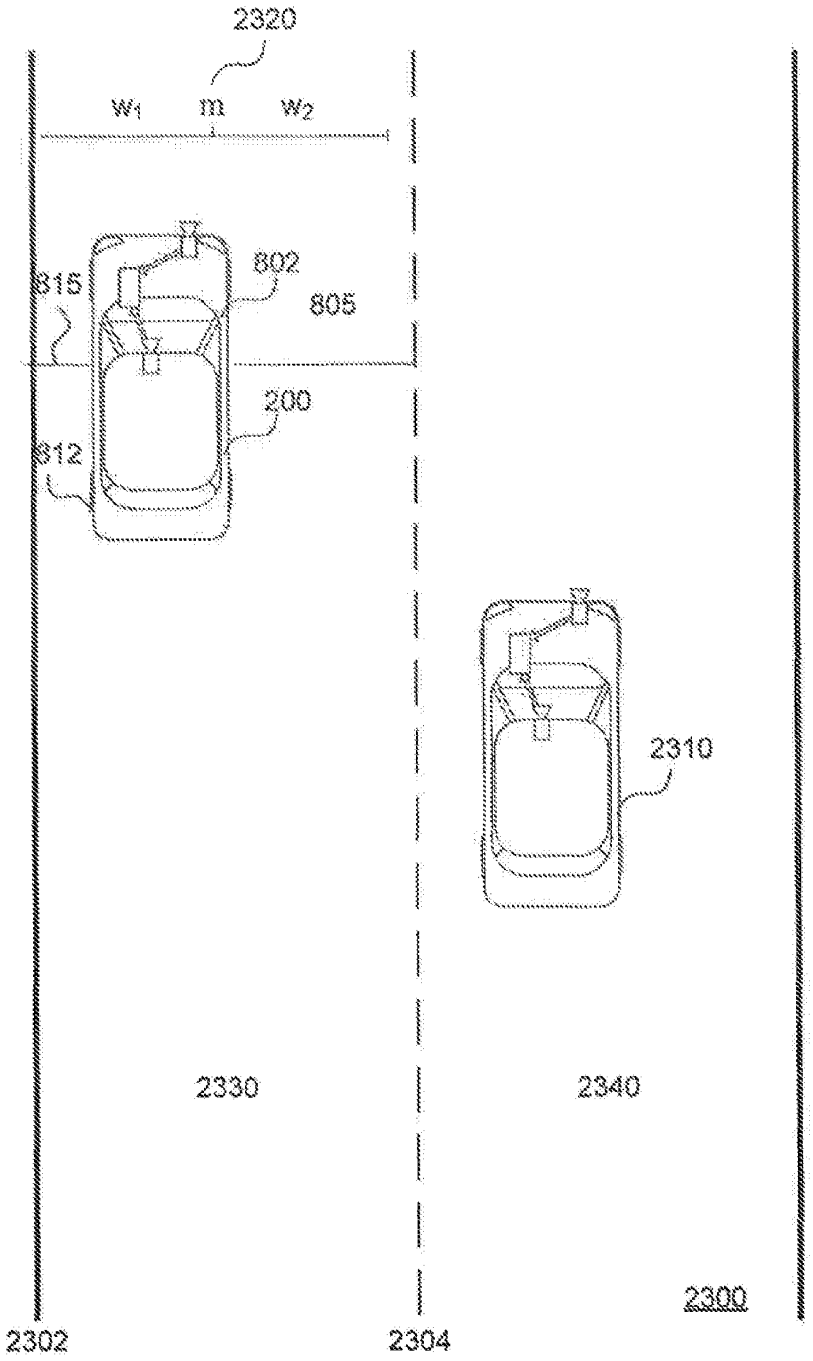


图23

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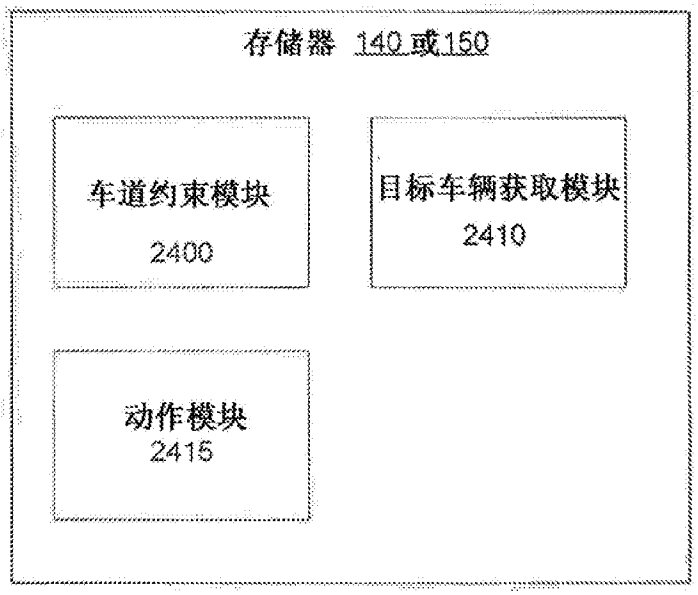


图24A

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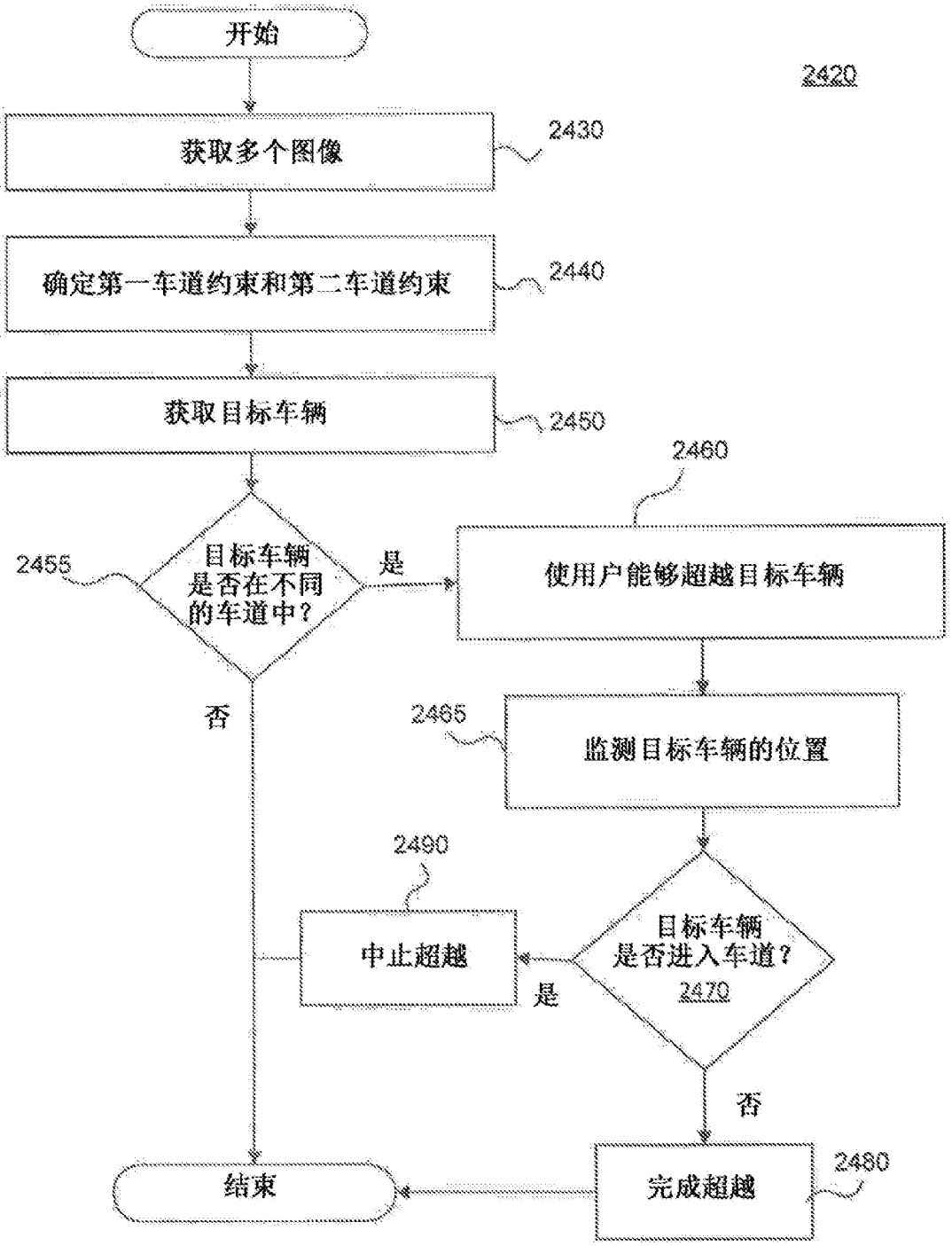


图24B

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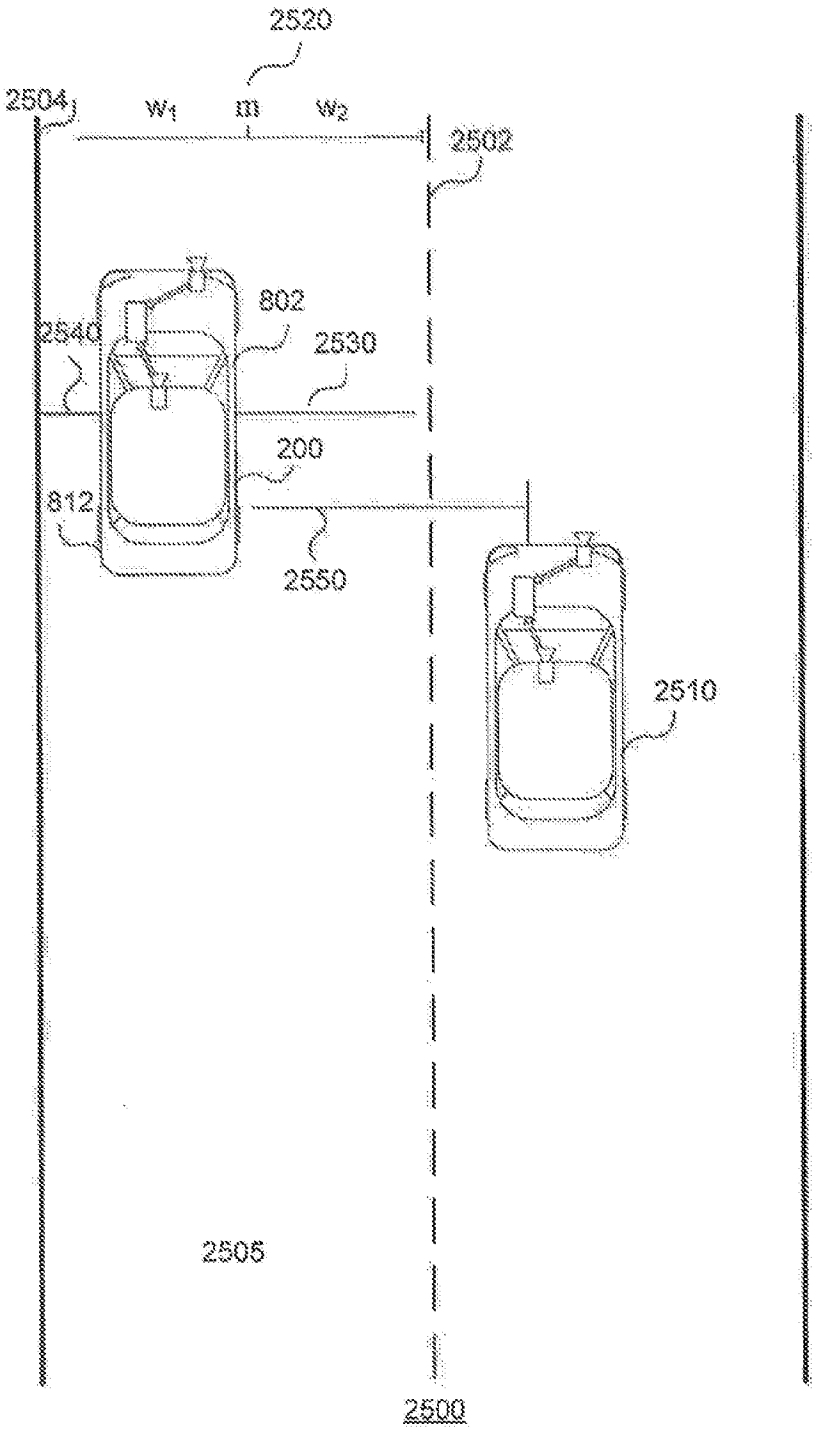


图25

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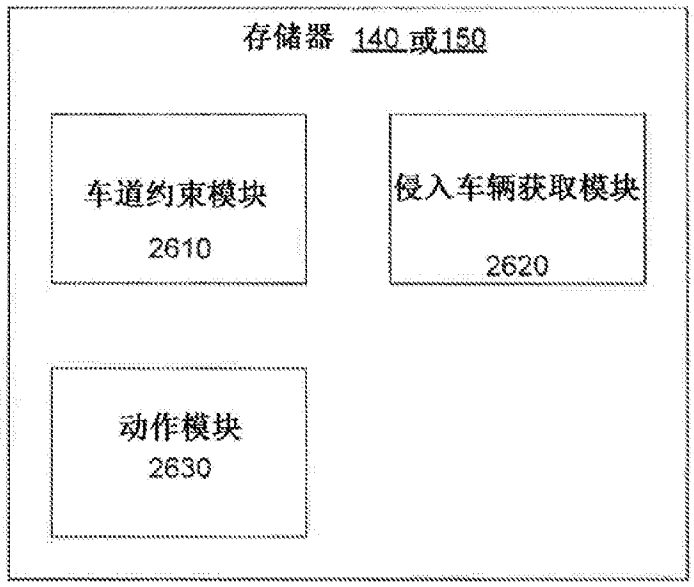


图26

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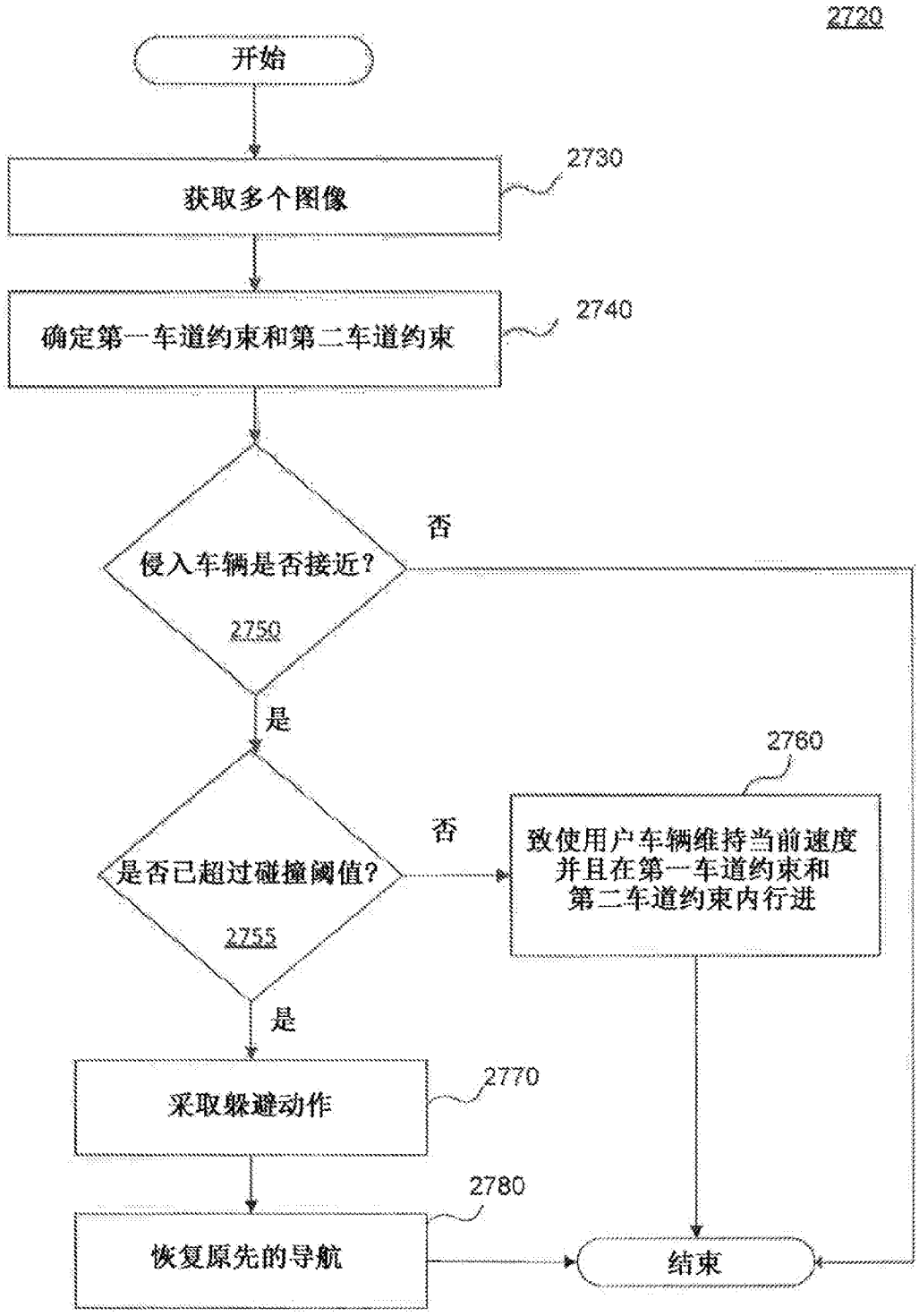


图27

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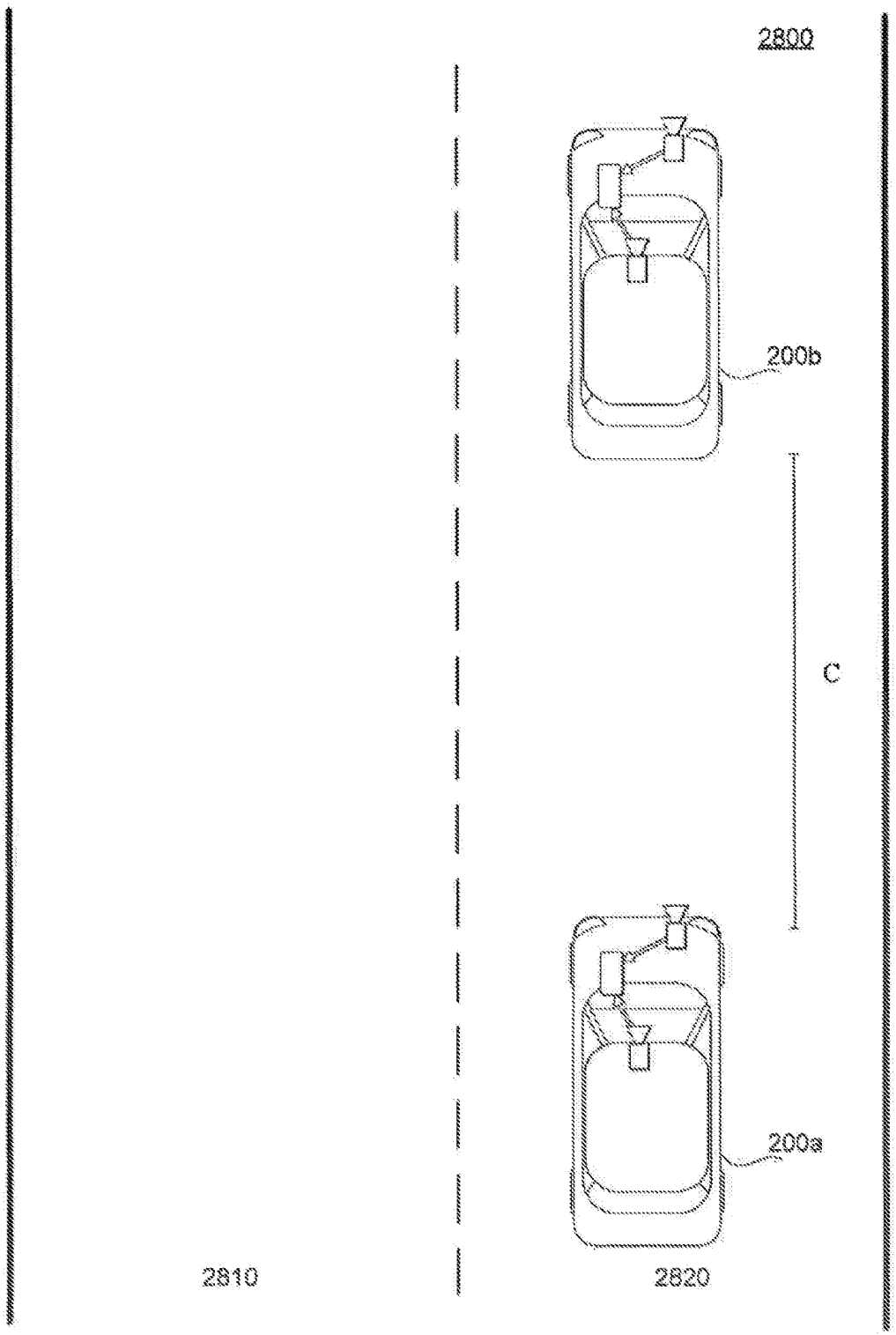


图28A

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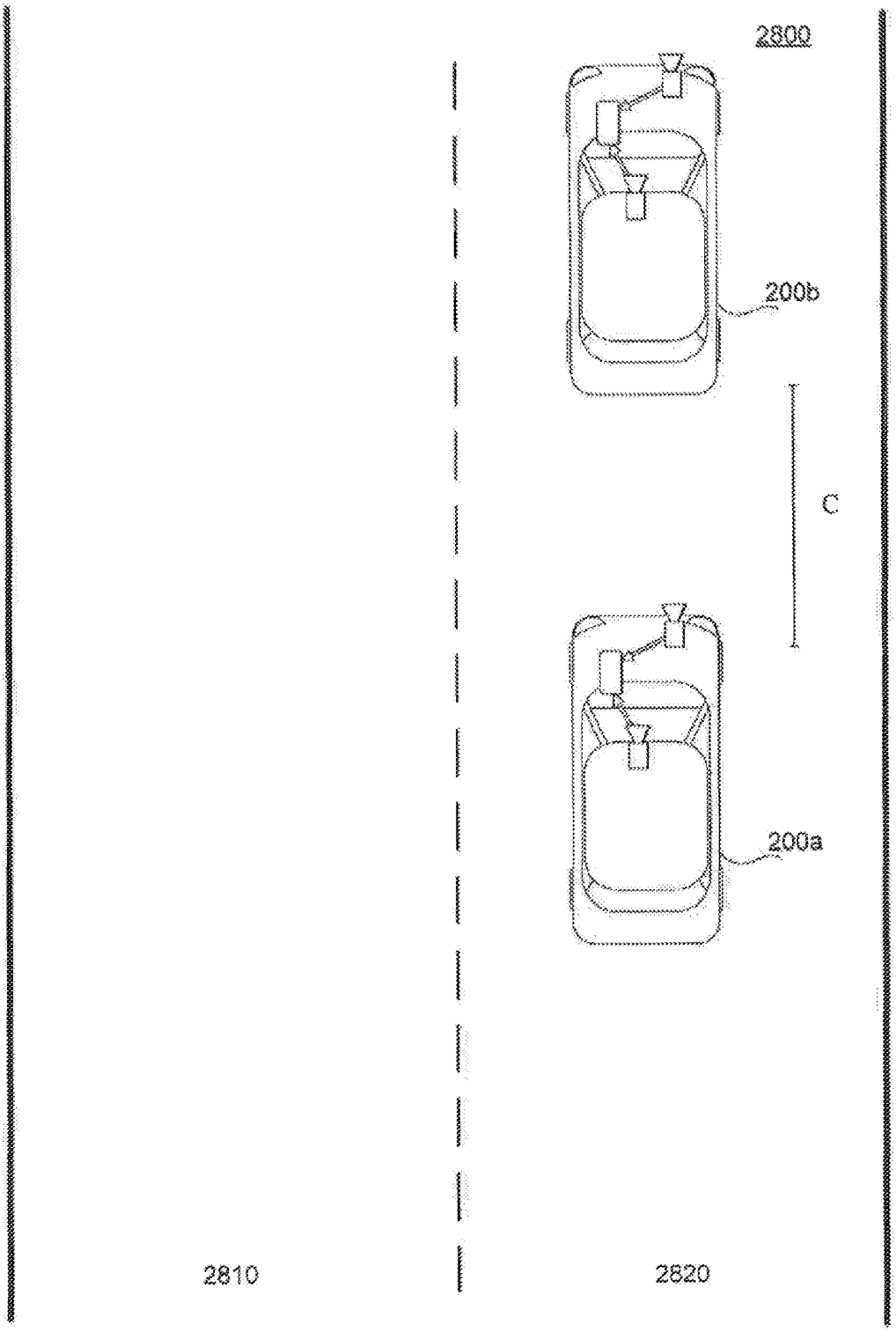


图28B

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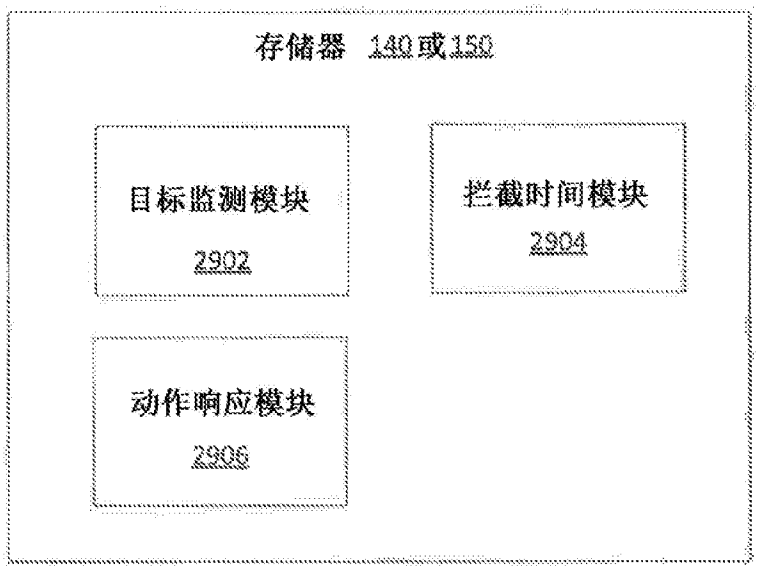


图29

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图30

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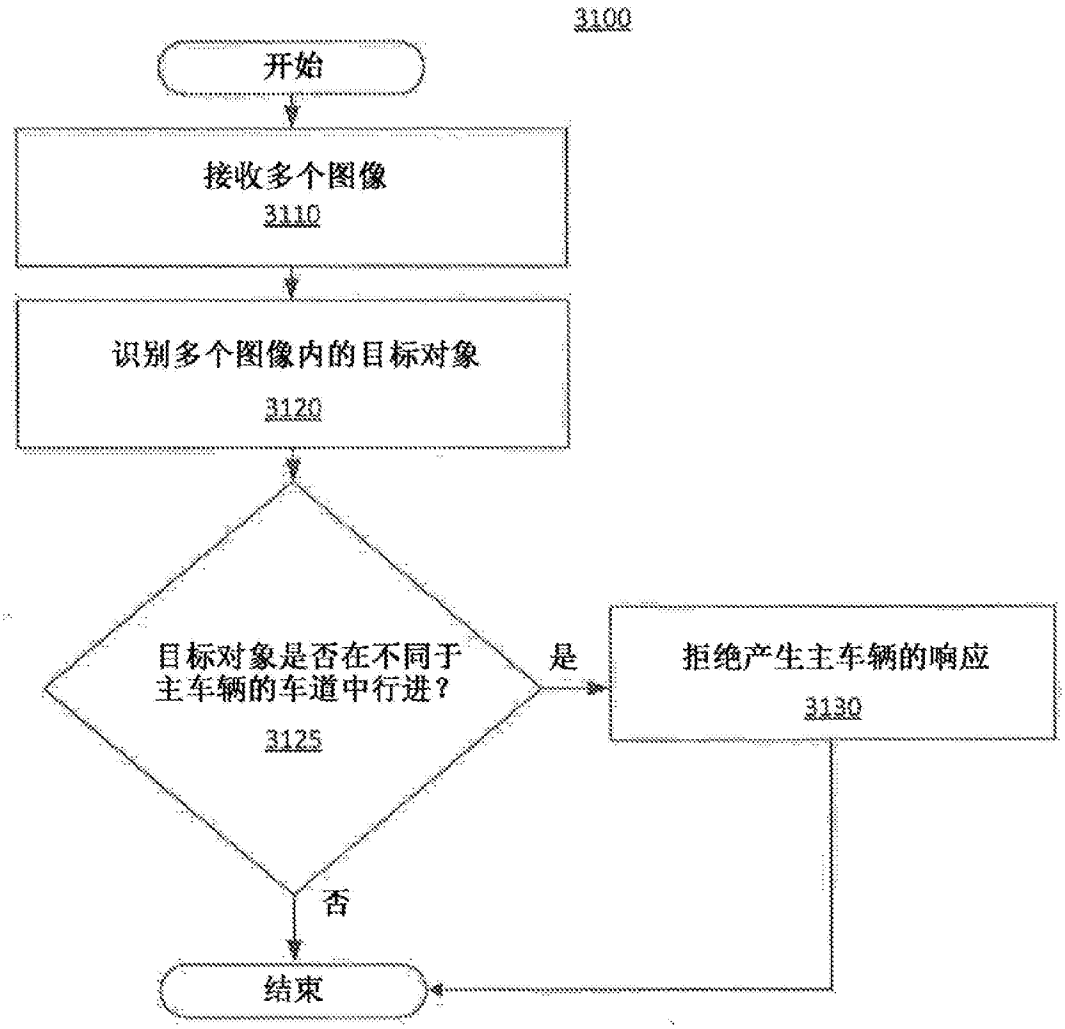


图31

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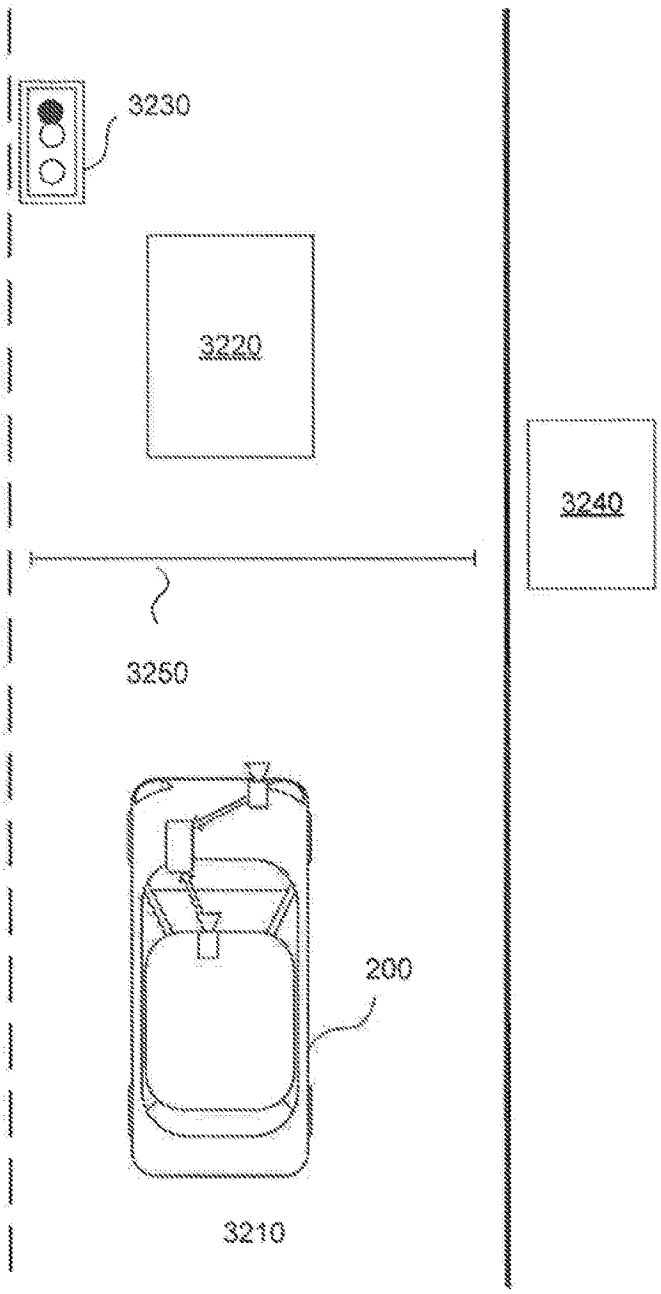


图32A

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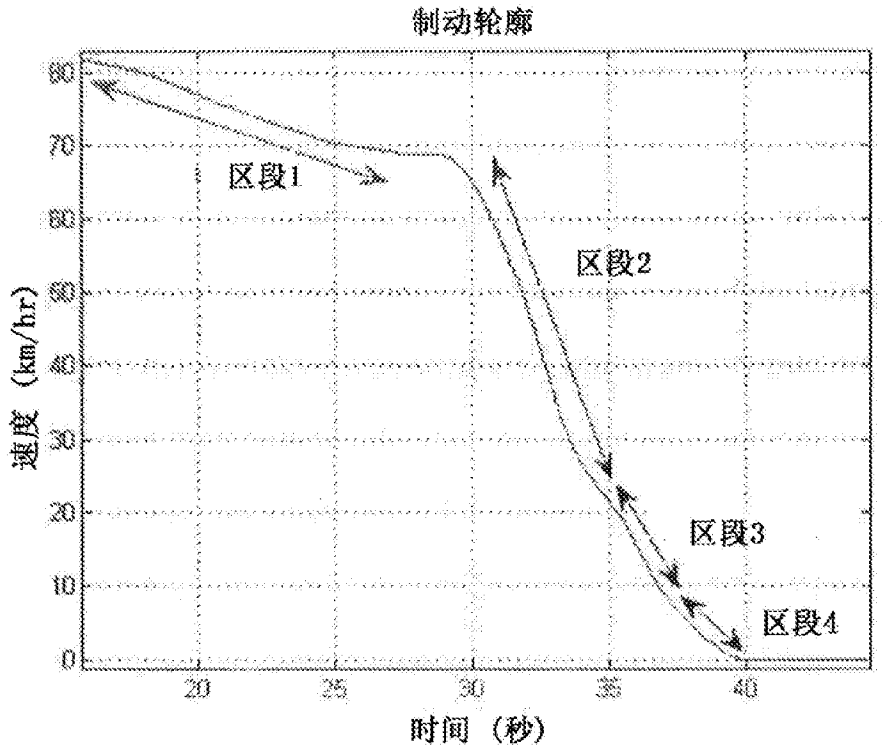


图32B



图33

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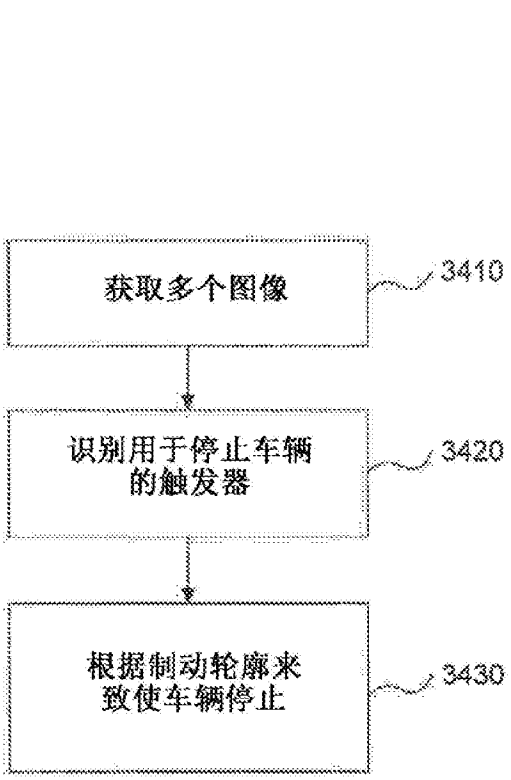


图34

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Remarks:
This application was filed on 03.12.2019 as a divisional application to the application mentioned under INID code 62.

(54) SYSTEMS AND METHODS FOR BRAKING A VEHICLE BASED ON A DETECTED OBJECT

(57) Systems and methods are provided for detecting an object and causing a vehicle to brake based on the detection. In one implementation, an object detecting and braking system for a vehicle includes at least one image capture device configured to acquire a plurality of images of an area including an object in front of the vehicle. The system includes at least one processing device programmed to perform a first image analysis to determine a first estimated time-to-collision of the vehicle with the object, and to perform a second image analysis to determine a second estimated time-to-collision of the vehicle with the object. The processing device is also programmed to calculate a difference between the first estimated time-to-collision and the second estimated time-to-collision, to determine that the difference does not exceed a predetermined threshold, and to cause the vehicle to brake based on the determination that the difference does not exceed the predetermined threshold.

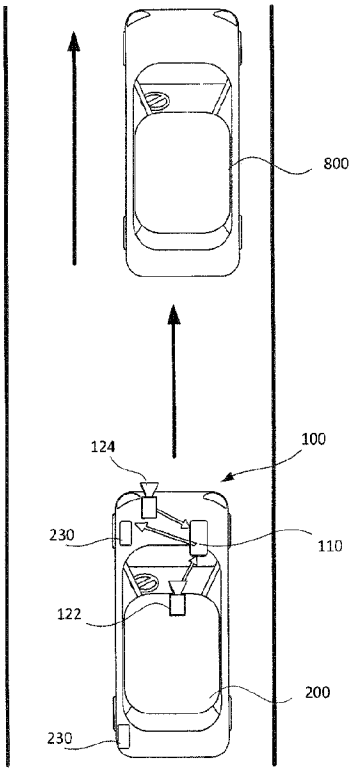


FIG. 8

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Description

Cross Reference to Related Application

[0001] This application claims the benefit of priority of United States Provisional Patent Application No. 62/001,772, filed on May 22, 2014. The foregoing application is incorporated herein by reference in its entirety.

BACKGROUND

I. Technical Field

[0002] The present disclosure relates generally to autonomous vehicle navigation and, more specifically, to systems and methods that use cameras to detect an object in front of the vehicle and that apply brakes based on the detected object.

II. Background Information

[0003] As technology continues to advance, the goal of a fully autonomous vehicle that is capable of navigating on roadways is on the horizon. Primarily, an autonomous vehicle may be able to identify its environment and navigate without input from a human operator. Autonomous vehicles may also take into account a variety of factors and make appropriate decisions based on those factors to safely and accurately reach an intended destination. For example, various objects-such as other vehicles and pedestrians-are encountered when a vehicle typically travels a roadway. Autonomous driving systems may recognize these objects in a vehicle's environment and take appropriate and timely action to avoid collisions. Additionally, autonomous driving systems may identify other indicators-such as traffic signals, traffic signs, and lane markings-that regulate vehicle movement (e.g., when the vehicle must stop and may go, a speed at which the vehicle must not exceed, where the vehicle must be positioned on the roadway, etc.). Autonomous driving systems may need to determine when a vehicle should change lanes, turn at intersections, change roadways, etc. As is evident from these examples, many factors may need to be addressed in order to provide an autonomous vehicle that is capable of navigating safely and accurately.

SUMMARY

[0004] Embodiments consistent with the present disclosure provide systems and methods for autonomous vehicle navigation. The disclosed embodiments may use cameras to provide autonomous vehicle navigation features. For example, consistent with the disclosed embodiments, the disclosed systems may include one, two, or more cameras that monitor the environment of a vehicle and cause a navigational response based on an analysis of images captured by one or more of the cameras.

[0005] Consistent with a disclosed embodiment, an object detecting and braking system for a vehicle is provided. The system may include at least one image capture device configured to acquire a plurality of images of an area including an object in front of the vehicle. The system may include a data interface. The system may include at least one processing device programmed to receive the plurality of images via the data interface, perform a first image analysis based on at least a first image and a second image to determine a first estimated time-to-collision of the vehicle with the object, and perform a second image analysis based on at least a third image and a fourth image to determine a second estimated time-to-collision of the vehicle with the object. The processing device may be programmed to calculate a difference between the first estimated time-to-collision and the second estimated time-to-collision, determine that the difference does not exceed a predetermined threshold, and cause the vehicle to brake based on the determination that the difference does not exceed the predetermined threshold.

[0006] Consistent with another disclosed embodiment, a vehicle is provided. The vehicle may include a body. The vehicle may include at least one image capture device configured to acquire a plurality of images of an area including an object in front of the vehicle. The system may include a data interface. The system may include at least one processing device programmed to receive the plurality of images via the data interface, perform a first image analysis based on at least a first image and a second image to determine a first estimated time-to-collision of the vehicle with the object, and perform a second image analysis based on at least a third image and a fourth image to determine a second estimated time-to-collision of the vehicle with the object. The processing device may be programmed to calculate a difference between the first estimated time-to-collision and the second estimated time-to-collision, determine that the difference does not exceed a predetermined threshold, and cause the vehicle to brake based on the determination that the difference does not exceed the predetermined threshold.

[0007] Consistent with yet another disclosed embodiment, a method for detecting an object and braking a vehicle is provided. The method may include acquiring, via at least one image capture device, a plurality of images of an area including an object in front of the vehicle. The method may include receiving, via a processing device, the plurality of images, performing, via the processing device, a first image analysis based on at least a first image and a second image to determine a first estimated time-to-collision of the vehicle with the object, and performing, via the processing device, a second image analysis based on at least a third image and a fourth image to determine a second estimated time-to-collision of the vehicle with the object. The method may include calculating, via the processing device, a difference between the first estimated time-to-collision and the second estimated time-to-collision, determining, via the processing device, that the difference does not exceed a predeter-

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mined threshold, and causing, via the processing device, the vehicle to brake based on the determination that the difference does not exceed the predetermined threshold.

[0008] Consistent with another disclosed embodiment, a method is provided for assessing an overall system failure rate associated with a braking decisioning system for a vehicle. The method includes determining, using a processing device, a first failure rate associated with a textural analysis based sub-system. The textural analysis based sub-system is configured to make a decision to brake based on a change in texture between at least two images of an area in front of a vehicle. The method further includes determining, using the processing device, a second failure rate associated with a structural analysis based sub-system. The structural analysis based sub-system is configured to make a decision to brake based on optical flow information derived from at least two images of the area in front of the vehicle. The method also includes determining, using the processing device, the overall system failure rate based on the first failure rate and the second failure rate.

[0009] Consistent with other disclosed embodiments, non-transitory computer-readable storage media may store program instructions, which are executed by at least one processing device and perform any of the methods described herein.

[0010] The foregoing general description and the following detailed description are exemplary and explanatory only and are not restrictive of the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] The accompanying drawings, which are incorporated in and constitute a part of this disclosure, illustrate various disclosed embodiments. In the drawings:

FIG. 1 is a diagrammatic representation of an exemplary system consistent with the disclosed embodiments.

FIG. 2A is a diagrammatic side view representation of an exemplary vehicle including a system consistent with the disclosed embodiments.

FIG. 2B is a diagrammatic top view representation of the vehicle and system shown in FIG. 2A consistent with the disclosed embodiments.

FIG. 2C is a diagrammatic top view representation of another embodiment of a vehicle including a system consistent with the disclosed embodiments.

FIG. 2D is a diagrammatic top view representation of yet another embodiment of a vehicle including a system consistent with the disclosed embodiments.

FIG. 2E is a diagrammatic top view representation of yet another embodiment of a vehicle including a system consistent with the disclosed embodiments.

FIG. 2F is a diagrammatic representation of exemplary vehicle control systems consistent with the disclosed embodiments.

FIG. 3A is a diagrammatic representation of an interior of a vehicle including a rearview mirror and a user interface for a vehicle imaging system consistent with the disclosed embodiments.

FIG. 3B is an illustration of an example of a camera mount that is configured to be positioned behind a rearview mirror and against a vehicle windshield consistent with the disclosed embodiments.

FIG. 3C is an illustration of the camera mount shown in FIG. 3B from a different perspective consistent with the disclosed embodiments.

FIG. 3D is an illustration of an example of a camera mount that is configured to be positioned behind a rearview mirror and against a vehicle windshield consistent with the disclosed embodiments.

FIG. 4 is an exemplary block diagram of a memory configured to store instructions for performing one or more operations consistent with the disclosed embodiments.

FIG. 5A is a flowchart showing an exemplary process for causing one or more navigational responses based on monocular image analysis consistent with disclosed embodiments.

FIG. 5B is a flowchart showing an exemplary process for detecting one or more vehicles and/or pedestrians in a set of images consistent with the disclosed embodiments.

FIG. 5C is a flowchart showing an exemplary process for detecting road marks and/or lane geometry information in a set of images consistent with the disclosed embodiments.

FIG. 5D is a flowchart showing an exemplary process for detecting traffic lights in a set of images consistent with the disclosed embodiments.

FIG. 5E is a flowchart showing an exemplary process for causing one or more navigational responses based on a vehicle path consistent with the disclosed embodiments.

FIG. 5F is a flowchart showing an exemplary process for determining whether a leading vehicle is changing lanes consistent with the disclosed embodiments.

FIG. 6 is a flowchart showing an exemplary process for causing one or more navigational responses based on stereo image analysis consistent with the disclosed embodiments.

FIG. 7 is a flowchart showing an exemplary process for causing one or more navigational responses based on an analysis of three sets of images consistent with the disclosed embodiments.

FIG. 8 is a diagrammatic representation of an exemplary vehicle including an object detecting and braking system traveling on a road behind another vehicle consistent with the disclosed embodiments.

FIG. 9 is a diagrammatic representation of an exemplary vehicle including an object detecting and braking system traveling on a road including an oncoming vehicle consistent with the disclosed embodiments.

FIG. 10 is an exemplary block diagram of a memory

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that may store instructions for performing one or more operations for detecting an object in front of the vehicle and causing the vehicle to brake based on the detection consistent with the disclosed embodiments.

FIG. 11 is a flowchart showing an exemplary process for detecting an object in front of the vehicle and causing the vehicle to brake based on the detection consistent with the disclosed embodiments.

FIG. 12 is a flowchart showing an exemplary first image analysis for determining a first estimated time-to-collision consistent with the disclosed embodiments.

FIG. 13 is a flowchart showing an exemplary second image analysis for determining a second estimated time-to-collision consistent with the disclosed embodiments.

FIGS. 14A-14C show an image with an optical flow field and a distribution of a second estimated time-to-collision in the optical flow field consistent with the disclosed embodiments.

FIGS. 15A and 15B show exemplary focuses of expansion when an object travels in different directions consistent with the disclosed embodiments.

FIG. 16 shows an exemplary optical flow field and a focus of expansion consistent with the disclosed embodiments.

FIGS. 17A and 17B show an image of an object and a linear relationship between distances from points in an optical flow field to the focus of expansion and magnitudes of movement of the points consistent with the disclosed embodiments.

FIGS. 18A and 18B show an image of an object and a non-linear relationship between distances from points in an optical flow field to the focus of expansion and magnitudes of movement of the points consistent with the disclosed embodiments.

FIG. 19 is a flowchart showing an exemplary process for triggering a warning based on probabilities indicating that a time-to-collision is smaller than one or more thresholds consistent with the disclosed embodiments.

FIG. 20 is a flowchart showing an exemplary process for determining the first time-to-collision (TTC1) that may be implemented in the first image analysis shown in FIG. 11 consistent with the disclosed embodiments.

FIG. 21 is a flowchart showing an exemplary process for performing a system validation using two modalities consistent with the disclosed embodiments.

DETAILED DESCRIPTION

[0012] The following detailed description refers to the accompanying drawings. Wherever possible, the same reference numbers are used in the drawings and the following description to refer to the same or similar parts. While several illustrative embodiments are described herein, modifications, adaptations and other implementations are possible. For example, substitutions, additions or modifications may be made to the components illustrated in the drawings, and the illustrative methods described herein may be modified by substituting, reordering, removing, or adding steps to the disclosed methods. Accordingly, the following detailed description is not limited to the disclosed embodiments and examples. Instead, the proper scope is defined by the appended claims.

[0013] FIG. 1 is a block diagram representation of a system 100 consistent with the exemplary disclosed embodiments. System 100 may include various components depending on the requirements of a particular implementation. In some embodiments, system 100 may include a processing unit 110, an image acquisition unit 120, a position sensor 130, one or more memory units 140, 150, a map database 160, and a user interface 170. Processing unit 110 may include one or more processing devices. In some embodiments, processing unit 110 may include an applications processor 180, an image processor 190, or any other suitable processing device. Similarly, image acquisition unit 120 may include any number of image acquisition devices and components depending on the requirements of a particular application. In some embodiments, image acquisition unit 120 may include one or more image capture devices (e.g., cameras), such as image capture device 122, image capture device 124, and image capture device 126. System 100 may also include a data interface 128 communicatively connecting processing device 110 to image acquisition device 120. For example, data interface 128 may include any wired and/or wireless link or links for transmitting image data acquired by image accusation device 120 to processing unit 110,

[0014] Both applications processor 180 and image processor 190 may include various types of processing devices. For example, either or both of applications processor 180 and image processor 190 may include a microprocessor, preprocessors (such as an image preprocessor), graphics processors, a central processing unit (CPU), support circuits, digital signal processors, integrated circuits, memory, or any other types of devices suitable for running applications and for image processing and analysis. In some embodiments, applications processor 180 and/or image processor 190 may include any type of single or multi-core processor, mobile device microcontroller, central processing unit, etc. Various processing devices may be used, including, for example, processors available from manufacturers such as Intel®, AMD®, etc. and may include various architectures (e.g., x86 processor, ARM®, etc.).

[0015] In some embodiments, applications processor 180 and/or image processor 190 may include any of the EyeQ series of processor chips available from Mobileye®. These processor designs each include multiple processing units with local memory and instruction sets. Such processors may include video inputs for receiving

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image data from multiple image sensors and may also include video out capabilities. In one example, the EyeQ2® uses 90nm-micron technology operating at 332Mhz. The EyeQ2® architecture consists of two floating point, hyper-thread 32-bit RISC CPUs (MIPS32® 34K® cores), five Vision Computing Engines (VCE), three Vector Microcode Processors (VMP®), Denali 64-bit Mobile DDR Controller, 128-bit internal Sonics Interconnect, dual 16-bit Video input and 18-bit Video output controllers, 16 channels DMA and several peripherals. The MIPS34K CPU manages the five VCEs, three VMP™ and the DMA, the second MIPS34K CPU and the multi-channel DMA as well as the other peripherals. The five VCEs, three VMP® and the MIPS34K CPU can perform intensive vision computations required by multi-function bundle applications. In another example, the EyeQ3®, which is a third generation processor and is six times more powerful that the EyeQ2®, may be used in the disclosed embodiments.

[0016] Any of the processing devices disclosed herein may be configured to perform certain functions. Configuring a processing device, such as any of the described EyeQ processors or other controller or microprocessor, to perform certain functions may include programming of computer executable instructions and making those instructions available to the processing device for execution during operation of the processing device. In some embodiments, configuring a processing device may include programming the processing device directly with architectural instructions. In other embodiments, configuring a processing device may include storing executable instructions on a memory that is accessible to the processing device during operation. For example, the processing device may access the memory to obtain and execute the stored instructions during operation.

[0017] While FIG. 1 depicts two separate processing devices included in processing unit 110, more or fewer processing devices may be used. For example, in some embodiments, a single processing device may be used to accomplish the tasks of applications processor 180 and image processor 190. In other embodiments, these tasks may be performed by more than two processing devices.

[0018] Processing unit 110 may comprise various types of devices. For example, processing unit 110 may include various devices, such as a controller, an image preprocessor, a central processing unit (CPU), support circuits, digital signal processors, integrated circuits, memory, or any other types of devices for image processing and analysis. The image preprocessor may include a video processor for capturing, digitizing and processing the imagery from the image sensors. The CPU may comprise any number of microcontrollers or microprocessors. The support circuits may be any number of circuits generally well known in the art, including cache, power supply, clock and input-output circuits. The memory may store software that, when executed by the processor, controls the operation of the system. The memory may include databases and image processing software. The memory may comprise any number of random access memories, read only memories, flash memories, disk drives, optical storage, tape storage, removable storage and other types of storage. In one instance, the memory may be separate from the processing unit 110. In another instance, the memory may be integrated into the processing unit 110.

[0019] Each memory 140, 150 may include software instructions that when executed by a processor (e.g., applications processor 180 and/or image processor 190), may control operation of various aspects of system 100. These memory units may include various databases and image processing software. The memory units may include random access memory, read only memory, flash memory, disk drives, optical storage, tape storage, removable storage and/or any other types of storage. In some embodiments, memory units 140, 150 may be separate from the applications processor 180 and/or image processor 190. In other embodiments, these memory units may be integrated into applications processor 180 and/or image processor 190.

[0020] Position sensor 130 may include any type of device suitable for determining a location associated with at least one component of system 100. In some embodiments, position sensor 130 may include a GPS receiver. Such receivers can determine a user position and velocity by processing signals broadcasted by global positioning system satellites. Position information from position sensor 130 may be made available to applications processor 180 and/or image processor 190.

[0021] User interface 170 may include any device suitable for providing information to or for receiving inputs from one or more users of system 100. In some embodiments, user interface 170 may include user input devices, including, for example, a touchscreen, microphone, keyboard, pointer devices, track wheels, cameras, knobs, buttons, etc. With such input devices, a user may be able to provide information inputs or commands to system 100 by typing instructions or information, providing voice commands, selecting menu options on a screen using buttons, pointers, or eye-tracking capabilities, or through any other suitable techniques for communicating information to system 100.

[0022] User interface 170 may be equipped with one or more processing devices configured to provide and receive information to or from a user and process that information for use by, for example, applications processor 180. In some embodiments, such processing devices may execute instructions for recognizing and tracking eye movements, receiving and interpreting voice commands, recognizing and interpreting touches and/or gestures made on a touchscreen, responding to keyboard entries or menu selections, etc. In some embodiments, user interface 170 may include a display, speaker, tactile device, and/or any other devices for providing output information to a user.

[0023] Map database 160 may include any type of da-

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tabase for storing map data useful to system 100. In some embodiments, map database 160 may include data relating to the position, in a reference coordinate system, of various items, including roads, water features, geographic features, businesses, points of interest, restaurants, gas stations, etc. Map database 160 may store not only the locations of such items, but also descriptors relating to those items, including, for example, names associated with any of the stored features. In some embodiments, map database 160 may be physically located with other components of system 100. Alternatively or additionally, map database 160 or a portion thereof may be located remotely with respect to other components of system 100 (e.g., processing unit 110). In such embodiments, information from map database 160 may be downloaded over a wired or wireless data connection to a network (e.g., over a cellular network and/or the Internet, etc.).

[0024] Image capture devices 122, 124, and 126 may each include any type of device suitable for capturing at least one image from an environment. Moreover, any number of image capture devices may be used to acquire images for input to the image processor. Some embodiments may include only a single image capture device, while other embodiments may include two, three, or even four or more image capture devices. Image capture devices 122, 124, and 126 will be further described with reference to FIGS. 2B-2E, below.

[0025] System 100, or various components thereof, may be incorporated into various different platforms. In some embodiments, system 100 may be included on a vehicle 200, as shown in FIG. 2A. For example, vehicle 200 may be equipped with a processing unit 110 and any of the other components of system 100, as described above relative to FIG. 1. While in some embodiments vehicle 200 may be equipped with only a single image capture device (e.g., camera), in other embodiments, such as those discussed in connection with FIGS. 2B-2E, multiple image capture devices may be used. For example, either of image capture devices 122 and 124 of vehicle 200, as shown in FIG. 2A, may be part of an ADAS (Advanced Driver Assistance Systems) imaging set.

[0026] The image capture devices included on vehicle 200 as part of the image acquisition unit 120 may be positioned at any suitable location. In some embodiments, as shown in FIGS. 2A-2E and 3A-3C, image capture device 122 may be located in the vicinity of the rearview mirror. This position may provide a line of sight similar to that of the driver of vehicle 200, which may aid in determining what is and is not visible to the driver. Image capture device 122 may be positioned at any location near the rearview mirror, but placing image capture device 122 on the driver side of the mirror may further aid in obtaining images representative of the driver's field of view and/or line of sight.

[0027] Other locations for the image capture devices of image acquisition unit 120 may also be used. For example, image capture device 124 may be located on or in a bumper of vehicle 200. Such a location may be especially suitable for image capture devices having a wide field of view. The line of sight of bumper-located image capture devices can be different from that of the driver and, therefore, the bumper image capture device and driver may not always see the same objects. The image capture devices (e.g., image capture devices 122, 124, and 126) may also be located in other locations. For example, the image capture devices may be located on or in one or both of the side mirrors of vehicle 200, on the roof of vehicle 200, on the hood of vehicle 200, on the trunk of vehicle 200, on the sides of vehicle 200, mounted on, positioned behind, or positioned in front of any of the windows of vehicle 200, and mounted in or near light figures on the front and/or back of vehicle 200, etc.

[0028] In addition to image capture devices, vehicle 200 may include various other components of system 100. For example, processing unit 110 may be included on vehicle 200 either integrated with or separate from an engine control unit (ECU) of the vehicle. Vehicle 200 may also be equipped with a position sensor 130, such as a GPS receiver and may also include a map database 160 and memory units 140 and 150.

[0029] FIG. 2A is a diagrammatic side view representation of an exemplary vehicle imaging system consistent with the disclosed embodiments. FIG. 2B is a diagrammatic top view illustration of the embodiment shown in FIG. 2A. As illustrated in FIG. 2B, the disclosed embodiments may include a vehicle 200 including in its body a system 100 with a first image capture device 122 positioned in the vicinity of the rearview mirror and/or near the driver of vehicle 200, a second image capture device 124 positioned on or in a bumper region (e.g., one of bumper regions 210) of vehicle 200, and a processing unit 110.

[0030] As illustrated in FIG. 2C, image capture devices 122 and 124 may both be positioned in the vicinity of the rearview mirror and/or near the driver of vehicle 200. Additionally, while two image capture devices 122 and 124 are shown in FIGS. 2B and 2C, it should be understood that other embodiments may include more than two image capture devices. For example, in the embodiments shown in FIGS. 2D and 2E, first, second, and third image capture devices 122, 124, and 126, are included in the system 100 of vehicle 200.

[0031] As illustrated in FIG. 2D, image capture device 122 may be positioned in the vicinity of the rearview mirror and/or near the driver of vehicle 200, and image capture devices 124 and 126 may be positioned on or in a bumper region (e.g., one of bumper regions 210) of vehicle 200. And as shown in FIG. 2E, image capture devices 122, 124, and 126 may be positioned in the vicinity of the rearview mirror and/or near the driver seat of vehicle 200. The disclosed embodiments are not limited to any particular number and configuration of the image capture devices, and the image capture devices may be positioned in any appropriate location within and/or on vehicle

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200.

[0032] It is to be understood that the disclosed embodiments are not limited to vehicles and could be applied in other contexts. It is also to be understood that disclosed embodiments are not limited to a particular type of vehicle 200 and may be applicable to all types of vehicles including automobiles, trucks, trailers, and other types of vehicles.

[0033] The first image capture device 122 may include any suitable type of image capture device. Image capture device 122 may include an optical axis. In one instance, the image capture device 122 may include an Aptina M9V024 WVGA sensor with a global shutter. In other embodiments, image capture device 122 may provide a resolution of 1280x960 pixels and may include a rolling shutter. Image capture device 122 may include various optical elements. In some embodiments one or more lenses may be included, for example, to provide a desired focal length and field of view for the image capture device. In some embodiments, image capture device 122 may be associated with a 6mm lens or a 12mm lens. In some embodiments, image capture device 122 may be configured to capture images having a desired field-of-view (FOV) 202, as illustrated in FIG. 2D. For example, image capture device 122 may be configured to have a regular FOV, such as within a range of 40 degrees to 56 degrees, including a 46 degree FOV, 50 degree FOV, 52 degree FOV, or greater. Alternatively, image capture device 122 may be configured to have a narrow FOV in the range of 23 to 40 degrees, such as a 28 degree FOV or 36 degree FOV. In addition, image capture device 122 may be configured to have a wide FOV in the range of 100 to 180 degrees. In some embodiments, image capture device 122 may include a wide angle bumper camera or one with up to a 180 degree FOV.

[0034] The first image capture device 122 may acquire a plurality of first images relative to a scene associated with the vehicle 200. Each of the plurality of first images may be acquired as a series of image scan lines, which may be captured using a rolling shutter. Each scan line may include a plurality of pixels.

[0035] The first image capture device 122 may have a scan rate associated with acquisition of each of the first series of image scan lines. The scan rate may refer to a rate at which an image sensor can acquire image data associated with each pixel included in a particular scan line.

[0036] Image capture devices 122, 124, and 126 may contain any suitable type and number of image sensors, including CCD sensors or CMOS sensors, for example. In one embodiment, a CMOS image sensor may be employed along with a rolling shutter, such that each pixel in a row is read one at a time, and scanning of the rows proceeds on a row-by-row basis until an entire image frame has been captured. In some embodiments, the rows may be captured sequentially from top to bottom relative to the frame.

[0037] The use of a rolling shutter may result in pixels in different rows being exposed and captured at different times, which may cause skew and other image artifacts in the captured image frame. On the other hand, when the image capture device 122 is configured to operate with a global or synchronous shutter, all of the pixels may be exposed for the same amount of time and during a common exposure period. As a result, the image data in a frame collected from a system employing a global shutter represents a snapshot of the entire FOV (such as FOV 202) at a particular time. In contrast, in a rolling shutter application, each row in a frame is exposed and data is capture at different times. Thus, moving objects may appear distorted in an image capture device having a rolling shutter. This phenomenon will be described in greater detail below.

[0038] The second image capture device 124 and the third image capturing device 126 may be any type of image capture device. Like the first image capture device 122, each of image capture devices 124 and 126 may include an optical axis. In one embodiment, each of image capture devices 124 and 126 may include an Aptina M9V024 WVGA sensor with a global shutter. Alternatively, each of image capture devices 124 and 126 may include a rolling shutter. Like image capture device 122, image capture devices 124 and 126 may be configured to include various lenses and optical elements. In some embodiments, lenses associated with image capture devices 124 and 126 may provide FOVs (such as FOVs 204 and 206) that are the same as, or narrower than, a FOV (such as FOV 202) associated with image capture device 122. For example, image capture devices 124 and 126 may have FOVs of 40 degrees, 30 degrees, 26 degrees, 23 degrees, 20 degrees, or less.

[0039] Image capture devices 124 and 126 may acquire a plurality of second and third images relative to a scene associated with the vehicle 200. Each of the plurality of second and third images may be acquired as a second and third series of image scan lines, which may be captured using a rolling shutter. Each scan line or row may have a plurality of pixels. Image capture devices 124 and 126 may have second and third scan rates associated with acquisition of each of image scan lines included in the second and third series.

[0040] Each image capture device 122, 124, and 126 may be positioned at any suitable position and orientation relative to vehicle 200. The relative positioning of the image capture devices 122, 124, and 126 may be selected to aid in fusing together the information acquired from the image capture devices. For example, in some embodiments, a FOV (such as FOV 204) associated with image capture device 124 may overlap partially or fully with a FOV (such as FOV 202) associated with image capture device 122 and a FOV (such as FOV 206) associated with image capture device 126.

[0041] Image capture devices 122, 124, and 126 may be located on vehicle 200 at any suitable relative heights. In one instance, there may be a height difference between the image capture devices 122, 124, and 126,

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which may provide sufficient parallax information to enable stereo analysis. For example, as shown in FIG. 2A, the two image capture devices 122 and 124 are at different heights. There may also be a lateral displacement difference between image capture devices 122, 124, and 126, giving additional parallax information for stereo analysis by processing unit 110, for example. The difference in the lateral displacement may be denoted by d_x, as shown in FIGS. 2C and 2D. In some embodiments, fore or aft displacement (e.g., range displacement) may exist between image capture devices 122, 124, and 126. For example, image capture device 122 may be located 0.5 to 2 meters or more behind image capture device 124 and/or image capture device 126. This type of displacement may enable one of the image capture devices to cover potential blind spots of the other image capture device(s).

[0042] Image capture devices 122 may have any suitable resolution capability (e.g., number of pixels associated with the image sensor), and the resolution of the image sensor(s) associated with the image capture device 122 may be higher, lower, or the same as the resolution of the image sensor(s) associated with image capture devices 124 and 126. In some embodiments, the image sensor(s) associated with image capture device 122 and/or image capture devices 124 and 126 may have a resolution of 640 x 480, 1024 x 768, 1280 x 960, or any other suitable resolution.

[0043] The frame rate (e.g., the rate at which an image capture device acquires a set of pixel data of one image frame before moving on to capture pixel data associated with the next image frame) may be controllable. The frame rate associated with image capture device 122 may be higher, lower, or the same as the frame rate associated with image capture devices 124 and 126. The frame rate associated with image capture devices 122, 124, and 126 may depend on a variety of factors that may affect the timing of the frame rate. For example, one or more of image capture devices 122, 124, and 126 may include a selectable pixel delay period imposed before or after acquisition of image data associated with one or more pixels of an image sensor in image capture device 122, 124, and/or 126. Generally, image data corresponding to each pixel may be acquired according to a clock rate for the device (e.g., one pixel per clock cycle). Additionally, in embodiments including a rolling shutter, one or more of image capture devices 122, 124, and 126 may include a selectable horizontal blanking period imposed before or after acquisition of image data associated with a row of pixels of an image sensor in image capture device 122, 124, and/or 126. Further, one or more of image capture devices 122, 124, and/or 126 may include a selectable vertical blanking period imposed before or after acquisition of image data associated with an image frame of image capture device 122, 124, and 126.

[0044] These timing controls may enable synchronization of frame rates associated with image capture devices 122, 124, and 126, even where the line scan rates of each are different. Additionally, as will be discussed in greater detail below, these selectable timing controls, among other factors (e.g., image sensor resolution, maximum line scan rates, etc.) may enable synchronization of image capture from an area where the FOV of image capture device 122 overlaps with one or more FOVs of image capture devices 124 and 126, even where the field of view of image capture device 122 is different from the FOVs of image capture devices 124 and 126.

[0045] Frame rate timing in image capture device 122, 124, and 126 may depend on the resolution of the associated image sensors. For example, assuming similar line scan rates for both devices, if one device includes an image sensor having a resolution of 640 x 480 and another device includes an image sensor with a resolution of 1280 x 960, then more time will be required to acquire a frame of image data from the sensor having the higher resolution.

[0046] Another factor that may affect the timing of image data acquisition in image capture devices 122, 124, and 126 is the maximum line scan rate. For example, acquisition of a row of image data from an image sensor included in image capture device 122, 124, and 126 will require some minimum amount of time. Assuming no pixel delay periods are added, this minimum amount of time for acquisition of a row of image data will be related to the maximum line scan rate for a particular device. Devices that offer higher maximum line scan rates have the potential to provide higher frame rates than devices with lower maximum line scan rates. In some embodiments, one or more of image capture devices 124 and 126 may have a maximum line scan rate that is higher than a maximum line scan rate associated with image capture device 122. In some embodiments, the maximum line scan rate of image capture device 124 and/or 126 may be 1.25, 1.5, 1.75, or 2 times or more than a maximum line scan rate of image capture device 122.

[0047] In another embodiment, image capture devices 122, 124, and 126 may have the same maximum line scan rate, but image capture device 122 may be operated at a scan rate less than or equal to its maximum scan rate. The system may be configured such that one or more of image capture devices 124 and 126 operate at a line scan rate that is equal to the line scan rate of image capture device 122. In other instances, the system may be configured such that the line scan rate of image capture device 124 and/or image capture device 126 may be 1.25, 1.5, 1.75, or 2 times or more than the line scan rate of image capture device 122.

[0048] In some embodiments, image capture devices 122, 124, and 126 may be asymmetric. That is, they may include cameras having different fields of view (FOV) and focal lengths. The fields of view of image capture devices 122, 124, and 126 may include any desired area relative to an environment of vehicle 200, for example. In some embodiments, one or more of image capture devices 122, 124, and 126 may be configured to acquire image data from an environment in front of vehicle 200, behind

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vehicle 200, to the sides of vehicle 200, or combinations thereof.

[0049] Further, the focal length associated with each image capture device 122, 124, and/or 126 may be selectable (e.g., by inclusion of appropriate lenses etc.) such that each device acquires images of objects at a desired distance range relative to vehicle 200. For example, in some embodiments image capture devices 122, 124, and 126 may acquire images of close-up objects within a few meters from the vehicle. Image capture devices 122, 124, and 126 may also be configured to acquire images of objects at ranges more distant from the vehicle (e.g., 25 m, 50 m, 100 m, 150 m, or more). Further, the focal lengths of image capture devices 122, 124, and 126 may be selected such that one image capture device (e.g., image capture device 122) can acquire images of objects relatively close to the vehicle (e.g., within 10 m or within 20 m) while the other image capture devices (e.g., image capture devices 124 and 126) can acquire images of more distant objects (e.g., greater than 20 m, 50 m, 100 m, 150 m, etc.) from vehicle 200.

[0050] According to some embodiments, the FOV of one or more image capture devices 122, 124, and 126 may have a wide angle. For example, it may be advantageous to have a FOV of 140 degrees, especially for image capture devices 122, 124, and 126 that may be used to capture images of the area in the vicinity of vehicle 200. For example, image capture device 122 may be used to capture images of the area to the right or left of vehicle 200 and, in such embodiments, it may be desirable for image capture device 122 to have a wide FOV (e.g., at least 140 degrees).

[0051] The field of view associated with each of image capture devices 122, 124, and 126 may depend on the respective focal lengths. For example, as the focal length increases, the corresponding field of view decreases.

[0052] Image capture devices 122, 124, and 126 may be configured to have any suitable fields of view. In one particular example, image capture device 122 may have a horizontal FOV of 46 degrees, image capture device 124 may have a horizontal FOV of 23 degrees, and image capture device 126 may have a horizontal FOV in between 23 and 46 degrees. In another instance, image capture device 122 may have a horizontal FOV of 52 degrees, image capture device 124 may have a horizontal FOV of 26 degrees, and image capture device 126 may have a horizontal FOV in between 26 and 52 degrees. In some embodiments, a ratio of the FOV of image capture device 122 to the FOVs of image capture device 124 and/or image capture device 126 may vary from 1.5 to 2.0. In other embodiments, this ratio may vary between 1.25 and 2.25.

[0053] System 100 may be configured so that a field of view of image capture device 122 overlaps, at least partially or fully, with a field of view of image capture device 124 and/or image capture device 126. In some embodiments, system 100 may be configured such that the fields of view of image capture devices 124 and 126, for example, fall within (e.g., are narrower than) and share a common center with the field of view of image capture device 122. In other embodiments, the image capture devices 122, 124, and 126 may capture adjacent FOVs or may have partial overlap in their FOVs. In some embodiments, the fields of view of image capture devices 122, 124, and 126 may be aligned such that a center of the narrower FOV image capture devices 124 and/or 126 may be located in a lower half of the field of view of the wider FOV device 122.

[0054] FIG. 2F is a diagrammatic representation of exemplary vehicle control systems, consistent with the disclosed embodiments. As indicated in FIG. 2F, vehicle 200 may include throttling system 220, braking system 230, and steering system 240. System 100 may provide inputs (e.g., control signals) to one or more of throttling system 220, braking system 230, and steering system 240 over one or more data links (e.g., any wired and/or wireless link or links for transmitting data). For example, based on analysis of images acquired by image capture devices 122, 124, and/or 126, system 100 may provide control signals to one or more of throttling system 220, braking system 230, and steering system 240 to navigate vehicle 200 (e.g., by causing an acceleration, a turn, a lane shift, etc.). Further, system 100 may receive inputs from one or more of throttling system 220, braking system 230, and steering system 24 indicating operating conditions of vehicle 200 (e.g., speed, whether vehicle 200 is braking and/or turning, etc.). Further details are provided in connection with FIGS. 4-7, below.

[0055] As shown in FIG. 3A, vehicle 200 may also include a user interface 170 for interacting with a driver or a passenger of vehicle 200. For example, user interface 170 in a vehicle application may include a touch screen 320, knobs 330, buttons 340, and a microphone 350. A driver or passenger of vehicle 200 may also use handles (e.g., located on or near the steering column of vehicle 200 including, for example, turn signal handles), buttons (e.g., located on the steering wheel of vehicle 200), and the like, to interact with system 100. In some embodiments, microphone 350 may be positioned adjacent to a rearview mirror 310. Similarly, in some embodiments, image capture device 122 may be located near rearview mirror 310. In some embodiments, user interface 170 may also include one or more speakers 360 (e.g., speakers of a vehicle audio system). For example, system 100 may provide various notifications (e.g., alerts) via speakers 360.

[0056] FIGS. 3B-3D are illustrations of an exemplary camera mount 370 configured to be positioned behind a rearview mirror (e.g., rearview mirror 310) and against a vehicle windshield, consistent with disclosed embodiments. As shown in FIG. 3B, camera mount 370 may include image capture devices 122, 124, and 126. Image capture devices 124 and 126 may be positioned behind a glare shield 380, which may be flush against the vehicle windshield and include a composition of film and/or anti-reflective materials. For example, glare shield 380 may

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be positioned such that it aligns against a vehicle windshield having a matching slope. In some embodiments, each of image capture devices 122, 124, and 126 may be positioned behind glare shield 380, as depicted, for example, in FIG. 3D. The disclosed embodiments are not limited to any particular configuration of image capture devices 122, 124, and 126, camera mount 370, and glare shield 380. FIG. 3C is an illustration of camera mount 370 shown in FIG. 3B from a front perspective.

[0057] As will be appreciated by a person skilled in the art having the benefit of this disclosure, numerous variations and/or modifications may be made to the foregoing disclosed embodiments. For example, not all components are essential for the operation of system 100. Further, any component may be located in any appropriate part of system 100 and the components may be rearranged into a variety of configurations while providing the functionality of the disclosed embodiments. Therefore, the foregoing configurations are examples and, regardless of the configurations discussed above, system 100 can provide a wide range of functionality to analyze the surroundings of vehicle 200 and navigate vehicle 200 in response to the analysis.

[0058] As discussed below in further detail and consistent with various disclosed embodiments, system 100 may provide a variety of features related to autonomous driving and/or driver assist technology. For example, system 100 may analyze image data, position data (e.g., GPS location information), map data, speed data, and/or data from sensors included in vehicle 200. System 100 may collect the data for analysis from, for example, image acquisition unit 120, position sensor 130, and other sensors. Further, system 100 may analyze the collected data to determine whether or not vehicle 200 should take a certain action, and then automatically take the determined action without human intervention. For example, when vehicle 200 navigates without human intervention, system 100 may automatically control the braking, acceleration, and/or steering of vehicle 200 (e.g., by sending control signals to one or more of throttling system 220, braking system 230, and steering system 240). Further, system 100 may analyze the collected data and issue warnings and/or alerts to vehicle occupants based on the analysis of the collected data. Additional details regarding the various embodiments that are provided by system 100 are provided below.

Forward-Facing Multi-Imaging System

[0059] As discussed above, system 100 may provide drive assist functionality that uses a multi-camera system. The multi-camera system may use one or more cameras facing in the forward direction of a vehicle. In other embodiments, the multi-camera system may include one or more cameras facing to the side of a vehicle or to the rear of the vehicle. In one embodiment, for example, system 100 may use a two-camera imaging system, where a first camera and a second camera (e.g., image capture devices 122 and 124) may be positioned at the front and/or the sides of a vehicle (e.g., vehicle 200). The first camera may have a field of view that is greater than, less than, or partially overlapping with, the field of view of the second camera. In addition, the first camera may be connected to a first image processor to perform monocular image analysis of images provided by the first camera, and the second camera may be connected to a second image processor to perform monocular image analysis of images provided by the second camera. The outputs (e.g., processed information) of the first and second image processors may be combined. In some embodiments, the second image processor may receive images from both the first camera and second camera to perform stereo analysis. In another embodiment, system 100 may use a three-camera imaging system where each of the cameras has a different field of view. Such a system may, therefore, make decisions based on information derived from objects located at varying distances both forward and to the sides of the vehicle. References to monocular image analysis may refer to instances where image analysis is performed based on images captured from a single point of view (e.g., from a single camera). Stereo image analysis may refer to instances where image analysis is performed based on two or more images captured with one or more variations of an image capture parameter. For example, captured images suitable for performing stereo image analysis may include images captured: from two or more different positions, from different fields of view, using different focal lengths, along with parallax information, etc.

[0060] For example, in one embodiment, system 100 may implement a three camera configuration using image capture devices 122-126. In such a configuration, image capture device 122 may provide a narrow field of view (e.g., 34 degrees, or other values selected from a range of about 20 to 45 degrees, etc.), image capture device 124 may provide a wide field of view (e.g., 150 degrees or other values selected from a range of about 100 to about 180 degrees), and image capture device 126 may provide an intermediate field of view (e.g., 46 degrees or other values selected from a range of about 35 to about 60 degrees). In some embodiments, image capture device 126 may act as a main or primary camera. Image capture devices 122-126 may be positioned behind rearview mirror 310 and positioned substantially side-by-side (e.g., 6 cm apart). Further, in some embodiments, as discussed above, one or more of image capture devices 122-126 may be mounted behind glare shield 380 that is flush with the windshield of vehicle 200. Such shielding may act to minimize the impact of any reflections from inside the car on image capture devices 122-126.

[0061] In another embodiment, as discussed above in connection with FIGS. 3B and 3C, the wide field of view camera (e.g., image capture device 124 in the above example) may be mounted lower than the narrow and main field of view cameras (e.g., image devices 122 and

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126 in the above example). This configuration may provide a free line of sight from the wide field of view camera. To reduce reflections, the cameras may be mounted close to the windshield of vehicle 200, and may include polarizers on the cameras to damp reflected light.

[0062] A three camera system may provide certain performance characteristics. For example, some embodiments may include an ability to validate the detection of objects by one camera based on detection results from another camera. In the three camera configuration discussed above, processing unit 110 may include, for example, three processing devices (e.g., three EyeQ series of processor chips, as discussed above), with each processing device dedicated to processing images captured by one or more of image capture devices 122-126.

[0063] In a three camera system, a first processing device may receive images from both the main camera and the narrow field of view camera, and perform vision processing of the narrow FOV camera to, for example, detect other vehicles, pedestrians, lane marks, traffic signs, traffic lights, and other road objects. Further, the first processing device may calculate a disparity of pixels between the images from the main camera and the narrow camera and create a 3D reconstruction of the environment of vehicle 200. The first processing device may then combine the 3D reconstruction with 3D map data or with 3D information calculated based on information from another camera.

[0064] The second processing device may receive images from main camera and perform vision processing to detect other vehicles, pedestrians, lane marks, traffic signs, traffic lights, and other road objects. Additionally, the second processing device may calculate a camera displacement and, based on the displacement, calculate a disparity of pixels between successive images and create a 3D reconstruction of the scene (e.g., a structure from motion). The second processing device may send the structure from motion based 3D reconstruction to the first processing device to be combined with the stereo 3D images.

[0065] The third processing device may receive images from the wide FOV camera and process the images to detect vehicles, pedestrians, lane marks, traffic signs, traffic lights, and other road objects. The third processing device may further execute additional processing instructions to analyze images to identify objects moving in the image, such as vehicles changing lanes, pedestrians, etc.

[0066] In some embodiments, having streams of image-based information captured and processed independently may provide an opportunity for providing redundancy in the system. Such redundancy may include, for example, using a first image capture device and the images processed from that device to validate and/or supplement information obtained by capturing and processing image information from at least a second image capture device.

[0067] In some embodiments, system 100 may use two image capture devices (e.g., image capture devices 122 and 124) in providing navigation assistance for vehicle 200 and use a third image capture device (e.g., image capture device 126) to provide redundancy and validate the analysis of data received from the other two image capture devices. For example, in such a configuration, image capture devices 122 and 124 may provide images for stereo analysis by system 100 for navigating vehicle 200, while image capture device 126 may provide images for monocular analysis by system 100 to provide redundancy and validation of information obtained based on images captured from image capture device 122 and/or image capture device 124. That is, image capture device 126 (and a corresponding processing device) may be considered to provide a redundant sub-system for providing a check on the analysis derived from image capture devices 122 and 124 (e.g., to provide an automatic emergency braking (AEB) system).

[0068] One of skill in the art will recognize that the above camera configurations, camera placements, number of cameras, camera locations, etc., are examples only. These components and others described relative to the overall system may be assembled and used in a variety of different configurations without departing from the scope of the disclosed embodiments. Further details regarding usage of a multi-camera system to provide driver assist and/or autonomous vehicle functionality follow below.

[0069] FIG. 4 is an exemplary functional block diagram of memory 140 and/or 150, which may be stored/programmed with instructions for performing one or more operations consistent with the disclosed embodiments. Although the following refers to memory 140, one of skill in the art will recognize that instructions may be stored in memory 140 and/or 150.

[0070] As shown in FIG. 4, memory 140 may store a monocular image analysis module 402, a stereo image analysis module 404, a velocity and acceleration module 406, and a navigational response module 408. The disclosed embodiments are not limited to any particular configuration of memory 140. Further, application processor 180 and/or image processor 190 may execute the instructions stored in any of modules 402-408 included in memory 140. One of skill in the art will understand that references in the following discussions to processing unit 110 may refer to application processor 180 and image processor 190 individually or collectively. Accordingly, steps of any of the following processes may be performed by one or more processing devices.

[0071] In one embodiment, monocular image analysis module 402 may store instructions (such as computer vision software) which, when executed by processing unit 110, performs monocular image analysis of a set of images acquired by one of image capture devices 122, 124, and 126. In some embodiments, processing unit 110 may combine information from a set of images with additional sensory information (e.g., information from radar) to perform the monocular image analysis. As described in con-

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nection with FIGS. 5A-5D below, monocular image analysis module 402 may include instructions for detecting a set of features within the set of images, such as lane markings, vehicles, pedestrians, road signs, highway exit ramps, traffic lights, hazardous objects, and any other feature associated with an environment of a vehicle. Based on the analysis, system 100 (e.g., via processing unit 110) may cause one or more navigational responses in vehicle 200, such as a turn, a lane shift, a change in acceleration, and the like, as discussed below in connection with navigational response module 408.

[0072] In one embodiment, stereo image analysis module 404 may store instructions (such as computer vision software) which, when executed by processing unit 110, performs stereo image analysis of first and second sets of images acquired by a combination of image capture devices selected from any of image capture devices 122, 124, and 126. In some embodiments, processing unit 110 may combine information from the first and second sets of images with additional sensory information (e.g., information from radar) to perform the stereo image analysis. For example, stereo image analysis module 404 may include instructions for performing stereo image analysis based on a first set of images acquired by image capture device 124 and a second set of images acquired by image capture device 126. As described in connection with FIG. 6 below, stereo image analysis module 404 may include instructions for detecting a set of features within the first and second sets of images, such as lane markings, vehicles, pedestrians, road signs, highway exit ramps, traffic lights, hazardous objects, and the like. Based on the analysis, processing unit 110 may cause one or more navigational responses in vehicle 200, such as a turn, a lane shift, a change in acceleration, and the like, as discussed below in connection with navigational response module 408.

[0073] In one embodiment, velocity and acceleration module 406 may store software configured to analyze data received from one or more computing and electromechanical devices in vehicle 200 that are configured to cause a change in velocity and/or acceleration of vehicle 200. For example, processing unit 110 may execute instructions associated with velocity and acceleration module 406 to calculate a target speed for vehicle 200 based on data derived from execution of monocular image analysis module 402 and/or stereo image analysis module 404. Such data may include, for example, a target position, velocity, and/or acceleration, the position and/or speed of vehicle 200 relative to a nearby vehicle, pedestrian, or road object, position information for vehicle 200 relative to lane markings of the road, and the like. In addition, processing unit 110 may calculate a target speed for vehicle 200 based on sensory input (e.g., information from radar) and input from other systems of vehicle 200, such as throttling system 220, braking system 230, and/or steering system 240 of vehicle 200. Based on the calculated target speed, processing unit 110 may transmit electronic signals to throttling system 220, braking system 230, and/or steering system 240 of vehicle 200 to trigger a change in velocity and/or acceleration by, for example, physically depressing the brake or easing up off the accelerator of vehicle 200.

[0074] In one embodiment, navigational response module 408 may store software executable by processing unit 110 to determine a desired navigational response based on data derived from execution of monocular image analysis module 402 and/or stereo image analysis module 404. Such data may include position and speed information associated with nearby vehicles, pedestrians, and road objects, target position information for vehicle 200, and the like. Additionally, in some embodiments, the navigational response may be based (partially or fully) on map data, a predetermined position of vehicle 200, and/or a relative velocity or a relative acceleration between vehicle 200 and one or more objects detected from execution of monocular image analysis module 402 and/or stereo image analysis module 404. Navigational response module 408 may also determine a desired navigational response based on sensory input (e.g., information from radar) and inputs from other systems of vehicle 200, such as throttling system 220, braking system 230, and steering system 240 of vehicle 200. Based on the desired navigational response, processing unit 110 may transmit electronic signals to throttling system 220, braking system 230, and steering system 240 of vehicle 200 to trigger a desired navigational response by, for example, turning the steering wheel of vehicle 200 to achieve a rotation of a predetermined angle. In some embodiments, processing unit 110 may use the output of navigational response module 408 (e.g., the desired navigational response) as an input to execution of velocity and acceleration module 406 for calculating a change in speed of vehicle 200.

[0075] FIG. 5A is a flowchart showing an exemplary process 500A for causing one or more navigational responses based on monocular image analysis, consistent with disclosed embodiments. At step 510, processing unit 110 may receive a plurality of images via data interface 128 between processing unit 110 and image acquisition unit 120. For instance, a camera included in image acquisition unit 120 (such as image capture device 122 having field of view 202) may capture a plurality of images of an area forward of vehicle 200 (or to the sides or rear of a vehicle, for example) and transmit them over a data connection (e.g., digital, wired, USB, wireless, Bluetooth, etc.) to processing unit 110. Processing unit 110 may execute monocular image analysis module 402 to analyze the plurality of images at step 520, as described in further detail in connection with FIGS. 5B-5D below. By performing the analysis, processing unit 110 may detect a set of features within the set of images, such as lane markings, vehicles, pedestrians, road signs, highway exit ramps, traffic lights, and the like.

[0076] Processing unit 110 may also execute monocular image analysis module 402 to detect various road hazards at step 520, such as, for example, parts of a

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truck tire, fallen road signs, loose cargo, small animals, and the like. Road hazards may vary in structure, shape, size, and color, which may make detection of such hazards more challenging. In some embodiments, processing unit 110 may execute monocular image analysis module 402 to perform multi-frame analysis on the plurality of images to detect road hazards. For example, processing unit 110 may estimate camera motion between consecutive image frames and calculate the disparities in pixels between the frames to construct a 3D-map of the road. Processing unit 110 may then use the 3D-map to detect the road surface, as well as hazards existing above the road surface.

[0077] At step 530, processing unit 110 may execute navigational response module 408 to cause one or more navigational responses in vehicle 200 based on the analysis performed at step 520 and the techniques as described above in connection with FIG. 4. Navigational responses may include, for example, a turn, a lane shift, a change in acceleration, and the like. In some embodiments, processing unit 110 may use data derived from execution of velocity and acceleration module 406 to cause the one or more navigational responses. Additionally, multiple navigational responses may occur simultaneously, in sequence, or any combination thereof. For instance, processing unit 110 may cause vehicle 200 to shift one lane over and then accelerate by, for example, sequentially transmitting control signals to steering system 240 and throttling system 220 of vehicle 200. Alternatively, processing unit 110 may cause vehicle 200 to brake while at the same time shifting lanes by, for example, simultaneously transmitting control signals to braking system 230 and steering system 240 of vehicle 200.

[0078] FIG. 5B is a flowchart showing an exemplary process 500B for detecting one or more vehicles and/or pedestrians in a set of images, consistent with disclosed embodiments. Processing unit 110 may execute monocular image analysis module 402 to implement process 500B. At step 540, processing unit 110 may determine a set of candidate objects representing possible vehicles and/or pedestrians. For example, processing unit 110 may scan one or more images, compare the images to one or more predetermined patterns, and identify within each image possible locations that may contain objects of interest (e.g., vehicles, pedestrians, or portions thereof). The predetermined patterns may be designed in such a way to achieve a high rate of "false hits" and a low rate of "misses." For example, processing unit 110 may use a low threshold of similarity to predetermined patterns for identifying candidate objects as possible vehicles or pedestrians. Doing so may allow processing unit 110 to reduce the probability of missing (e.g., not identifying) a candidate object representing a vehicle or pedestrian.

[0079] At step 542, processing unit 110 may filter the set of candidate objects to exclude certain candidates (e.g., irrelevant or less relevant objects) based on classification criteria. Such criteria may be derived from various properties associated with object types stored in a database (e.g., a database stored in memory 140). Properties may include object shape, dimensions, texture, position (e.g., relative to vehicle 200), and the like. Thus, processing unit 110 may use one or more sets of criteria to reject false candidates from the set of candidate objects.

[0080] At step 544, processing unit 110 may analyze multiple frames of images to determine whether objects in the set of candidate objects represent vehicles and/or pedestrians. For example, processing unit 110 may track a detected candidate object across consecutive frames and accumulate frame-by-frame data associated with the detected object (e.g., size, position relative to vehicle 200, etc.). Additionally, processing unit 110 may estimate parameters for the detected object and compare the object's frame-by-frame position data to a predicted position.

[0081] At step 546, processing unit 110 may construct a set of measurements for the detected objects. Such measurements may include, for example, position, velocity, and acceleration values (relative to vehicle 200) associated with the detected objects. In some embodiments, processing unit 110 may construct the measurements based on estimation techniques using a series of time-based observations such as Kalman filters or linear quadratic estimation (LQE), and/or based on available modeling data for different object types (e.g., cars, trucks, pedestrians, bicycles, road signs, etc.). The Kalman filters may be based on a measurement of an object's scale, where the scale measurement is proportional to a time to collision (e.g., the amount of time for vehicle 200 to reach the object). Thus, by performing steps 540-546, processing unit 110 may identify vehicles and pedestrians appearing within the set of captured images and derive information (e.g., position, speed, size) associated with the vehicles and pedestrians. Based on the identification and the derived information, processing unit 110 may cause one or more navigational responses in vehicle 200, as described in connection with FIG. 5A, above.

[0082] At step 548, processing unit 110 may perform an optical flow analysis of one or more images to reduce the probabilities of detecting a "false hit" and missing a candidate object that represents a vehicle or pedestrian. The optical flow analysis may refer to, for example, analyzing motion patterns relative to vehicle 200 in the one or more images associated with other vehicles and pedestrians, and that are distinct from road surface motion. Processing unit 110 may calculate the motion of candidate objects by observing the different positions of the objects across multiple image frames, which are captured at different times. Processing unit 110 may use the position and time values as inputs into mathematical models for calculating the motion of the candidate objects. Thus, optical flow analysis may provide another method of detecting vehicles and pedestrians that are nearby vehicle 200. Processing unit 110 may perform optical flow analysis in combination with steps 540-546 to provide redundancy for detecting vehicles and pedes-

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trians and increase the reliability of system 100.

[0083] FIG. 5C is a flowchart showing an exemplary process 500C for detecting road marks and/or lane geometry information in a set of images, consistent with disclosed embodiments. Processing unit 110 may execute monocular image analysis module 402 to implement process 500C. At step 550, processing unit 110 may detect a set of objects by scanning one or more images. To detect segments of lane markings, lane geometry information, and other pertinent road marks, processing unit 110 may filter the set of objects to exclude those determined to be irrelevant (e.g., minor potholes, small rocks, etc.). At step 552, processing unit 110 may group together the segments detected in step 550 belonging to the same road mark or lane mark. Based on the grouping, processing unit 110 may develop a model to represent the detected segments, such as a mathematical model.

[0084] At step 554, processing unit 110 may construct a set of measurements associated with the detected segments. In some embodiments, processing unit 110 may create a projection of the detected segments from the image plane onto the real-world plane. The projection may be characterized using a 3rd-degree polynomial having coefficients corresponding to physical properties such as the position, slope, curvature, and curvature derivative of the detected road. In generating the projection, processing unit 110 may take into account changes in the road surface, as well as pitch and roll rates associated with vehicle 200. In addition, processing unit 110 may model the road elevation by analyzing position and motion cues present on the road surface. Further, processing unit 110 may estimate the pitch and roll rates associated with vehicle 200 by tracking a set of feature points in the one or more images.

[0085] At step 556, processing unit 110 may perform multi-frame analysis by, for example, tracking the detected segments across consecutive image frames and accumulating frame-by-frame data associated with detected segments. As processing unit 110 performs multi-frame analysis, the set of measurements constructed at step 554 may become more reliable and associated with an increasingly higher confidence level. Thus, by performing steps 550-556, processing unit 110 may identify road marks appearing within the set of captured images and derive lane geometry information. Based on the identification and the derived information, processing unit 110 may cause one or more navigational responses in vehicle 200, as described in connection with FIG. 5A, above.

[0086] At step 558, processing unit 110 may consider additional sources of information to further develop a safety model for vehicle 200 in the context of its surroundings. Processing unit 110 may use the safety model to define a context in which system 100 may execute autonomous control of vehicle 200 in a safe manner. To develop the safety model, in some embodiments, processing unit 110 may consider the position and motion of other vehicles, the detected road edges and barriers, and/or general road shape descriptions extracted from map data (such as data from map database 160). By considering additional sources of information, processing unit 110 may provide redundancy for detecting road marks and lane geometry and increase the reliability of system 100.

[0087] FIG. 5D is a flowchart showing an exemplary process 500D for detecting traffic lights in a set of images, consistent with disclosed embodiments. Processing unit 110 may execute monocular image analysis module 402 to implement process 500D. At step 560, processing unit 110 may scan the set of images and identify objects appearing at locations in the images likely to contain traffic lights. For example, processing unit 110 may filter the identified objects to construct a set of candidate objects, excluding those objects unlikely to correspond to traffic lights. The filtering may be done based on various properties associated with traffic lights, such as shape, dimensions, texture, position (e.g., relative to vehicle 200), and the like. Such properties may be based on multiple examples of traffic lights and traffic control signals and stored in a database. In some embodiments, processing unit 110 may perform multi-frame analysis on the set of candidate objects reflecting possible traffic lights. For example, processing unit 110 may track the candidate objects across consecutive image frames, estimate the real-world position of the candidate objects, and filter out those objects that are moving (which are unlikely to be traffic lights). In some embodiments, processing unit 110 may perform color analysis on the candidate objects and identify the relative position of the detected colors appearing inside possible traffic lights.

[0088] At step 562, processing unit 110 may analyze the geometry of a junction. The analysis may be based on any combination of: (i) the number of lanes detected on either side of vehicle 200, (ii) markings (such as arrow marks) detected on the road, and (iii) descriptions of the junction extracted from map data (such as data from map database 160). Processing unit 110 may conduct the analysis using information derived from execution of monocular analysis module 402. In addition, Processing unit 110 may determine a correspondence between the traffic lights detected at step 560 and the lanes appearing near vehicle 200.

[0089] As vehicle 200 approaches the junction, at step 564, processing unit 110 may update the confidence level associated with the analyzed junction geometry and the detected traffic lights. For instance, the number of traffic lights estimated to appear at the junction as compared with the number actually appearing at the junction may impact the confidence level. Thus, based on the confidence level, processing unit 110 may delegate control to the driver of vehicle 200 in order to improve safety conditions. By performing steps 560-564, processing unit 110 may identify traffic lights appearing within the set of captured images and analyze junction geometry information. Based on the identification and the analysis, processing unit 110 may cause one or more navigational responses in vehicle 200, as described in connection with

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FIG. 5A, above.

[0090] FIG. 5E is a flowchart showing an exemplary process 500E for causing one or more navigational responses in vehicle 200 based on a vehicle path, consistent with the disclosed embodiments. At step 570, processing unit 110 may construct an initial vehicle path associated with vehicle 200. The vehicle path may be represented using a set of points expressed in coordinates (x, z), and the distance d_i between two points in the set of points may fall in the range of 1 to 5 meters. In one embodiment, processing unit 110 may construct the initial vehicle path using two polynomials, such as left and right road polynomials. Processing unit 110 may calculate the geometric midpoint between the two polynomials and offset each point included in the resultant vehicle path by a predetermined offset (e.g., a smart lane offset), if any (an offset of zero may correspond to travel in the middle of a lane). The offset may be in a direction perpendicular to a segment between any two points in the vehicle path. In another embodiment, processing unit 110 may use one polynomial and an estimated lane width to offset each point of the vehicle path by half the estimated lane width plus a predetermined offset (e.g., a smart lane offset).

[0091] At step 572, processing unit 110 may update the vehicle path constructed at step 570. Processing unit 110 may reconstruct the vehicle path constructed at step 570 using a higher resolution, such that the distance d_k between two points in the set of points representing the vehicle path is less than the distance d_i described above. For example, the distance d_k may fall in the range of 0.1 to 0.3 meters. Processing unit 110 may reconstruct the vehicle path using a parabolic spline algorithm, which may yield a cumulative distance vector S corresponding to the total length of the vehicle path (i.e., based on the set of points representing the vehicle path).

[0092] At step 574, processing unit 110 may determine a look-ahead point (expressed in coordinates as (x_l, z_l)) based on the updated vehicle path constructed at step 572. Processing unit 110 may extract the look-ahead point from the cumulative distance vector S, and the look-ahead point may be associated with a look-ahead distance and look-ahead time. The look-ahead distance, which may have a lower bound ranging from 10 to 20 meters, may be calculated as the product of the speed of vehicle 200 and the look-ahead time. For example, as the speed of vehicle 200 decreases, the look-ahead distance may also decrease (e.g., until it reaches the lower bound). The look-ahead time, which may range from 0.5 to 1.5 seconds, may be inversely proportional to the gain of one or more control loops associated with causing a navigational response in vehicle 200, such as the heading error tracking control loop. For example, the gain of the heading error tracking control loop may depend on the bandwidth of a yaw rate loop, a steering actuator loop, car lateral dynamics, and the like. Thus, the higher the gain of the heading error tracking control loop, the lower the look-ahead time.

[0093] At step 576, processing unit 110 may determine a heading error and yaw rate command based on the look-ahead point determined at step 574. Processing unit 110 may determine the heading error by calculating the arctangent of the look-ahead point, e.g., arctan (x_l/z_l). Processing unit 110 may determine the yaw rate command as the product of the heading error and a high-level control gain. The high-level control gain may be equal to: (2 / look-ahead time), if the look-ahead distance is not at the lower bound. Otherwise, the high-level control gain may be equal to: (2 * speed of vehicle 200 / look-ahead distance).

[0094] FIG. 5F is a flowchart showing an exemplary process 500F for determining whether a leading vehicle is changing lanes, consistent with the disclosed embodiments. At step 580, processing unit 110 may determine navigation information associated with a leading vehicle (e.g., a vehicle traveling ahead of vehicle 200). For example, processing unit 110 may determine the position, velocity (e.g., direction and speed), and/or acceleration of the leading vehicle, using the techniques described in connection with FIGS. 5A and 5B, above. Processing unit 110 may also determine one or more road polynomials, a look-ahead point (associated with vehicle 200), and/or a snail trail (e.g., a set of points describing a path taken by the leading vehicle), using the techniques described in connection with FIG. 5E, above.

[0095] At step 582, processing unit 110 may analyze the navigation information determined at step 580. In one embodiment, processing unit 110 may calculate the distance between a snail trail and a road polynomial (e.g., along the trail). If the variance of this distance along the trail exceeds a predetermined threshold (for example, 0.1 to 0.2 meters on a straight road, 0.3 to 0.4 meters on a moderately curvy road, and 0.5 to 0.6 meters on a road with sharp curves), processing unit 110 may determine that the leading vehicle is likely changing lanes. In the case where multiple vehicles are detected traveling ahead of vehicle 200, processing unit 110 may compare the snail trails associated with each vehicle. Based on the comparison, processing unit 110 may determine that a vehicle whose snail trail does not match with the snail trails of the other vehicles is likely changing lanes. Processing unit 110 may additionally compare the curvature of the snail trail (associated with the leading vehicle) with the expected curvature of the road segment in which the leading vehicle is traveling. The expected curvature may be extracted from map data (e.g., data from map database 160), from road polynomials, from other vehicles' snail trails, from prior knowledge about the road, and the like. If the difference in curvature of the snail trail and the expected curvature of the road segment exceeds a predetermined threshold, processing unit 110 may determine that the leading vehicle is likely changing lanes.

[0096] In another embodiment, processing unit 110 may compare the leading vehicle's instantaneous position with the look-ahead point (associated with vehicle

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200) over a specific period of time (e.g., 0.5 to 1.5 seconds). If the distance between the leading vehicle's instantaneous position and the look-ahead point varies during the specific period of time, and the cumulative sum of variation exceeds a predetermined threshold (for example, 0.3 to 0.4 meters on a straight road, 0.7 to 0.8 meters on a moderately curvy road, and 1.3 to 1.7 meters on a road with sharp curves), processing unit 110 may determine that the leading vehicle is likely changing lanes. In another embodiment, processing unit 110 may analyze the geometry of the snail trail by comparing the lateral distance traveled along the trail with the expected curvature of the snail trail. The expected radius of curvature may be determined according to the calculation: $(\delta_z^2 + \delta_x^2) / 2 / (\delta_x)$, where δ_x represents the lateral distance traveled and δ_z represents the longitudinal distance traveled. If the difference between the lateral distance traveled and the expected curvature exceeds a predetermined threshold (e.g., 500 to 700 meters), processing unit 110 may determine that the leading vehicle is likely changing lanes. In another embodiment, processing unit 110 may analyze the position of the leading vehicle. If the position of the leading vehicle obscures a road polynomial (e.g., the leading vehicle is overlaid on top of the road polynomial), then processing unit 1 10 may determine that the leading vehicle is likely changing lanes. In the case where the position of the leading vehicle is such that, another vehicle is detected ahead of the leading vehicle and the snail trails of the two vehicles are not parallel, processing unit 110 may determine that the (closer) leading vehicle is likely changing lanes.

[0097] At step 584, processing unit 110 may determine whether or not leading vehicle 200 is changing lanes based on the analysis performed at step 582. For example, processing unit 110 may make the determination based on a weighted average of the individual analyses performed at step 582. Under such a scheme, for example, a decision by processing unit 110 that the leading vehicle is likely changing lanes based on a particular type of analysis may be assigned a value of "1"(and "0" to represent a determination that the leading vehicle is not likely changing lanes). Different analyses performed at step 582 may be assigned different weights, and the disclosed embodiments are not limited to any particular combination of analyses and weights.

[0098] FIG. 6 is a flowchart showing an exemplary process 600 for causing one or more navigational responses based on stereo image analysis, consistent with disclosed embodiments. At step 610, processing unit 110 may receive a first and second plurality of images via data interface 128. For example, cameras included in image acquisition unit 120 (such as image capture devices 122 and 124 having fields of view 202 and 204) may capture a first and second plurality of images of an area forward of vehicle 200 and transmit them over a digital connection (e.g., USB, wireless, Bluetooth, etc.) to processing unit 110. In some embodiments, processing unit 110 may receive the first and second plurality of images via two or more data interfaces. The disclosed embodiments are not limited to any particular data interface configurations or protocols.

[0099] At step 620, processing unit 110 may execute stereo image analysis module 404 to perform stereo image analysis of the first and second plurality of images to create a 3D map of the road in front of the vehicle and detect features within the images, such as lane markings, vehicles, pedestrians, road signs, highway exit ramps, traffic lights, road hazards, and the like. Stereo image analysis may be performed in a manner similar to the steps described in connection with FIGS. 5A-5D, above. For example, processing unit 110 may execute stereo image analysis module 404 to detect candidate objects (e.g., vehicles, pedestrians, road marks, traffic lights, road hazards, etc.) within the first and second plurality of images, filter out a subset of the candidate objects based on various criteria, and perform multi-frame analysis, construct measurements, and determine a confidence level for the remaining candidate objects. In performing the steps above, processing unit 110 may consider information from both the first and second plurality of images, rather than information from one set of images alone. For example, processing unit 110 may analyze the differences in pixel-level data (or other data subsets from among the two streams of captured images) for a candidate object appearing in both the first and second plurality of images. As another example, processing unit 110 may estimate a position and/or velocity of a candidate object (e.g., relative to vehicle 200) by observing that the object appears in one of the plurality of images but not the other or relative to other differences that may exist relative to objects appearing if the two image streams. For example, position, velocity, and/or acceleration relative to vehicle 200 may be determined based on trajectories, positions, movement characteristics, etc. of features associated with an object appearing in one or both of the image streams.

[0100] At step 630, processing unit 110 may execute navigational response module 408 to cause one or more navigational responses in vehicle 200 based on the analysis performed at step 620 and the techniques as described above in connection with FIG. 4. Navigational responses may include, for example, a turn, a lane shift, a change in acceleration, a change in velocity, braking, and the like. In some embodiments, processing unit 110 may use data derived from execution of velocity and acceleration module 406 to cause the one or more navigational responses. Additionally, multiple navigational responses may occur simultaneously, in sequence, or any combination thereof.

[0101] FIG. 7 is a flowchart showing an exemplary process 700 for causing one or more navigational responses based on an analysis of three sets of images, consistent with disclosed embodiments. At step 710, processing unit 110 may receive a first, second, and third plurality of images via data interface 128. For instance, cameras included in image acquisition unit 120 (such as

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image capture devices 122, 124, and 126 having fields of view 202, 204, and 206) may capture a first, second, and third plurality of images of an area forward and/or to the side of vehicle 200 and transmit them over a digital connection (e.g., USB, wireless, Bluetooth, etc.) to processing unit 110. In some embodiments, processing unit 110 may receive the first, second, and third plurality of images via three or more data interfaces. For example, each of image capture devices 122, 124, 126 may have an associated data interface for communicating data to processing unit 110. The disclosed embodiments are not limited to any particular data interface configurations or protocols.

[0102] At step 720, processing unit 110 may analyze the first, second, and third plurality of images to detect features within the images, such as lane markings, vehicles, pedestrians, road signs, highway exit ramps, traffic lights, road hazards, and the like. The analysis may be performed in a manner similar to the steps described in connection with FIGS. 5A-5D and 6, above. For instance, processing unit 110 may perform monocular image analysis (e.g., via execution of monocular image analysis module 402 and based on the steps described in connection with FIGS. 5A-5D, above) on each of the first, second, and third plurality of images. Alternatively, processing unit 110 may perform stereo image analysis (e.g., via execution of stereo image analysis module 404 and based on the steps described in connection with

[0103] FIG. 6, above) on the first and second plurality of images, the second and third plurality of images, and/or the first and third plurality of images. The processed information corresponding to the analysis of the first, second, and/or third plurality of images may be combined. In some embodiments, processing unit 110 may perform a combination of monocular and stereo image analyses. For example, processing unit 110 may perform monocular image analysis (e.g., via execution of monocular image analysis module 402) on the first plurality of images and stereo image analysis (e.g., via execution of stereo image analysis module 404) on the second and third plurality of images. The configuration of image capture devices 122, 124, and 126-including their respective locations and fields of view 202, 204, and 206-may influence the types of analyses conducted on the first, second, and third plurality of images. The disclosed embodiments are not limited to a particular configuration of image capture devices 122, 124, and 126, or the types of analyses conducted on the first, second, and third plurality of images.

[0104] In some embodiments, processing unit 110 may perform testing on system 100 based on the images acquired and analyzed at steps 710 and 720. Such testing may provide an indicator of the overall performance of system 100 for certain configurations of image capture devices 122, 124, and 126. For example, processing unit 110 may determine the proportion of "false hits" (e.g., cases where system 100 incorrectly determined the presence of a vehicle or pedestrian) and "misses."

[0105] At step 730, processing unit 110 may cause one or more navigational responses in vehicle 200 based on information derived from two of the first, second, and third plurality of images. Selection of two of the first, second, and third plurality of images may depend on various factors, such as, for example, the number, types, and sizes of objects detected in each of the plurality of images. Processing unit 110 may also make the selection based on image quality and resolution, the effective field of view reflected in the images, the number of captured frames, the extent to which one or more objects of interest actually appear in the frames (e.g., the percentage of frames in which an object appears, the proportion of the object that appears in each such frame, etc.), and the like.

[0106] In some embodiments, processing unit 110 may select information derived from two of the first, second, and third plurality of images by determining the extent to which information derived from one image source is consistent with information derived from other image sources. For example, processing unit 110 may combine the processed information derived from each of image capture devices 122, 124, and 126 (whether by monocular analysis, stereo analysis, or any combination of the two) and determine visual indicators (e.g., lane markings, a detected vehicle and its location and/or path, a detected traffic light, etc.) that are consistent across the images captured from each of image capture devices 122, 124, and 126. Processing unit 110 may also exclude information that is inconsistent across the captured images (e.g., a vehicle changing lanes, a lane model indicating a vehicle that is too close to vehicle 200, etc.). Thus, processing unit 110 may select information derived from two of the first, second, and third plurality of images based on the determinations of consistent and inconsistent information.

[0107] Navigational responses may include, for example, a turn, a lane shift, a change in acceleration, and the like. Processing unit 110 may cause the one or more navigational responses based on the analysis performed at step 720 and the techniques as described above in connection with FIG. 4. Processing unit 110 may also use data derived from execution of velocity and acceleration module 406 to cause the one or more navigational responses. In some embodiments, processing unit 110 may cause the one or more navigational responses based on a relative position, relative velocity, and/or relative acceleration between vehicle 200 and an object detected within any of the first, second, and third plurality of images. Multiple navigational responses may occur simultaneously, in sequence, or any combination thereof.

Object Detecting and Braking System

[0108] In some embodiments, vehicle 200 may include an object detecting and braking system configured to detect an object in front of vehicle 200 and cause vehicle 200 to brake, e.g., using braking system 230, based on the detection of the object. For example, the object detecting and braking system may cause vehicle 200 to

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brake automatically, or autonomously, without or with limited driver intervention. The automatic or autonomous object detecting and braking system may or may not allow a driver to intervene to take over control of braking system 230.

[0109] The object detecting and braking system may include a plurality of other systems discussed above. For example, the object detecting and braking system may include system 100, braking system 230, and one or more of image capture devices 122, 124, and 126. The one or more of image capture devices 122, 124, and 126 may acquire one or more images of an environment or an area in front of vehicle 200, which may include an object, such as another vehicle, a pedestrian, a road surface, etc. Processing unit 110 may process the images based on at least two independent analyses to determine at least two times-to-collision (TTCs) of vehicle 200 with the object. In some embodiments, the two TTCs of vehicle 200 with the object may be determined separately and independently of each other. A "time-to-collision" (TTC) may also be referred to as a "time-to-contact." The time-to-collision is an estimated time that would lapse before vehicle 200 collides with another object. Processing unit 110 may determine that a difference between the two times-to-collision does not exceed a predetermined threshold. Based on this determination, processing unit 110 may cause vehicle 200 to brake using, e.g., braking system 230. The automatic or autonomous braking may assist the driver to avoid collision with the object in front of vehicle 200, thereby improving driving safety. By causing vehicle 200 to brake when the difference between the two TTCs does not exceed the predetermined threshold, false braking may be prevented or reduced.

[0110] In some embodiments, the object detecting and braking system may use two independent channels of information inherent to monocular video sensing. The first channel of information may be referred to as a "texture" or "appearance information" channel. System 100 may perform an analysis based on the texture or appearance information. In this channel, system 100 may perform pattern recognition over the pixels intensities in each image separately among different images (e.g., two sequential images or frames). System 100 may estimate the change of a footprint size (e.g., a dimension length of a feature of an object in the image) by comparing image data of the two sequential images. The second channel of information may be referred to as a "structural" or "optical flow information" channel. System 100 may perform an analysis based on the structural or optical flow information. For example, system 100 may process two or more images (e.g., sequentially acquired images or frames) to obtain an optical flow field. The optical flow field may provide information regarding the movement of trackable textures between the two or more images or frames. The analysis of the optical flow field may indicate a low time-to-collision upright object in the images. The two analyses may also be referred to as two modalities, methods, or models.

[0111] In some embodiments, the structure (or optical flow) based analysis may serve to validate a result of a texture based analysis. For example, the texture based analysis may be performed on a plurality of images (e.g., at least two images), and the structure based analysis may be performed based on the same two or more images used in the texture based analysis after the texture based analysis is performed. In such embodiments, the structure based analysis may validate a result of the texture based analysis. In some embodiments, the texture based analysis may be performed after the structure based analysis has been performed, and may validate a result of the structure based analysis.

[0112] In some embodiments, the texture based analysis may use a first group of at least two images, and the structure based analysis may use a second group of at least two images. The first group and the second group may be the same or different. In some embodiments, the first group of at least two images may be selected from odd numbered images among a plurality of images acquired by at least one of image capture devices 122-126, and the second group of at least two images may be selected from even numbered images among the same plurality of images acquired by at least of image capture devices 122-126.

[0113] In some embodiments, the first group of at least two images may be selected from a plurality of images that are acquired at a first time interval and the second group of at least two images may be selected from the same plurality of images that are acquired at a second time interval, which may be different from the first time interval. In some embodiments, a first image capture device (or a first image sensor) may be designated for capturing images for the texture based analysis, and a second image capture device (or a second image sensor) may be designated for capturing images for structure based analysis.

[0114] The texture based analysis and the structure based analysis may complement each other, and the combination of their results that may be used by processing unit 110 to make a braking decision. For example, the texture based analysis may result in a first estimate of time-to-collision, and the structure based analysis may also result in a second estimate of the time-to-collision. Processing unit 110 may cause braking system 230 to brake vehicle 200 when the difference between the first and second estimates is smaller than a threshold. One of the texture based analysis and the structure based analysis may provide a redundancy for the other, thereby improve accuracy of braking, for example, autonomous braking in emergency driving situation, by preventing or reducing the occurrence of false braking.

[0115] In some embodiments, when the structure based analysis serves as a validator of the texture based analysis, the texture based analysis may detect an object (e.g., a car or a pedestrian) in front of vehicle 200, and may determine that the time-to-collision is low (e.g., lower than a predetermined threshold). The texture based anal-

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ysis may reach this determination by calculating the time-to-collision based on a change of a footprint size through time in at least two sequentially acquired images. This determination from the texture based analysis may then trigger the structure based analysis. In some embodiments, a determination that the time-to-collision is low from the texture based analysis may serve as a precondition for releasing a braking decision (e.g., an autonomous emergency braking decision) to vehicle systems. In some embodiments, braking (e.g., autonomous emergency braking) may not be performed until the structure based analysis confirms the determination made via the texture based analysis.

[0116] In some embodiments, system 100 may require that the estimated time-to-collision (TTC) determined by the structure based analysis is identical to or substantially identical to (up to an error tolerance) to the estimated time-to-collision (TTC) determined by the texture based analysis. For example, as discussed below, processing unit 10 may determine that a difference between the two TTCs determined by the texture based analysis and the structure based analysis does not exceed a predetermined threshold, which may be the error tolerance. In some embodiments, system 100 may take into account the divergence of the object's focus of expansion from that of the static environment. If the focus of expansion of the object diverges (e.g., moves) away from the focus of expansion of the static environment, this may be a strong indication that the object is a low TTC upright object. An example is discussed in greater detail with respect to FIGS. 15A and 15B. This requirement is optional because it may only apply in the case where the target object has a velocity component that is perpendicular to the driving direction of vehicle 200 (e.g., target object traveling in a direction that is not parallel to the driving direction of vehicle 200).

[0117] In some embodiments, processing unit 110 may use certain criteria for deciding whether structure based analysis supports texture based analysis in making a braking (e.g., autonomous emergency braking) decision. For example, such criteria may include a requirement that the optical flow fits a model of low time-to-collision upright object (LTU object), and not an open-road (or an open road surface).

[0118] FIG. 8 is a diagrammatic representation of an exemplary vehicle 200 including an object detecting and braking system (or referred to as an emergency braking decisioning system). The object detecting and braking system may include system 100 and braking system 230. The object detecting and braking system may also include at least one of image capture devices 122 and 124 (and 126, which is not shown in FIG. 8). The object detecting and braking system may include processing unit 110, which may be part of system 100. At least one of image capture devices 122 and 124 may acquire one or a plurality of images of an area including an object in front of vehicle 200. The object may be another vehicle, such as a vehicle 800 that may be traveling in front of vehicle 200. As shown in FIG. 8, in some embodiments, vehicle 800 may be traveling in a direction that is parallel to a traveling direction of vehicle 200. A parallel direction may include a situation in which vehicle 800 is traveling in the same direction as and in alignment or substantially in alignment with vehicle 200 (e.g., vehicle 800 traveling in front of vehicle 200), as shown in FIG. 8. A parallel direction may also include a situation in which vehicle 800 is traveling in an opposite direction relative to vehicle 200 and in alignment with vehicle 200 (e.g., vehicle 800 moving toward vehicle 200 in a direction that is 180 degrees, or substantially 180 degrees, opposite to the traveling direction of vehicle 200). A parallel direction may also include a situation in which vehicle 800 is not traveling in alignment with vehicle 200, but is traveling in a direction parallel to the traveling direction of vehicle 200 (e.g., vehicle 800 traveling on a front side of vehicle 200 at an offset distance).

[0119] In some embodiments, the object may be a pedestrian who may be standing in the road, or walking or running across the road. The area included in the images may include other objects, such as a road surface, a house, a wall, a sign, etc., which may form a static environment. When an object is not traveling in a direction parallel to the traveling direction of vehicle 200, the traveling direction of the object may transverse the traveling direction of vehicle 200 with an angle that is neither zero (or substantially zero) nor 180 degrees (or substantially 180 degrees). The images may include both moving and/or static objects.

[0120] Processing unit 110 may communicate with braking system 230 and at least one of image capture devices 122 and 124. For example, processing unit 110 may receive images from at least one of image capture devices 122 and 124, and may process the images using various methods or modalities to detect one or more times-to-collision of vehicle 200 with object 800. Although two image capture devices 122 and 124 are shown in FIG. 8, the use of additional image capture devices (e.g., 3, 4, 5, etc., image capture devices) is consistent with the disclosed embodiments.

[0121] FIG. 9 is a diagrammatic representation of an exemplary vehicle 200 including an object detecting and braking system that may be configured to detect an object not traveling in a direction parallel to the traveling direction of vehicle 200. The object may be a vehicle 900 or a pedestrian (not shown). The object detecting and braking system may detect vehicle 900 traveling toward vehicle 200 based on one or more images acquired by at least one of image capture devices 122 and 124. In addition, the object detecting and braking system may determine at least two times-to-collision of vehicle 200 with vehicle 900 based on the at least one or more images. When a difference between the at least two times-to-collision does not exceed the predetermined threshold, processing unit 110 may cause vehicle 200 to brake in order to prevent collision with vehicle 900.

[0122] FIG. 10 is an exemplary block diagram of mem-

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ory 140 or 150 that may store instructions for performing one or more operations for detecting an object in front of vehicle 200 and causing vehicle 200 to brake based on the detection. As shown in FIG. 10, memory 140 or 150 may store one or more modules for performing the operations, as described herein. For example, memory 140 or 150 may store a first image analysis module 1002, a second image analysis module 1003, and a braking module 1004. Application processor 180 and/or image processor 190 may execute the instructions stored in any of modules 1002-1004 included in memory 140 or 150. One of skill in the art will understand that references in the following discussions to processing unit 110 may refer to application processor 180 and image processor 190 individually or collectively. Accordingly, steps of any of the following processes may be performed by one or more processing devices.

[0123] First image analysis module 1002 may store instructions which, when executed by processing unit 110, may perform a first image analysis to calculate or generate a first estimated time-to-collision (TTC1) of vehicle 200 with an object (e.g., vehicle 800 or 900). First image analysis module 1002 may process at least two images acquired by at least one of image capture devices 122 and 124 using, for example, an appearance based detection method, which may calculate TTC1 based on a change in the appearance (e.g., a size) of the object in the at least two images. An exemplary first image analysis is discussed below in greater detail with respect to FIG. 12.

[0124] Second image analysis module 1002 may store instructions which, when executed by processing unit 110, may perform a second image analysis to calculate or generate a second estimated time-to-collision (TTC2) of vehicle 200 with the object (e.g., vehicle 800 or 900). Second image analysis module 1003 may process at least two images acquired by at least one of image capture devices 122 and 124 using, for example, an optical flow based method, which may calculate TTC2 based on optical flow information derived from the at least two images. An exemplary second image analysis is discussed below in greater detail with respect to FIG. 13.

[0125] Braking module 1004 may store instructions which, when executed by processing unit 110, may cause vehicle 200 to brake using braking system 230. For example, when processing unit 110 determines that a difference between TTC1 and TTC2 does not exceed the predetermined threshold, braking module 1004 may cause braking system 230 to apply braking to reduce the speed of vehicle 200 or stop vehicle 200, thereby preventing collision with the object.

[0126] FIG. 11 is a flowchart showing an exemplary process or method 1100 for detecting an object in front of vehicle 200 and causing vehicle 200 to brake based on the detection. Method 1100 may include acquiring a plurality of images of an area in front of vehicle 200 (step 1 1 10). For example, at least one of image capture devices 122 and 124 may acquire one or more images of an area in front of vehicle 200. The area may include an object, such as another vehicle or a pedestrian. The area may include other static objects, such as a sign, a house, a mountain, a road surface, etc., which may form a static environment.

[0127] Method 1100 may include performing the first image analysis based on at least a first image and a second image to generate a first time-to-collision (TTC1) (step 1120). For example, processing unit 110 may perform the first image analysis based on at least the first image and the second image. More than two images may be used in the first image analysis to generate TTC1. In some embodiments, the first image analysis may include an appearance based detection method. The appearance based detection may detect TTC1 based on a change in appearance (e.g., a change in size) of an object in the first image and the second image. The appearance based detection technique is further discussed below in connection with FIG. 12.

[0128] FIG. 12 is a flowchart showing an exemplary first image analysis 1200 for determining the first estimated time-to-collision (TTC1). The first image analysis 1200 may include the appearance or texture based detection method (hence, the first image analysis may be referred to as the texture based analysis or textural analysis). The appearance based detection method may include determining a change in the appearance of an object or a feature of the object in at least two images (e.g., the first image and the second image), and may calculate TTC1 based on the change in the appearance. In some embodiments, the change in the appearance may be a change in a size of the object (or the feature of the object).

[0129] In the exemplary first image analysis 1200 shown in FIG. 12, processing unit 110 may determine a first size of an object (or a feature of the object) appearing in the first image (step 1210). Processing unit 110 may determine a second size of the object (or the feature of the object) appearing in the second image (step 1220). The second size may be larger than the first size as vehicle 200 approaches the object. Processing unit 110 may determine the first size and the second size based on the dimensions (e.g., pixel sizes) of the object appearing in the first image and the second image. Processing unit 110 may determine a change in size (or relative scale) of the object (or the feature of the object) (step 1230). For example, processing unit 110 may subtract the first size from the second size to determine a difference in size. In some embodiments, processing unit 110 may divide the difference in size by the first size to determine a relative difference in size. The change in size (or relative scale) may refer to the relative difference in size, which may be a percentage. Processing unit 110 may determine TTC1 based on the change in size and a first predetermined time interval between times of acquisition of the first image and the second image (step 1240). The first predetermined time interval may depend on settings of the camera (e.g., the camera included in the first image capture device 122) that acquires the first

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image and the second image, and may be known once the camera settings are fixed. The first predetermined time interval may be any suitable interval, such as, for example, 0.05 second, 0.1 second, 0.2 second, etc. For example, the first predetermined time interval may be represented by dt1, the relative change in size may be represented by S0, and processing unit 110 may calculate TTC1 from TTC1 = dt1 / S0.

[0130] Referring back to FIG. 11, method 1100 may include performing a second image analysis based on at least a third image and a fourth image to generate a second estimated time-to-collision (TTC2) (step 1130). For example, processing unit 110 may derive optical flow information from the third image and the fourth image, and may calculate TTC2 based on the optical flow information. The second image analysis may be referred to as the structure based analysis or structural analysis. In some embodiments, more than two images may be used in the second image analysis to derive the optical flow information.

[0131] FIG. 13 is a flowchart showing an exemplary second image analysis 1300 for determining the second estimated time-to-collision (TTC2). The second image analysis 1300 may include obtaining or deriving an optical flow field from at least the third image and the fourth image (step 1310). In some embodiments, processing unit 110 may derive the optical flow field from the third image and the fourth image, and/or additional images acquired by at least one of image capture devices 122 and 124. The optical flow field may be a vector field in which each point may be represented by a vector showing a magnitude and a direction of movement from a first point in, e.g., the third image, to a corresponding second point in, e.g., the fourth image.

[0132] As shown in FIG. 13, the second image analysis 1300 may include determining a focus of expansion based on the optical flow field (step 1320). The focus of expansion may be a converging point of vectors in the optical flow field, which is discussed below in greater detail with respect to FIG. 16. The second image analysis 1300 may also include determining a rate of expansion relative to the focus of expansion for each point in the optical flow field (step 1330). For example, for each point in the optical flow field, processing unit 110 may calculate the rate of expansion based on a magnitude of movement of the point, and a distance from the point to the focus of expansion. For example, the magnitude of movement of any point may be represented by d, the distance from the point to the focus of expansion may be represented by r, and processing unit 110 may calculate the rate of expansion from $R_{exp} = d / r$. For each point in the optical flow field, the magnitude of movement r may be calculated from the magnitude of the vector associated with that point. The magnitude of movement r may indicate how much a first point in, e.g., the third image, has moved to reach a second point in, e.g., the fourth image.

[0133] As shown in FIG. 13, the second image analysis 1300 may include determining the second estimated time-to-collision (TTC2) based on the rate of expansion and a second predetermined time interval. The second predetermined time interval may be the difference between times of acquisition of the third image and the fourth image. The second predetermined time interval dt2 may depend on the settings (e.g., the frame rate) of the camera, and may or may not be the same as the first predetermined time interval used in the first image analysis. The second predetermined time interval may be any suitable interval, such as, for example, 0.05 second, 0.1 second, 0.2 second, etc. In some embodiments, TTC2 may be inversely proportional to the rate of expansion d/r, and may be directly proportional to the second predetermined time interval dt2. For example, processing unit 110 may calculate TTC2 from TTC2 = dt2 / (d/r).

[0134] The first image analysis 1200 and second image analysis 1300 shown in FIGS. 12 and 13 may be performed independently and separately. The first image and second image used in the first image analysis 1200 may be the same as or different from the third image and fourth image used in the second image analysis 1300. In some embodiments, the first image may be the same as the third image, and the second image may be the same as the fourth image. In some embodiments, the first image may be different from the third image, and the second image may be different from the fourth image. In some embodiments, images of alternating sequences may be used for the first and second analyses. For example, from the same set of images, odd numbered images may be used for the first image analysis, and even numbered images may be used for the second image analysis. In some embodiments, at least one image capture device (e.g., image capture device 122) may be configured to capture images (e.g., the first and second images) for use in the first image analysis to generate the first estimated time-to-collision. At least one other image capture device (e.g., image capture device 124) may be configured to capture images (e.g., the third and fourth images) for use in the second image analysis to generate the second estimated time-to-collision. In some embodiments, when at least one image capture device is used for capturing a plurality of images for the first image analysis and the second image analysis, the at least one image capture device may include a first image sensor configured to capture images (e.g., the first and second images) for use in the first image analysis, and a second image sensor that is separate and independent of the first image sensor configured to capture images (e.g., the third and fourth images) for use in the second image analysis.

[0135] Referring back to FIG. 11, method 1100 may include calculating a difference between the first estimated time-to-collision (TTC1) and the second estimated time-to-collision (TTC2) (step 1140). In some embodiments, processing unit 110 may subtract TTC1 from TTC2 to result in a difference. Processing unit 110 may determine whether the difference exceed a predetermined threshold (step 1150). The predetermined thresh-

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old may be any suitable threshold, such as, for example, 0.05 second, 0.1 second, 0.2 second, etc. When processing unit 110 determines that the difference exceeds the predetermined threshold (Yes, step 1150), processing unit 110 may repeat steps 1110-1150. When processing unit 110 determines that the difference does not exceed the predetermined threshold (No, step 1150), processing unit 110 may cause vehicle 200 to brake using, e.g., braking system 230 (step 1160).

[0136] FIGS. 14A-14C show an image with an optical flow field and a distribution of the second estimated time-to-collision (TTC2) in the optical flow field. FIG. 14A shows an image 1400 showing a vehicle 1410 traveling on a road 1420. For illustrative purposes, other objects included in image 1400 are not shown. FIG. 14B shows an optical flow field 1430 derived based on at least two images. For example, optical flow field 1430 may be derived from image 1400 and at least one second image (not shown) of vehicle 1410 acquired at the second predetermined time interval dt2 apart from the time when image 1400 was acquired. A plurality of image points may be selected in the image 1400 or the at least one second image, and vectors connecting the corresponding points of these images may be generated by processing unit 110. The vectors may form optical flow field 1430, which is schematically shown in FIG. 14B, as a region surrounding vehicle 1410.

[0137] Although optical flow field 1430 is shown within a region surrounding vehicle 1410 for illustrative purposes, optical flow field 1430 may be derived for a smaller region (e.g., focusing on the window of vehicle 1430) or a greater region (e.g., the entire area shown in image 1400). Each point in optical flow field 1430 may be associated with a vector represented in FIG. 14B by an arrow having a length and pointing at a direction. The length of the arrow may represent a magnitude of the vector. For example, the magnitude of the vector may indicate a magnitude of movement of a first point in image 1400 to a second point in the at least one second image. The direction of the arrow may indicate the direction of movement between each pair of corresponding points in these two images.

[0138] After performing the second image analysis 1300 discussed above, processing unit 110 may determine the second estimated time-to-collision (TTC2) for each point in the optical flow field 1430. FIG. 14C shows an exemplary distribution of TTC2 over the entire area shown in image 1400. As shown in FIG. 14C, points in different regions may be associated with different values of TTC2. The different patterns and/or shades shown in FIG. 14C are shown to schematically illustrate different values of TTC2. For a region 1440 substantially focusing on the body of vehicle 1410, all or most of the points within region 1440 may be associated with substantially the same value of TTC2. In other words, for an upright moving object like vehicle 1410, all or most of the points on that upright object may have the same or substantially the same times-to-collision.

[0139] For road surfaces, however, all or most of the points may not have the same or substantially the same times-to-collision. For example, points in a first portion 1450 of road 1420 may be associated with one time-to-collision, and points in a second portion 1460 of road 1420 may be associated with another time-to-collision. These times-to-collision may be different, as shown with different patterns/shades in FIG. 14C. In some embodiments, there may be a discontinuity between the times-to-collision for the first portion 1450 and second portion 1460 of road 1420 (e.g., the changes between these times-to-collision may not be gradual). Although the first and second portions 1450 and 1460 appear as upright objects in a single image, the optical flow field generated from at least two images may reveal additional information (e.g., time-to-collision) that may distinguish a true upright object (which may or may not be moving) and a road surface, which is not upright. This aspect is further discussed with respect to FIGS. 17A-18B.

[0140] As shown in FIG. 14C, points in regions 1470, 1480, and 1490 may be associated with different times-to-collision, as indicated by the different patterns/shading shown in the figure. Regions 1470 and 1480 may each represent a portion of road 1420, and the change in time-to-collision values in regions 1470 and 1480 and first portion 1450 may be gradual (e.g., continuous). For example, region 1490 may represent a portion of the sky, which may be associated with a time-to-collision that is different from those associated with regions 1470 and/or 1480.

[0141] FIGS. 15A and 15B show exemplary focuses of expansion in an optical flow field. FIG. 15A shows an object in an image traveling in the same direction (or substantially the same direction) as and in alignment (or substantially in alignment) with vehicle 200 (e.g., in the same line of movement in front of vehicle 200, toward or away from vehicle 200). As shown in FIG. 15A, a focus of expansion of the object may overlap completely or substantially with a focus of expansion of the static environment. FIG. 15B shows an object not traveling in a direction parallel to the traveling direction of vehicle 200, e.g., when the object is traveling laterally in a direction that transverses the traveling direction of vehicle 200. As shown in FIG. 15B, a focus of expansion of the object may not overlap the focus of expansion of the static environment.

[0142] For example, FIG. 15A shows an environment 1500 of an area in front of vehicle 200. Consistent with disclosed embodiments, an image capture device (e.g., one of image capture devices 122-126) may acquire a first image 1510 of environment 1500 that includes an object located within the first image 1510. The area surrounding the object may represent a static environment (e.g., roads, buildings, mountains, sky, etc.). FIG. 15A also shows a second image 1520 that an image capture device (e.g., one of image capture devices 122-126) may acquire of the object after the second predetermined time interval dt2. Image 1520 may be acquired as vehicle 200 moves toward the object and, therefore, may be larger than image 1510, indicating an expansion.

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[0143] FIG. 15A further shows a focus of expansion 1530. The focus of expansion 1530 may be a focus of expansion of the static environment, as indicated by two dashed lines converging to focus of expansion point 1530. The location of focus of expansion 1530 of the static environment may depend on the camera, and may not change over time as the camera continuously acquires a plurality of images of the object or area for deriving optical flow information. When the object is traveling in the same (or substantially the same) direction as and in (or substantially in) alignment with vehicle 200, e.g., in front of vehicle 200 and in the same or opposite traveling direction as vehicle 200, the focus of expansion 1530 may also constitute a focus of expansion of the object. In other words, the focus of expansion of the object traveling in the same direction as and in alignment with vehicle 200 may completely or substantially overlap (or completely or substantially converge with) the focus of expansion of the static environment. Thus, processing unit 110 may detect one focus of expansion from the optical flow field derived from a plurality of images. FIG. 15A also shows, for illustrative purpose, the distance r from certain points to the focus of expansion.

[0144] FIG. 15B shows an environment 1540 of an area in front of vehicle 200, and a first image 1550 and a second image 1560 of an object (the object being included in the first image 1550 and second image 1560) acquired by the camera one after another at the second predetermined time interval dt2. For example, as vehicle 200 moves toward the object, the image of the object may expand, e.g., from image 1550 to image 1560. FIG. 15B further shows a first focus of expansion 1570 that may be calculated from the optical flow field derived from image 1550 and image 1560 of the object. For illustrative purposes, FIG. 15B shows the distances r from certain points to the first focus of expansion 1570. FIG. 15B also shows a second focus of expansion 1580, which may be a focus of expansion of the static environment. The location of the second focus of expansion 1580 may depend on the camera, and may not change as the camera continuously acquires images of the object or area for deriving the optical flow information. In the example shown in FIG. 15B, the first focus of expansion 1570 may not overlap the second focus of expansion 1580. The detection of two or at least two non-overlapping focuses of expansion may indicate that there is at least one object in the image 1540 that is traveling laterally, e.g., in a direction that is not parallel to the traveling direction of vehicle 200, or in a direction that transverses the traveling direction of vehicle 200 at an angle that is neither zero (or substantially zero) nor 180 degrees (or substantially 180 degrees).

[0145] FIG. 16 shows an exemplary optical flow field and a focus of expansion. The following discussion of FIG. 16 illustrates how an optical flow field may be derived and how a focus of expansion may be determined. For example, vehicle 1600 is an object included in an image acquired by, e.g., image capture device 122 installed on vehicle 200, and vehicle 200 is traveling toward vehicle 1600. Image capture device 122 may sequentially and/or continuously acquire a plurality of images of an area in front of vehicle 200 as vehicle 200 approaches vehicle 1600. Any two or more images may be selected from the plurality of images to derive an optical flow field. In FIG. 16, the first image is represented by vehicle 1600 shown in solid lines, and the second image is represented by vehicle 1610 shown in dashed lines. For a plurality of selected points on the first image, e.g., points (x1, y1), (x2, y2), and (x3, y3), processing unit 110 may determine their corresponding points, e.g., (u1, v1), (u2, v2), and (u3, v3) in the second image. Vectors may be determined for each pair of points (x1, y1) and (u1, v1), (x2, y2) and (u2, v2), and (x3, y3) and (u3, v3). The vectors may indicate a magnitude and direction of expansion for the points in the first image. The length of each vector (represented by a solid arrow in FIG. 16) may indicate the distance or magnitude of movement of from one point in the first image to a corresponding point in the second image, and the direction of the vector may indicate the expansion direction or direction of movement. The converging point 1620 of the vectors may represent the focus of expansion. In some embodiments, the location of the converging point 1620 may be calculated using a suitable mathematical model based on the coordinates of the vectors. For example, the location of converging point 1620 may be calculated from:

$$SS * (x_i - FOE_x) = u_i \quad (1)$$

$$SS * (y_i - FOE_y) = v_i \quad (2)$$

Where SS may be a constant, (x_i, y_i) may be coordinates of the i-th point within a first image, and (u_i, v_i) may be coordinates of the corresponding i-th point within the second image. FOE_x and FOE_y may be coordinates representing the location of converging point 1620 (i.e., focus of expansion).

[0146] FIGS. 17A and 17B show an image of an object and a linear relationship between distances from points in an optical flow field to the focus of expansion and magnitudes of movement of the points. FIGS. 17A and 17B show that a linear relationship between distances from points to the focus of expansion and magnitudes of movement of the points may be used to determine that the object is an upright object (e.g., a low time-to-collision upright object).

[0147] FIG. 17A shows an image including an object, i.e., a vehicle 1700. The image of vehicle 1700 may include an image of two car windows 1710 and 1720, which appear to be darker in the image of vehicle 1700. A plurality of points 1730 may be selected, most of which may be from a region in the image of vehicle 1700. An optical flow field may be derived from at least two images of vehicle 1700 acquired one after another with the second

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predetermined time interval dt2. Processing unit 110 may determine the magnitudes of movement d and the distances r from the points to the focus of expansion based on the optical flow field. Processing unit 110 may determine a relationship between the magnitudes d and distances r. In some embodiments, the relationship may be a linear relationship, as shown in FIG. 17B, indicating that d/r (e.g., slope of the plotted line) is the same for all or substantially all of the points in the optical flow field. As discussed above, d/r may be inversely proportional to the second estimated time-to-collision (TTC2). Thus, a linear relationship between d and r may indicate a constant or substantially constant value of d/r, which in turn may indicate a constant or substantially constant TTC2 for all or substantially all of the points in the optical flow field. The constant or same TTC2 may indicate that the object within the optical flow field is an upright object, or a low time-to-collision upright object.

[0148] To illustrate the linear relationship between magnitudes of movement d and distances r, FIG. 17B shows a plot of the vertical components (y components) related to the magnitudes of movement d (e.g., the magnitude of movement in the y direction, "dy" in FIG. 17B) versus vertical components of distances r (e.g., the distance to the focus of expansion in the y direction, "y" in FIG. 17B). Although not shown in FIG. 17B, a plot of the horizontal components, e.g., magnitudes in the x direction and distances in the x direction, may also indicate a linear relationship, which in turn may indicate a constant or substantially constant time-to-collision for all or substantially all of the selected points in the optical flow field. In addition, a plot of distances r and magnitudes d may also indicate a linear relationship, which in turn may indicate a constant (or same) or substantially constant (or same) time-to-collision for all or substantially all of the selected points in the optical flow field.

[0149] When a non-linear relationship between the magnitudes of movement d and the distances r to the focus of expansion is detected or determined, the non-linear relationship may indicate that the second estimated times-to-collision are different for different points included in the optical flow field, which in turn may indicate that the image may include a road surface, rather than an upright object. As discussed above, the second estimated times-to-collision may be determined based on the optical flow information derived from at least two images. FIGS. 18A and 18B show an image of an object and a non-linear relationship between distances r from points in an optical flow field to the focus of expansion and magnitudes d of movement of the points. FIG. 18A shows an image 1800 of a house 1810 having two garages 1820 and 1830 with garage doors opened, and a driveway 1840 (e.g., a road surface) leading up to the garages 1820 and 1830. Because the garage doors are opened, garages 1820 and 1830 may appear darker on the image, similar to the car windows 1710 and 1720 shown in FIG. 17A. A region 1850 of the image may be selected for image processing. A plurality of points may be selected within region 1850, and at least two images including regions corresponding to region 1850 may be acquired to derive an optical flow field. Based on the optical flow field having a plurality of vectors, processing unit 110 may determine a focus of expansion, the distances r of the points to the focus of expansion, and the magnitudes d of movement of the points included in the optical flow field. Processing unit 110 may determine a relationship between the distances r and the magnitudes d. In the situation shown in FIG. 18A, processing unit 110 may determine that the relationship between the distances r and the magnitudes d is non-linear. The non-linear relationship between the distances r and the magnitudes d may indicate that the times-to-collision for the points are different for different points. This in turn may indicate that selected region 1850 includes an image of a road surface, rather than an upright object like vehicle 1700 shown in FIG. 17A.

[0150] To illustrate the non-linear relationship between magnitudes of movement d and distances r, FIG. 18B shows a plot of the vertical components (y components) related to the magnitudes d of movement (e.g., the magnitude of movement in the y direction, "dy" in FIG. 18B) versus vertical components of distances r (e.g., the distance to the focus of expansion in the y direction, "y" in FIG. 18B). Although not shown in FIG. 18B, a plot of the horizontal components, e.g., magnitudes in the x direction and distances in the x direction, may also indicate a nonlinear relationship, and hence, different times-to-collision for the selected points in the optical flow field. In addition, a plot of distances r and magnitudes d may also indicate a nonlinear relationship, and hence, different times-to-collision for the selected points in the optical flow field. Here, the image in the region 1850 may appear similar to the image of vehicle 1700 shown in FIG. 17A in a single image. The optical flow field derived from a plurality of images acquired at the second predetermined time interval dt2 may reveal additional information, e.g., time-to-collision information, about the objects included in the selected region. The time-to-collision information may be used to determine whether the object is an upright object or a road surface. Processing unit 110 may combine this determination with the calculated TTC2 to determine whether or not to cause vehicle 200 to brake.

[0151] FIG. 19 is a flowchart showing an exemplary process 1900 for triggering a warning based on one or more probabilities indicating that a time-to-collision is smaller than one or more thresholds. Instead of determining the time-to-collision as discussed above, processing unit 110 may determine, based on at least two images acquired by one or more image capture devices 122, 124, and 126, a probability that the time-to-collision is smaller than a predetermined threshold. For example, in process 1900, one or more image capture devices 122-126 may acquire a plurality of images of an area in front of vehicle 200 (step 1910). In some embodiments, one image capture device having one camera may be used. In some embodiments, two or more image

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capture devices have two or more cameras may be used. For example, one camera may have a 45-degree field of view of the area in front of vehicle 200, and another camera may have a 30-degree field of view.

[0152] In some embodiments, processing unit 110 may perform a third image analysis based on at least two images to determine a first probability (P1) that a time-to-collision (TTC) is smaller than a first predetermined threshold T1 (i.e., TTC<T1) (step 1920). The first predetermined threshold T1 may be any suitable value, such as, for example, 0.1 second, 0.2 second, 05. second, etc. Processing unit 110 may determine a second probability (P2) that the time-to-collision (TTC) is smaller than a second predetermined threshold T2 (i.e., TTC < T2) (step 1930). The second predetermined threshold T2 may be any suitable value, such as, for example, 0.1 second, 0.2 second, 05. second, etc. The second predetermined threshold T2 may or may not be the same as the first predetermined threshold T1.

[0153] Processing unit 110 may trigger a warning if the first probability P1 is greater than a first predetermined probability threshold Tpl, or if the second probability P2 is greater than a second predetermined probability threshold Tp2. Tp1 and Tp2 may be any suitable value, such as, for example, 0.5, 0.8, 0.9, etc. Tp1 and Tp2 may or may not be the same. In some embodiments, Tp2 may be smaller than Tp1. Processing unit 110 may compare the first probability P1 with the first predetermined probability threshold Tp1 to determine whether the first probability P1 is greater than the first predetermined probability threshold Tp1. Processing unit 110 may also compare the second probability P2 with the second predetermined probability threshold Tp2 to determine whether the second probability P2 is greater than the second predetermined probability threshold Tp2. The warning may include an audio alert, a video alert, a vibrational alert, or a combination thereof. The warning may alert the driver so that the driver may take suitable navigational action, such as applying brakes, steering the wheel, etc.

[0154] FIG. 20 is a flowchart showing an exemplary process 2000 for determining the first time-to-collision (TTC1) that may be implemented in the first image analysis shown in FIG. 11. Process 2000 may be used in the first image analysis as an alternative texture based TTC1 calculation method replacing the process 1200 shown in FIG. 12. Processing unit 110 may process at least two images that are acquired at a predetermined time interval DT. Processing unit 110 may determine a first dimension length y1 of an object in a first image (step 2010). The first dimension length of the object may be a length of a feature of the object in the vertical direction, horizontal direction, or in any direction on the first image. For example, when the object is a vehicle, the feature may be a vertical side of a license plate on the vehicle. Processing unit 110 may determine a second dimension length y2 of the same object (or the same feature of the same object) in a second image, which may be acquired after the first image at a time that is DT after the time the first image is acquired (step 2020). Processing unit 110 may determine a scaling factor Sf based on the first dimension length and the second dimension length. For example, processing unit 110 may calculate Sf based on Sf = y1 / y2. In some embodiments, processing unit may track the horizontal and vertical coordinates (dx, dy) of the object in the first and second image, and may calculate Sf based on the coordinates (dx, dy), for example, Sf = dy1 / dy2.

[0155] Processing unit 110 may determine a time-to-collision (which may be the first time-to-collision shown in FIG. 11) based on the scaling factor and the time interval DT. In some embodiments, processing unit 110 may calculate TTC1 from TTC1 = DT / (Sf-1).

[0156] Using two, i.e., texture based and structure based, sensing modalities, methods, or models, as described above, have several benefits or advantages. For example, an immediate result of using two modalities in a braking decisioning system is a reduction of the probability of system failure may be achieved, as compared to braking decisioning systems using only one of the modalities (or only one information channel).

[0157] Another benefit relates to system validation. Using at least two modalities (or channels of information, or two independent and/or separate analyses) enable the vehicle to assess the overall system failure rate (e.g., mean-time-between-failures or MTBF). The overall system failure rate may be determined by assessing each modality's failure rate separately (e.g., by assessing the failure rate of the texture based analysis and the failure rate of the structure based analysis separately). The two modalities may be implemented in two sub-systems: a textural analysis based sub-system and a structural analysis based sub-system. The failure rates of the two modalities may be multiplied. A result of the multiplication may be used as an indicator of or may be used to compute the overall system failure rate. In some embodiments, the MTBF may be estimated based on the result of the multiplication, even if it is significantly higher than the extent (in time) of available validation data.

[0158] For example, in one scenario, a record of only 1000 hours of data is available, and the combined systems MTBF is 1000000 hours. In 1/100 hours the texture based analysis may trigger a false braking decision. In 1/10000 of the cases the texture based analysis is checking the hypothesized decision (e.g., the hypothesized decision being a decision to brake because of a low TTC upright object in front of vehicle 200). In such cases, the texture based analysis may falsely approve the hypothesized decision. By direct assessment of the combined system (or combined analyses of the texture based analysis and the structure based analysis), vehicle systems may only achieve 0 failure over 1000 hours, and may not be able to assess the MTBF. By taking two independent channels of information into account in the braking decisioning for vehicle 200, e.g., using the texture based analysis and the structure based analysis, a vehicle system may be able to assess the failure rate of each sub-system (e.g., textural analysis based sub-system and structural

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analysis based sub-system) separately. Such failure rates may be multiplied, and a result of the multiplication may be used to assess the MTBF. For example, in some embodiments, the textural analysis based sub-system may be keep running alone and it may fail 10 times over 1000 hours. If the structural analysis based sub-system is falsely provoked 1000000 times, as if, for example, the textural analysis based sub-system reached a decision that there is a need to issue an autonomous emergency braking on an open road, the structural analysis based sub-system may fail once in 10000 provocations. Based on these observations, processing unit 110 may deduce (or determine) that the total system mean-time-between failures (MTBFs) is indeed 1000000 hours. This estimate may be reached using only 1000 hours of recorded data. Thus, by using the disclosed two modalities, system validation may be more efficiently performed based on only limited hours of recorded data.

[0159] FIG. 21 is a flowchart showing an exemplary process 2100 for performing system validation using two modalities. Process 2100 summarizes the system validation discussed above. Processing unit 110 may determine a first failure rate associated with the textural analysis based sub-system (step 2110). For example, processing unit 110 may determine the first failure rate based on the total number of times the textural analysis based sub-system makes a false braking decision (e.g., falsely detected a low TTC upright object) among a total number of system running hours. As discussed above, the textural analysis based sub-system may make a decision to brake based on detection of a change in a texture (e.g., a change in footprint size) between at least two images of an area in front of vehicle 200. Processing unit 110 may determine a second failure rate associated with the structural analysis based sub-system (step 2120). For example, processing unit 110 may determine the second failure rate based on the total number of times the structural analysis based sub-system makes a false braking decision (e.g., falsely detected a low TTC upright object) among the same total number of system running hours or a different total number of system running hours. Processing unit 110 may determine an overall system failure rate based on the first failure rate and the second failure rate (step 2130). For example, processing unit 110 may multiply the first failure rate and the second failure rate, and use a result of the multiplication as an indicator of overall system mean-time-between-failures (MTBF).

[0160] The foregoing description has been presented for purposes of illustration. It is not exhaustive and is not limited to the precise forms or embodiments disclosed. Modifications and adaptations will be apparent to those skilled in the art from consideration of the specification and practice of the disclosed embodiments. Additionally, although aspects of the disclosed embodiments are described as being stored in memory, one skilled in the art will appreciate that these aspects can also be stored on other types of computer readable media, such as secondary storage devices, for example, hard disks or CD ROM, or other forms of RAM or ROM, USB media, DVD, Blu-ray, or other optical drive media.

[0161] Computer programs based on the written description and disclosed methods are within the skill of an experienced developer. The various programs or program modules can be created using any of the techniques known to one skilled in the art or can be designed in connection with existing software. For example, program sections or program modules can be designed in or by means of .Net Framework, .Net Compact Framework (and related languages, such as Visual Basic, C, etc.), Java, C++, Objective-C, HTML, HTML/AJAX combinations, XML, or HTML with included Java applets.

[0162] Moreover, while illustrative embodiments have been described herein, the scope of any and all embodiments having equivalent elements, modifications, omissions, combinations (e.g., of aspects across various embodiments), adaptations and/or alterations as would be appreciated by those skilled in the art based on the present disclosure. The limitations in the claims are to be interpreted broadly based on the language employed in the claims and not limited to examples described in the present specification or during the prosecution of the application. The examples are to be construed as non-exclusive. Furthermore, the steps of the disclosed methods may be modified in any manner, including by reordering steps and/or inserting or deleting steps. It is intended, therefore, that the specification and examples be considered as illustrative only, with a true scope and spirit being indicated by the following claims and their full scope of equivalents.

[0163] Also disclosed herein are the following clauses:

1. An object detecting and braking system for a vehicle, comprising:

at least one image capture device configured to acquire a plurality of images of an area including an object in front of the vehicle;
a data interface; and
at least one processing device programmed to:

receive the plurality of images via the data interface;
perform a first image analysis based on at least a first image and a second image to determine a first estimated time-to-collision of the vehicle with the object;
perform a second image analysis based on at least a third image and a fourth image to determine a second estimated time-to-collision of the vehicle with the object;
calculate a difference between the first estimated time-to-collision and the second estimated time-to-collision;
determine that the difference does not exceed a predetermined threshold; and
cause the vehicle to brake based on the de-

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termination that the difference does not exceed the predetermined threshold.

2. The object detecting and braking system of clause 1, wherein the first image analysis includes:

determining a first size of the object appearing in the first image;
determining a second size of the object appearing in the second image;
determining a change in size of the object based on the first size and the second size; and
determining the first estimated time-to-collision based on the change in size of the object and a predetermined time interval between times of acquisition of the first image and the second image.

3. The object detecting and braking system of clause 1, wherein the second image analysis includes:

obtaining a vector field from at least the third image and fourth image, wherein each point in the vector field is represented by a vector indicating a magnitude and a direction of movement from a first point in the third image to a corresponding second point in the fourth image;
determining a focus of expansion based on the vector field, the focus of expansion being a converging point of vectors in the vector field; and
determining a rate of expansion relative to the focus of expansion for each point in the vector field; and
determining the second estimated time-to-collision based on the rate of expansion and a time interval between times of acquisition of the third image and the fourth image.

4. The object detecting and braking system of clause 3, wherein determining the rate of expansion relative to the focus of expansion includes:

determining a distance from each point in the vector field to the focus of expansion; and
dividing the magnitude by the distance to obtain the rate of expansion for each point in the vector field.

5. The object detecting and braking system of clause 4, wherein the second image analysis includes:

determining a relationship between magnitudes and distances for a plurality of points in the vector field; and
determining that the object represented by the plurality of points is a low time-to-collision upright object based on a determination that the relationship is a linear relationship.

6. The object detecting and braking system of clause 4, wherein the second image analysis includes:

determining a relationship between magnitudes and distances for a plurality of points in the vector field; and
determining that at least a portion of the object is a road surface based on a determination that the relationship is a non-linear relationship.

7. The object detecting and braking system of clause 1, wherein the second image analysis includes:

obtaining a vector field from at least the third image and the fourth image, wherein each point in the vector field is represented by a vector indicating a magnitude and a direction of movement from a first point in the third image to a corresponding second point in the fourth image;
detecting a first focus of expansion that is a first converging point of a first plurality of vectors in the vector field;
detecting a second focus of expansion that is a second converging point of a second plurality of vectors in the vector field; and
determining that the third image and the fourth image include a moving object that moves in a direction that is not parallel to a travel direction of the vehicle.

8. The object detecting and braking system of clause 1, wherein the second image analysis includes:

obtaining a vector field from at least the third image and the fourth image, wherein each point in the vector field is represented by a vector indicating a magnitude and a direction of movement from a first point in the third image to a corresponding second point in the fourth image;
detecting a focus of expansion based on the vector field, the focus of expansion being a converging point of vectors in the vector field; and
determining that the third image and the fourth image represent an environment that is static relative to a road surface on which the vehicle is traveling.

9. The object detecting and braking system of clause 1, wherein the first image used for the first image analysis is different from the third image used for the second image analysis, and wherein the second image used for the first image analysis is different from the fourth image used for the second image analysis.

10. The object detecting and braking system of clause 1, wherein the first image used for the first image analysis is the same as the third image used for the second image analysis, and wherein the second image used for the first image analysis is the

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same as the fourth image used for the second image analysis.

11. The object detecting and braking system of clause 1, wherein the first image analysis and the second image analysis are independent of each other.

12. The object detecting and braking system of clause 1, wherein the at least one image capture device includes:

a first image sensor configured to capture the first image and the second image to be used in the first image analysis; and
a second image sensor independent of the first image sensor and configured to capture the third image and the fourth image to be used in the second image analysis.

13. A vehicle, comprising:

a body;
at least one image capture device configured to acquire a plurality of images of an area including an object in front of the vehicle;
a data interface; and
at least one processing device programmed to:

receive the plurality of images via the data interface;
perform a first image analysis based on at least a first image and a second image to determine a first estimated time-to-collision of the vehicle with the object;
perform a second image analysis based on at least a third image and a fourth image to determine a second estimated time-to-collision of the vehicle with the object;
calculate a difference between the first estimated time-to-collision and the second estimated time-to-collision;
determine that the difference does not exceed a predetermined threshold; and
cause the vehicle to brake based on the determination that the difference does not exceed the predetermined threshold.

14. The vehicle of clause 13, wherein the first image analysis includes:

determining a first size of the object appearing in the first image;
determining a second size of the object appearing in the second image;
determining a change in size of the object based on the first size and the second size; and
determining the first estimated time-to-collision based on the change in size of the object and a predetermined time interval between times of acquisition of the first image and the second image.

15. The vehicle of clause 13, wherein the second image analysis includes:

obtaining a vector field from at least the third image and fourth image, wherein each point in the vector field is represented by a vector indicating a magnitude and a direction of movement from a first point in the third image to a corresponding second point in the fourth image;
determining a focus of expansion based on the vector field, the focus of expansion being a converging point of vectors in the vector field; and
determining a rate of expansion relative to the focus of expansion for each point in the vector field; and
determining the second estimated time-to-collision based on the rate of expansion and a time interval between times of acquisition of the third image and the fourth image.

16. The vehicle of clause 15, wherein determining the rate of expansion relative to the focus of expansion includes:

determining a distance from each point in the vector field to the focus of expansion; and
dividing the magnitude by the distance to obtain the rate of expansion for each point in the vector field.

17. The vehicle of clause 16, wherein the second image analysis includes:

determining a relationship between magnitudes and distances for a plurality of points in the vector field; and
determining that the object represented by the plurality of points is a low time-to-collision upright object based on a determination that the relationship is a linear relationship.

18. A method for detecting an object and braking a vehicle, comprising:

acquiring, via at least one image capture device, a plurality of images of an area including an object in front of the vehicle;
receiving, via a processing device, the plurality of images;
performing, via the processing device, a first image analysis based on at least a first image and a second image to determine a first estimated time-to-collision of the vehicle with the object;
performing, via the processing device, a second image analysis based on at least a third image

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and a fourth image to determine a second estimated time-to-collision of the vehicle with the object;
calculating, via the processing device, a difference between the first estimated time-to-collision and the second estimated time-to-collision;
determining, via the processing device, that the difference does not exceed a predetermined threshold; and
causing, via the processing device, the vehicle to brake based on the determination that the difference does not exceed the predetermined threshold.

19. The method of clause 18, wherein the first image analysis includes:

determining a first size of the object appearing in the first image;
determining a second size of the object appearing in the second image;
determining a change in size of the object based on the first size and the second size; and
determining the first estimated time-to-collision based on the change in size of the object and a predetermined time interval between times of acquisition of the first image and the second image.

20. The method of clause 18, wherein the second image analysis includes:

obtaining a vector field from at least the third image and fourth image, wherein each point in the vector field is represented by a vector indicating a magnitude and a direction of movement from a first point in the third image to a corresponding second point in the fourth image;
determining a focus of expansion based on the vector field, the focus of expansion being a converging point of vectors in the vector field; and
determining a rate of expansion relative to the focus of expansion for each point in the vector field; and
determining the second estimated time-to-collision based on the rate of expansion and a time interval between times of acquisition of the third image and the fourth image.

21. A method for assessing an overall system failure rate associated with a braking decisioning system for a vehicle, comprising:

determining, using a processing device, a first failure rate associated with a textural analysis based sub-system, wherein the textural analysis based sub-system is configured to make a decision to brake based on a change in texture between at least two images of an area in front of a vehicle;
determining, using the processing device, a second failure rate associated with a structural analysis based sub-system, wherein the structural analysis based sub-system is configured to make a decision to brake based on optical flow information derived from at least two images of the area in front of the vehicle; and
determining, using the processing device, the overall system failure rate based on the first failure rate and the second failure rate.

22. The method of clause 21, wherein determining the overall system failure rate comprises multiplying the first failure rate with the second failure rate to generate the overall system failure rate.

Claims

1. A computer-implemented method for controlling a vehicle, the method comprising:

determining a first failure rate associated with a textural analysis, the textural analysis including a textural decision based on a change in texture between at least two images captured by at least one image capture device configured to monitor an environment of the vehicle, wherein determining the first failure rate is based on a total number of times the textural analysis yields a false braking decision;
determining a second failure rate associated with a structural analysis, the structural analysis including a structural decision based on optical flow information derived from at least two images captured by the at least one image capture device, wherein determining the second failure rate is based on a total number of times the structural analysis yields a false braking decision;
determining an overall system failure rate based on the first failure rate and the second failure rate; and
causing a braking system of the vehicle to brake based on the determined overall system failure rate.

2. The method of claim 1, wherein determining the overall system failure rate comprises multiplying the first failure rate and the second failure rate.

3. The method of claim 2, wherein multiplying the first failure rate and the second failure rate results in an indicator of an overall system mean-time-between-failures.

4. The method of any of claims 1 to 3, wherein deter-

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mining the first failure rate comprises determining the first failure rate based on a total number of times the textural analysis makes a false braking decision among a total number of system-running hours.

5. The method of any of claims 1 to 3, wherein determining the second failure rate comprises determining the second failure rate based on a total number of times the structural analysis makes a false braking decision among a total number of system-running hours.

6. The method of any of claims 1 to 5, wherein determining the first failure rate comprises performing, with the textural analysis, a pattern recognition over pixel intensities in the at least two images.

7. The method of claim 6, wherein performing the pattern recognition comprises estimating a change of a footprint size by comparing image data of the at least two images.

8. The method of claim 7, wherein the footprint size comprises a dimension length of a feature of an object in the at least two images.

9. The method of any of claims 1 to 8, wherein determining the second failure rate comprises processing the at least two images with the structural analysis to obtain an optical flow field.

10. The method of any of claims 1 to 9, wherein the optical flow information provides information regarding a movement of trackable textures between the at least two images.

11. The method of any of claims 1 to 10, wherein the at least two images used in determining the second failure rate are the same as the at least two images used in determining the first failure rate.

12. The method of any of claims 1 to 11, wherein determining the second failure rate is performed after determining the first failure rate.

13. A vehicle control system comprising:

at least one image capture device configured to capture a plurality of images of an environment of a vehicle; and
at least one processing device configured to perform the method of any of claims 1 to 12 using the captured plurality of images.

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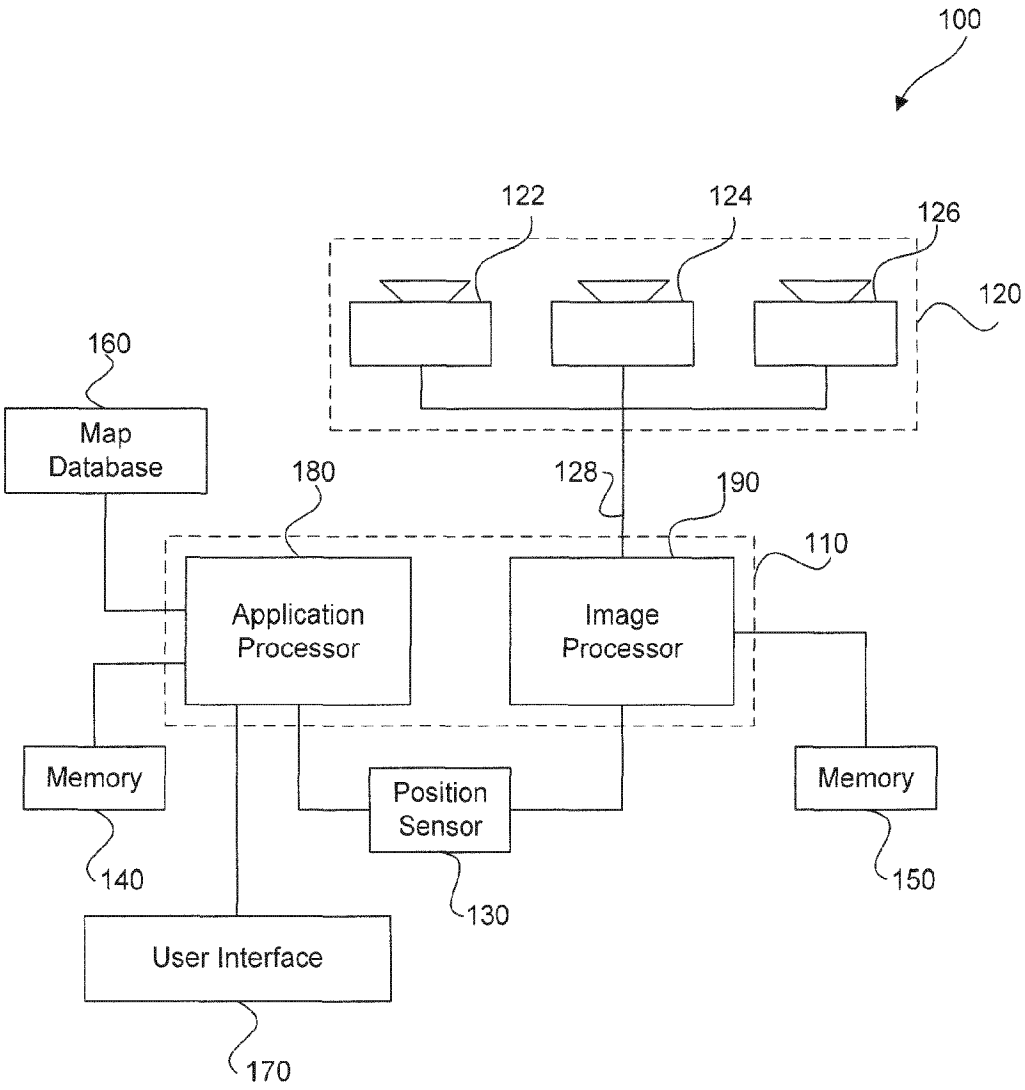


FIG. 1

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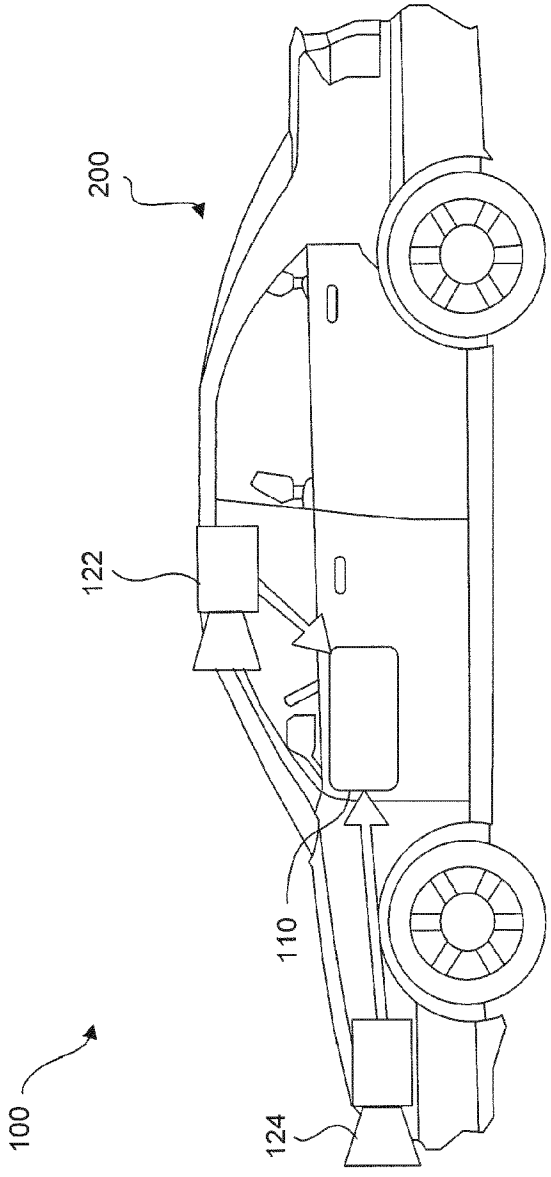


FIG. 2A

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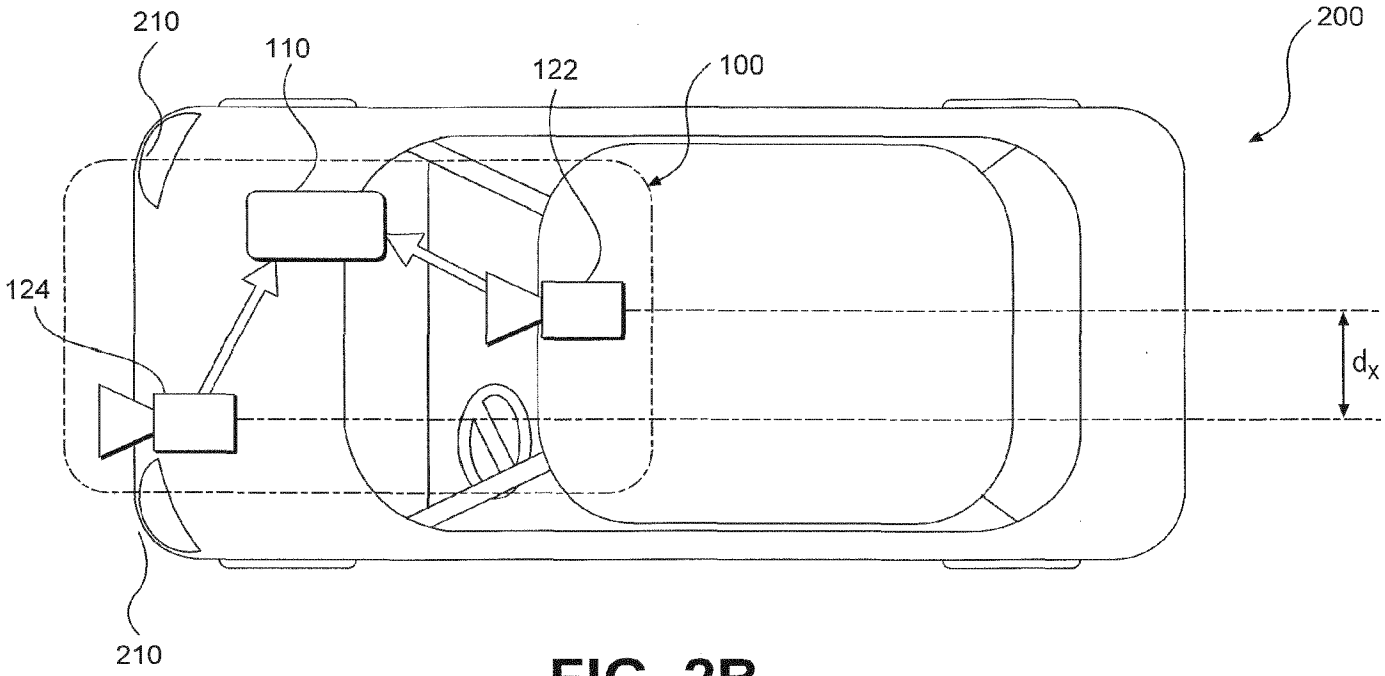


FIG. 2B

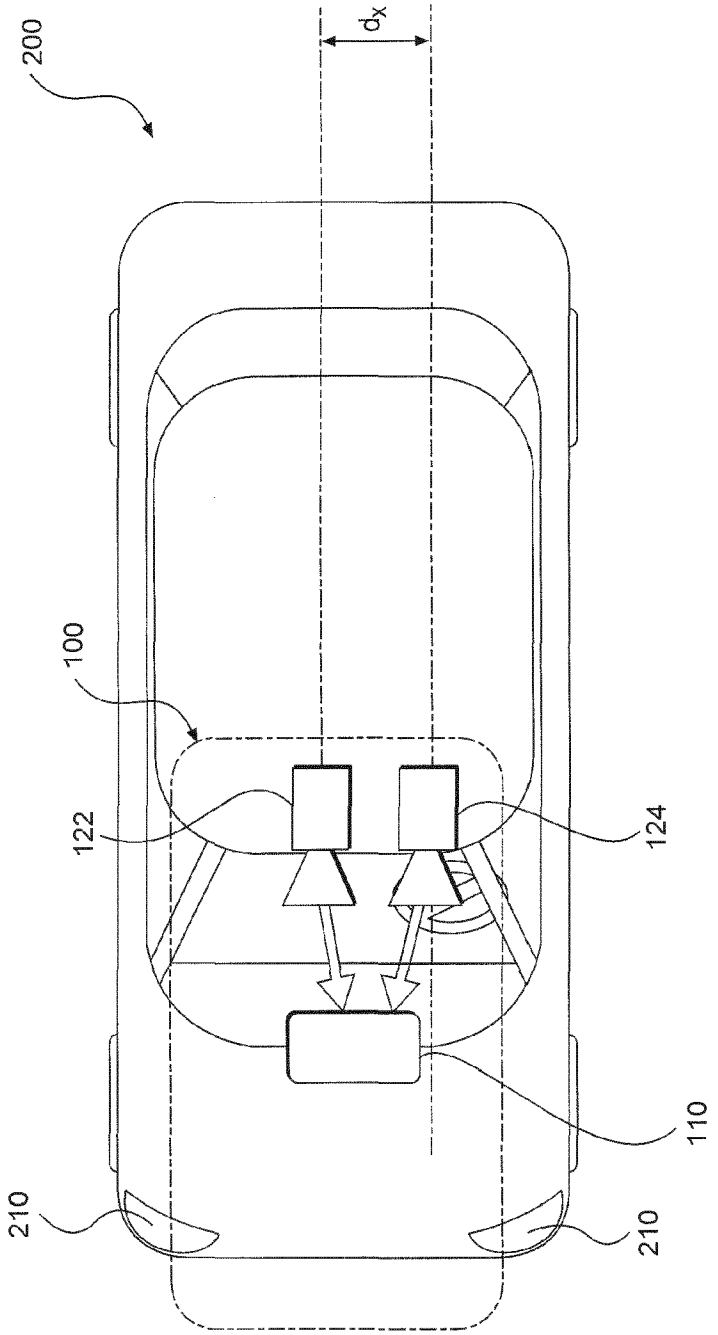


FIG. 2C

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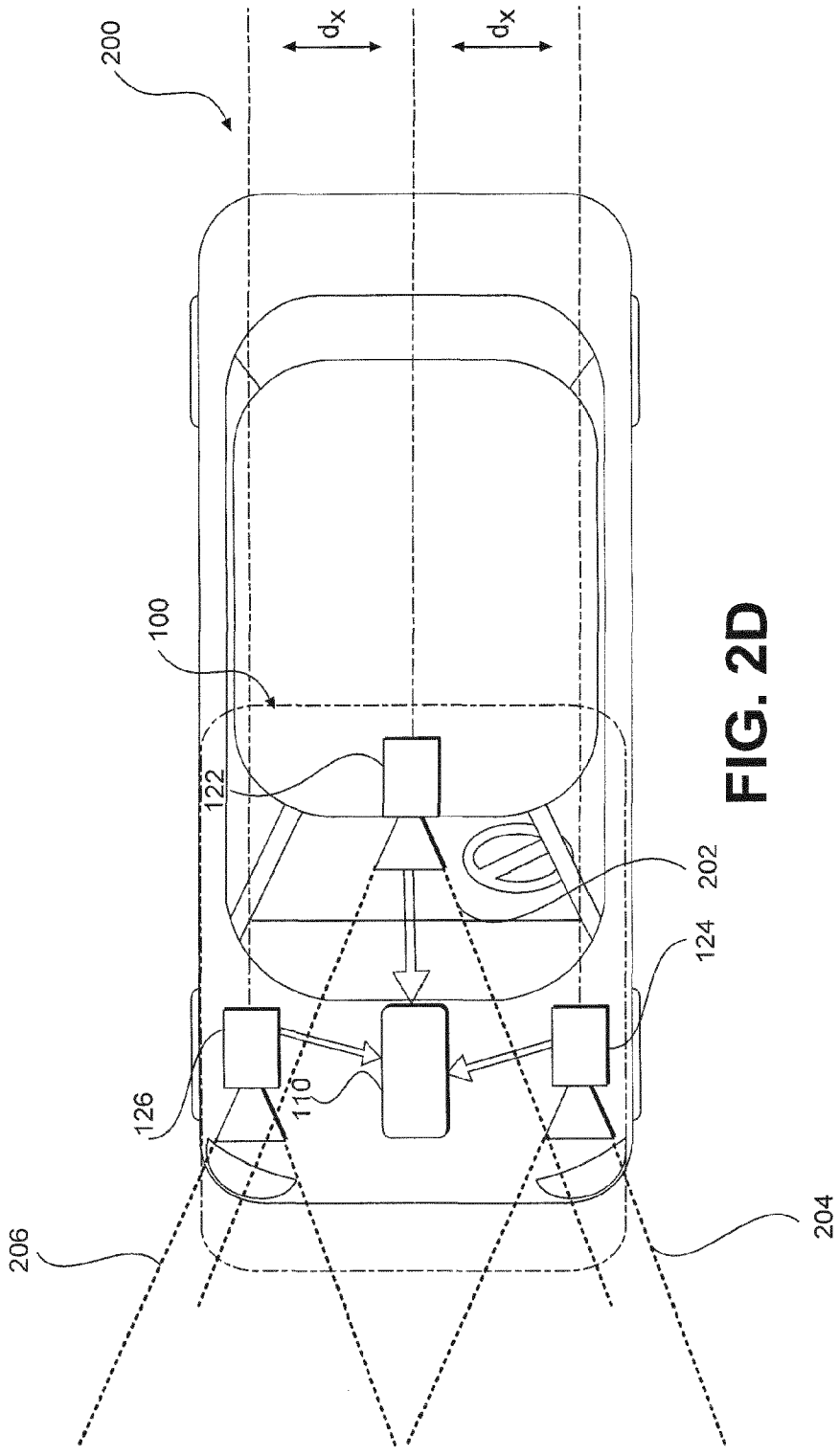


FIG. 2D

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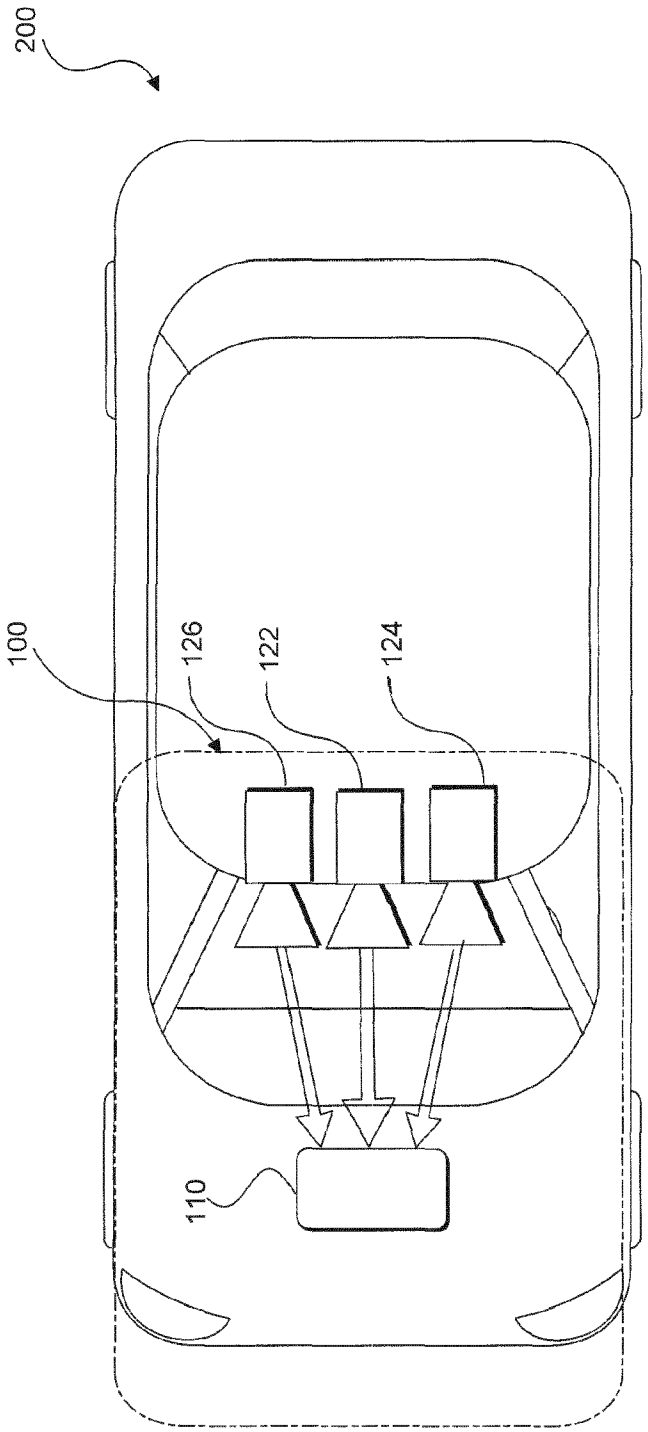


FIG. 2E

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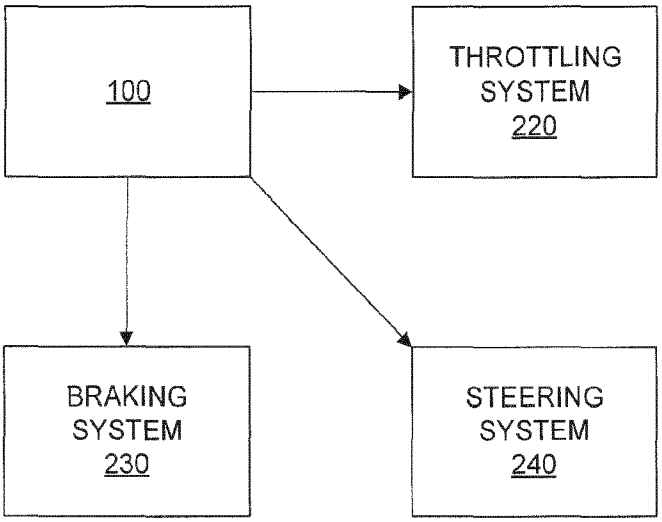


FIG. 2F

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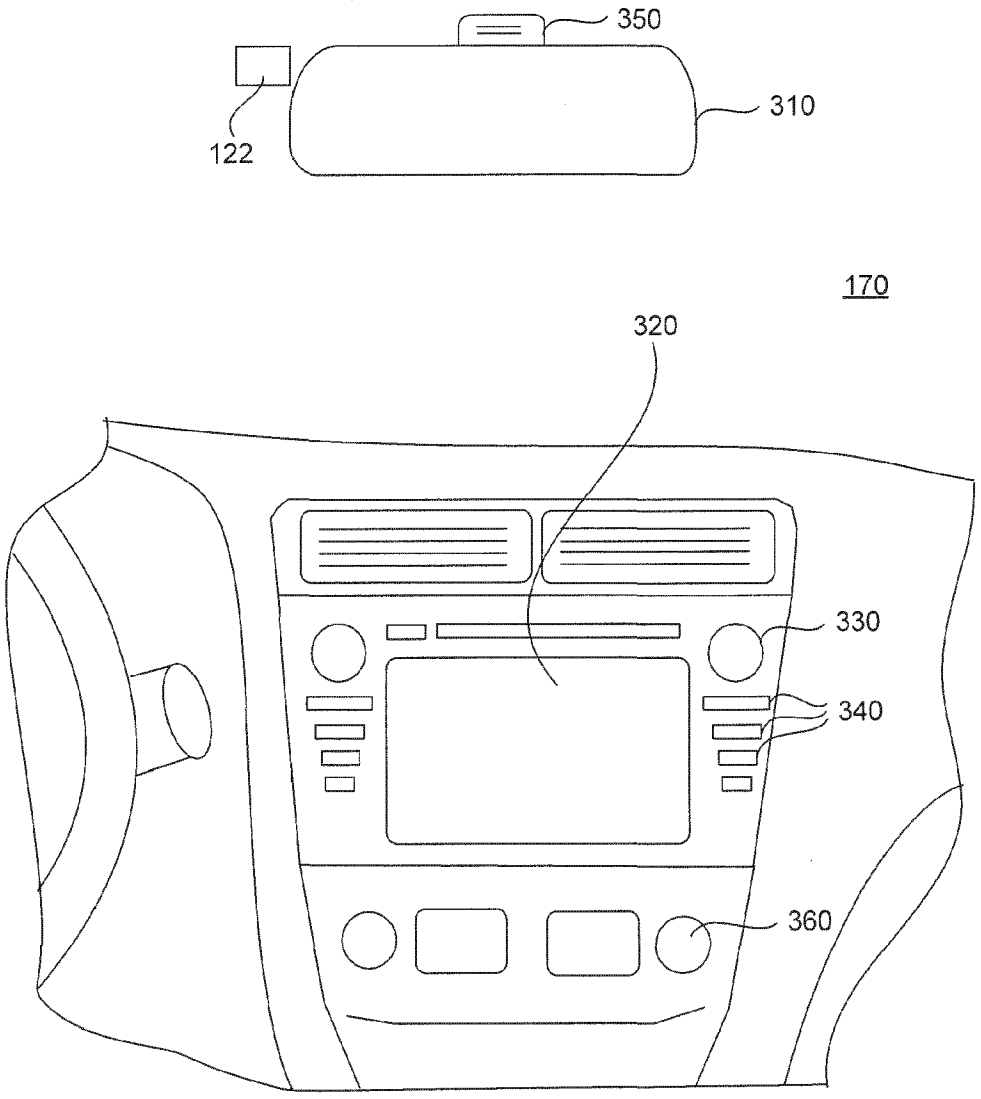


FIG. 3A

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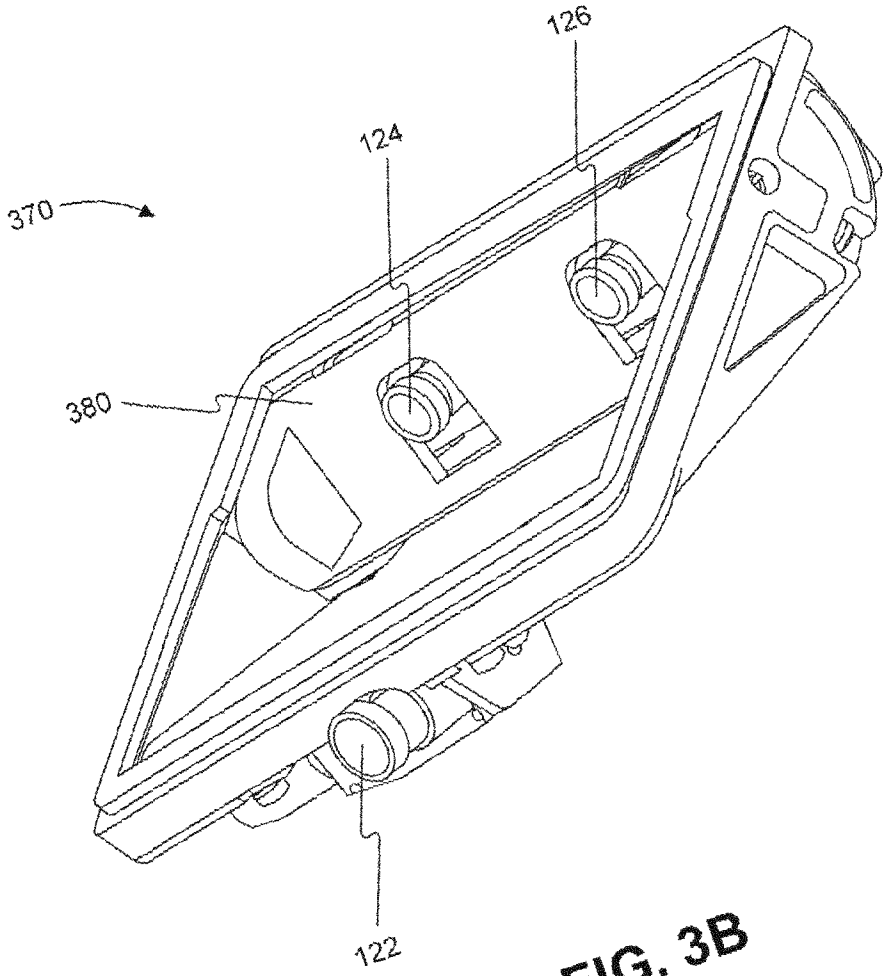


FIG. 3B

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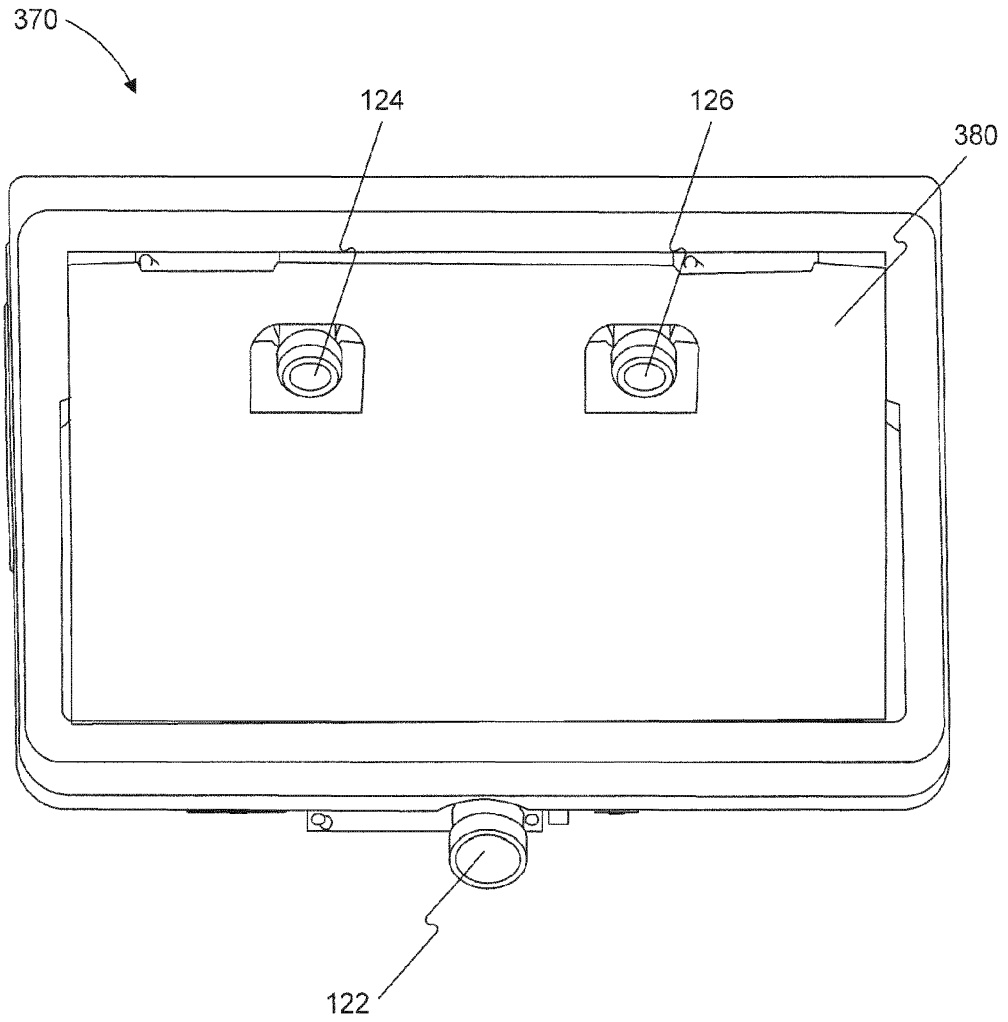


FIG. 3C

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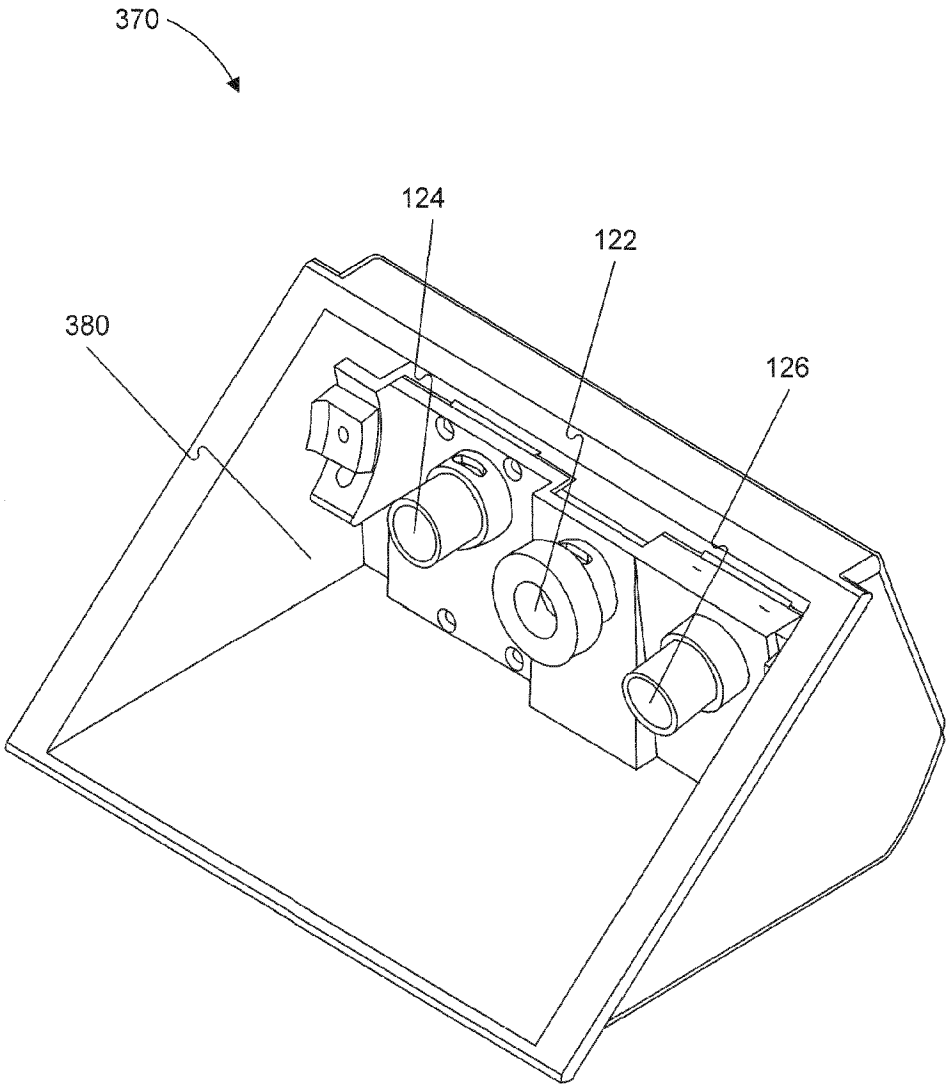


FIG. 3D

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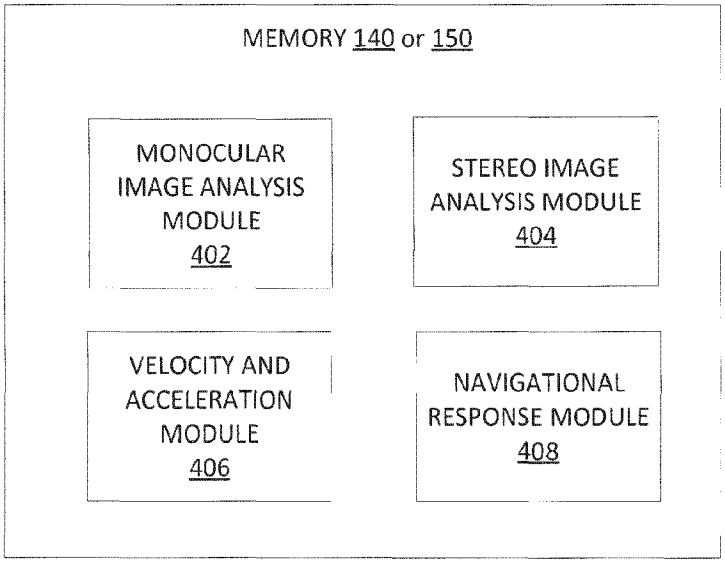


FIG. 4

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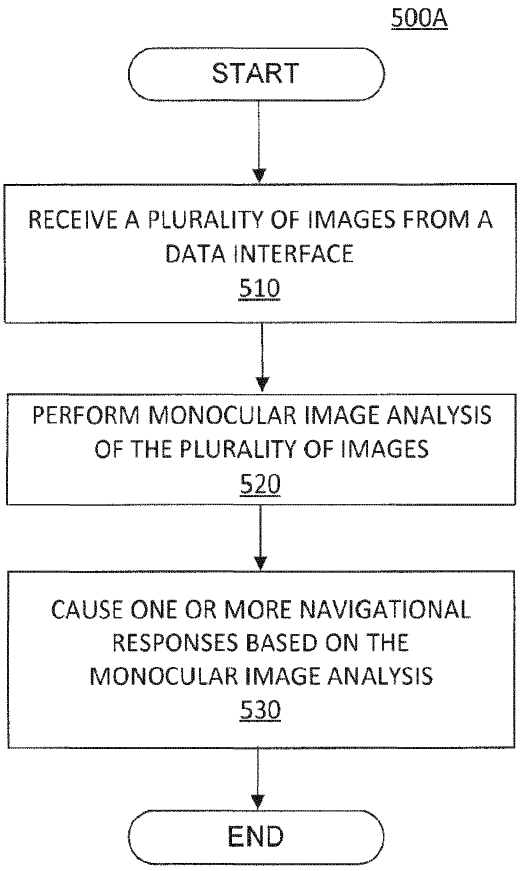


FIG. 5A

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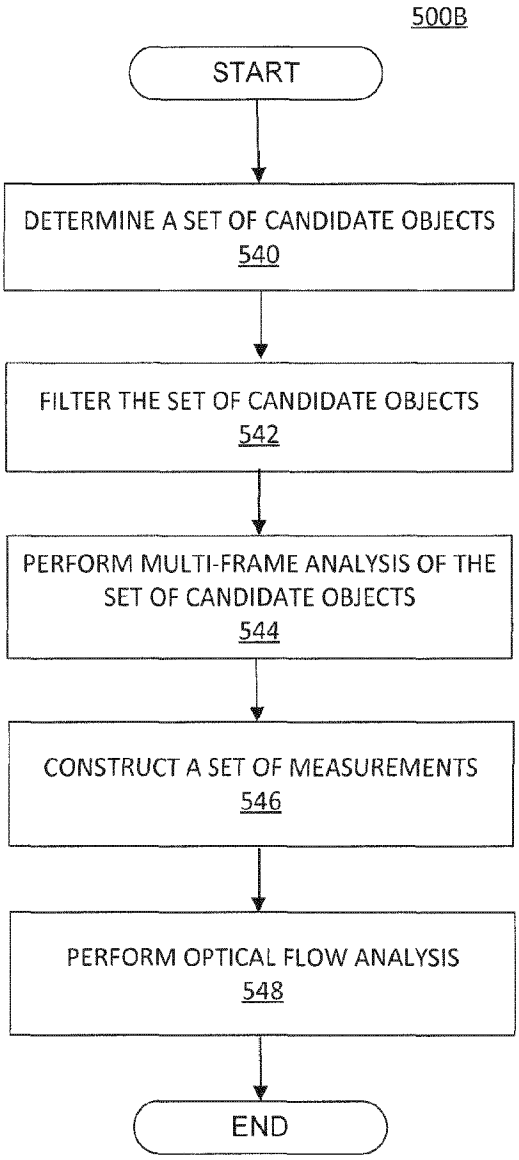


FIG. 5B

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Tesla EX1002 Page 3188

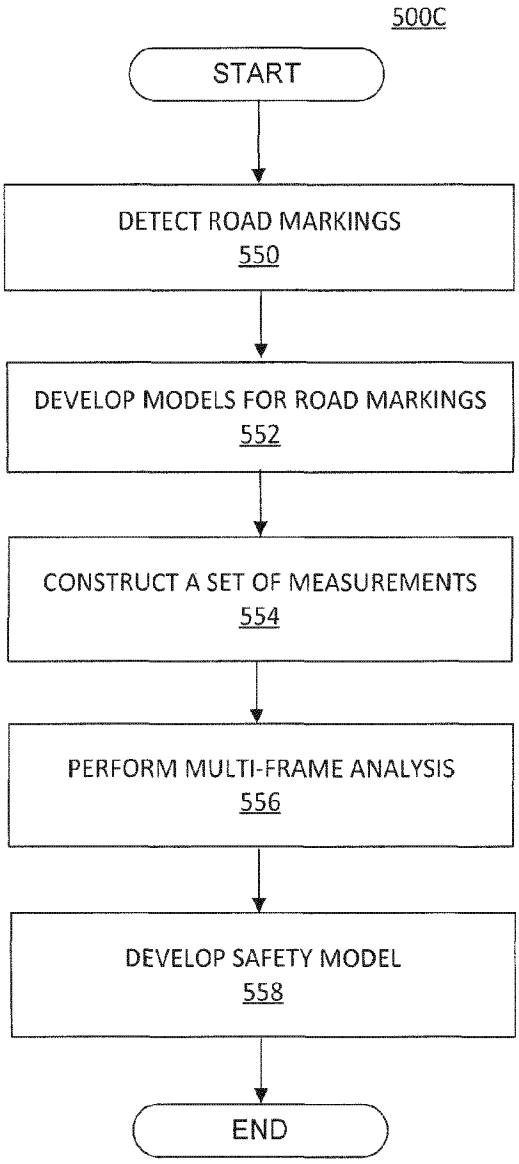


FIG. 5C

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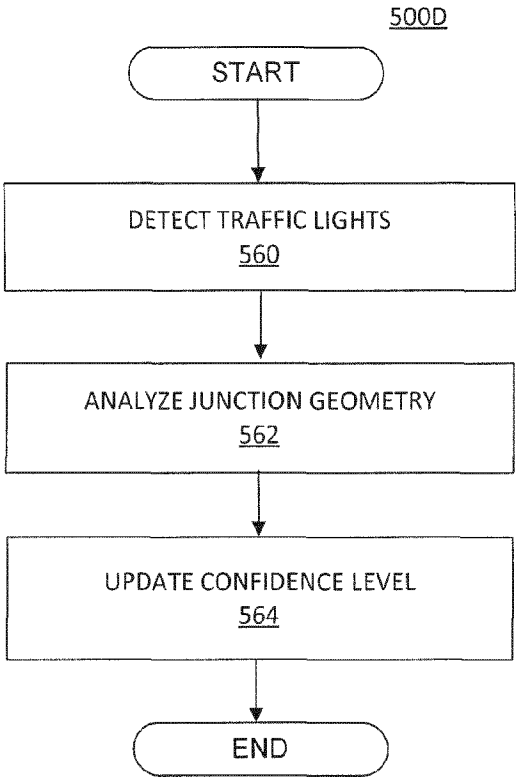


FIG. 5D

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Tesla EX1002 Page 3190

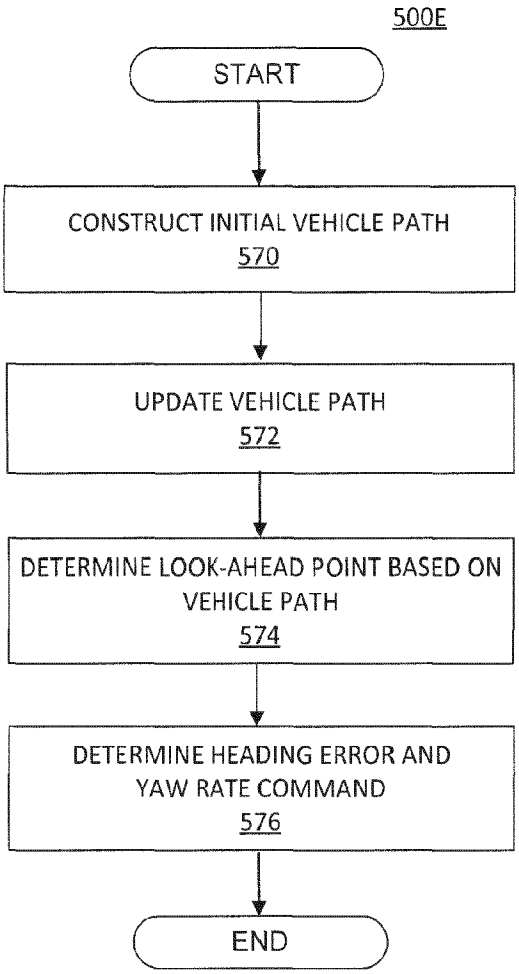


FIG. 5E

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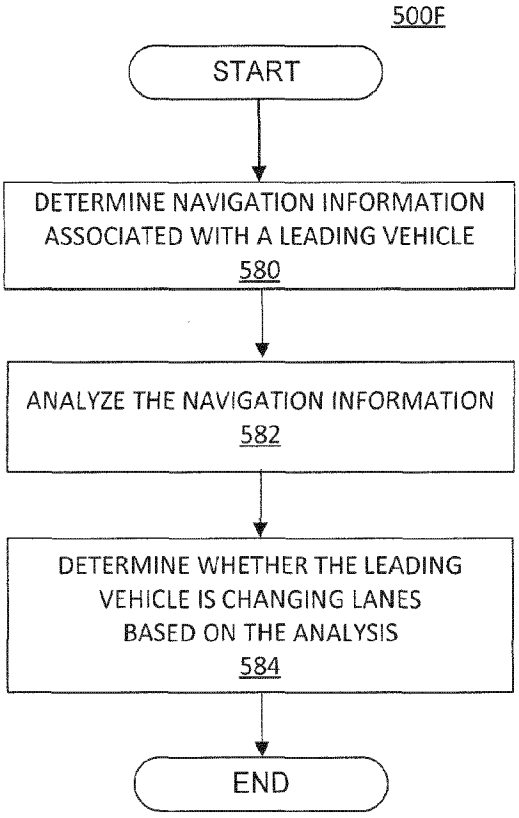


FIG. 5F

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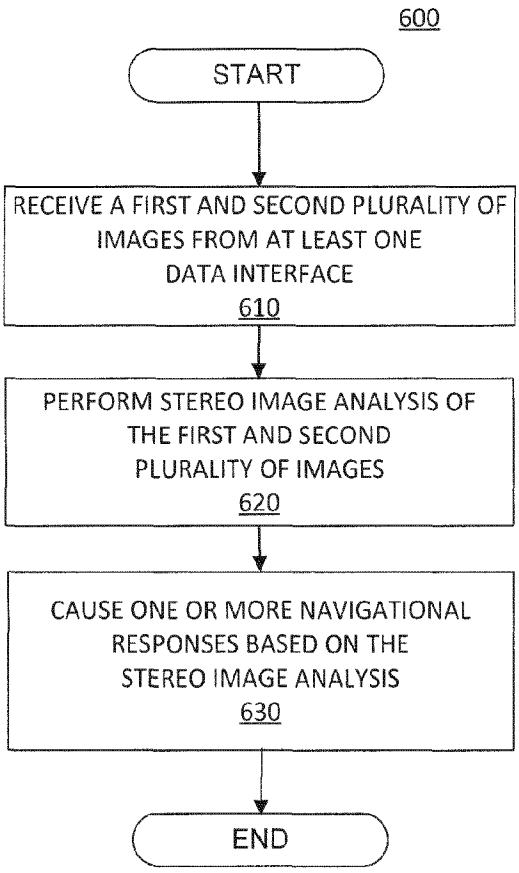


FIG. 6

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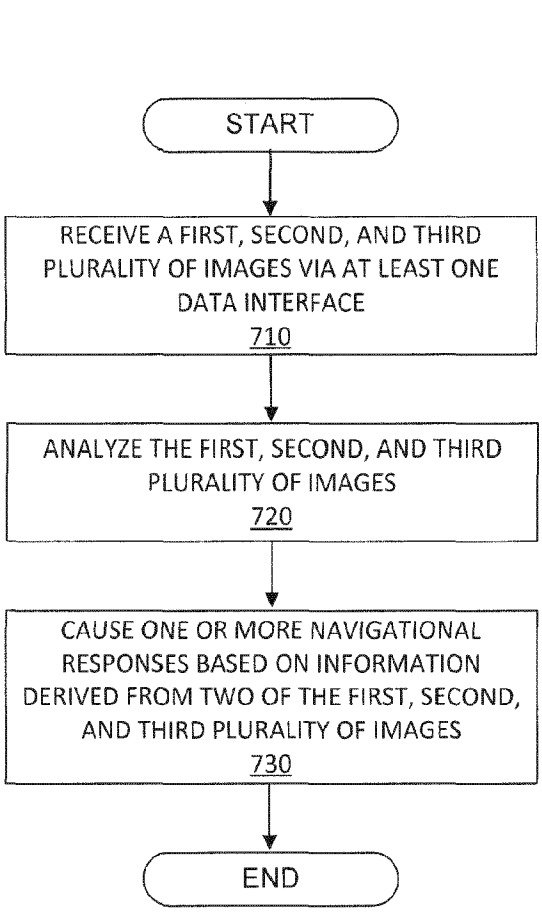


FIG. 7

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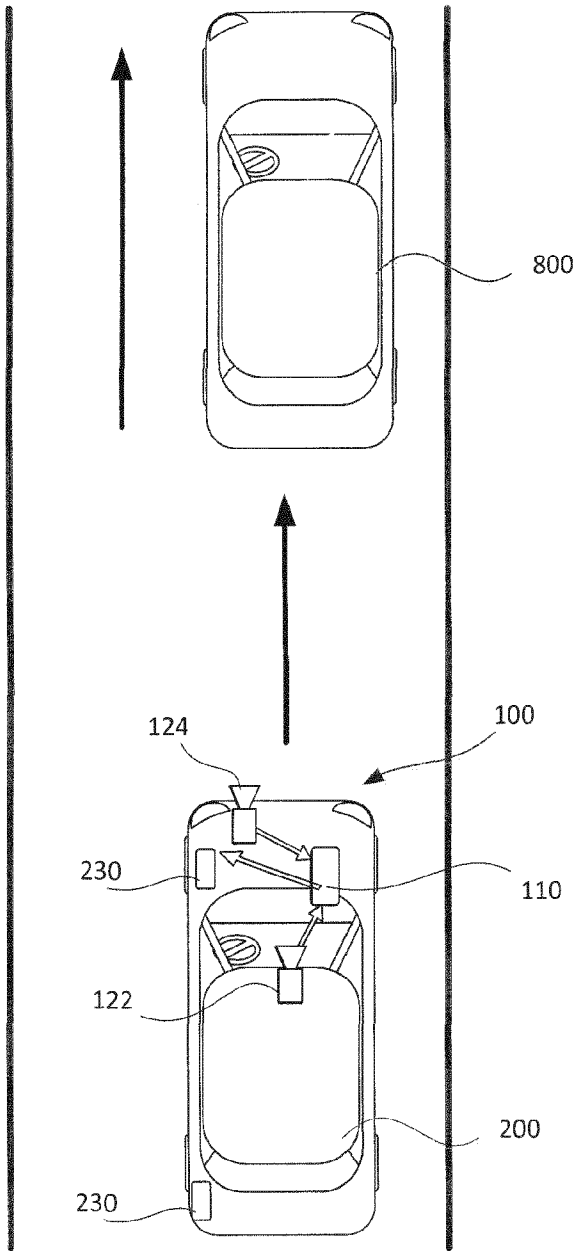


FIG. 8

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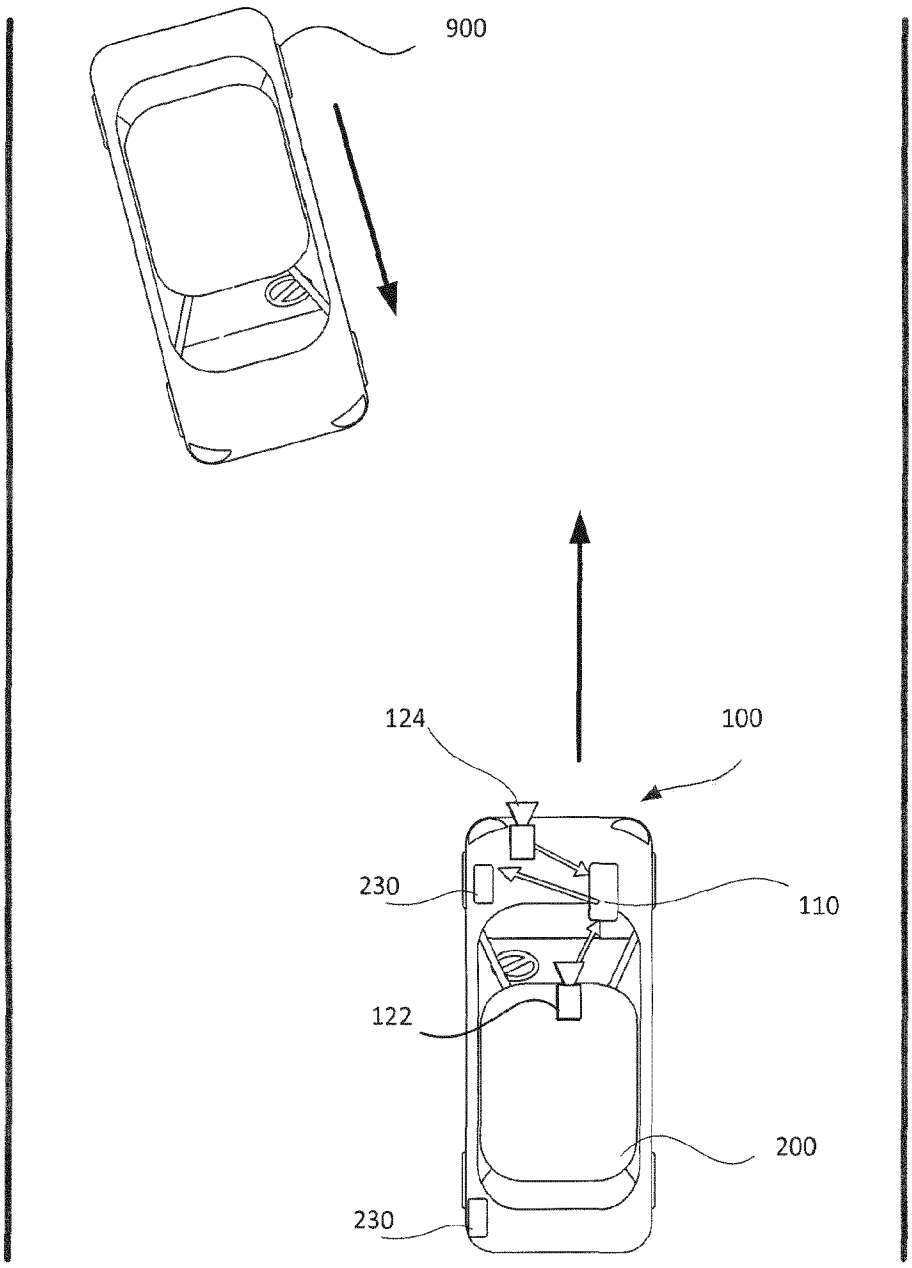


FIG. 9

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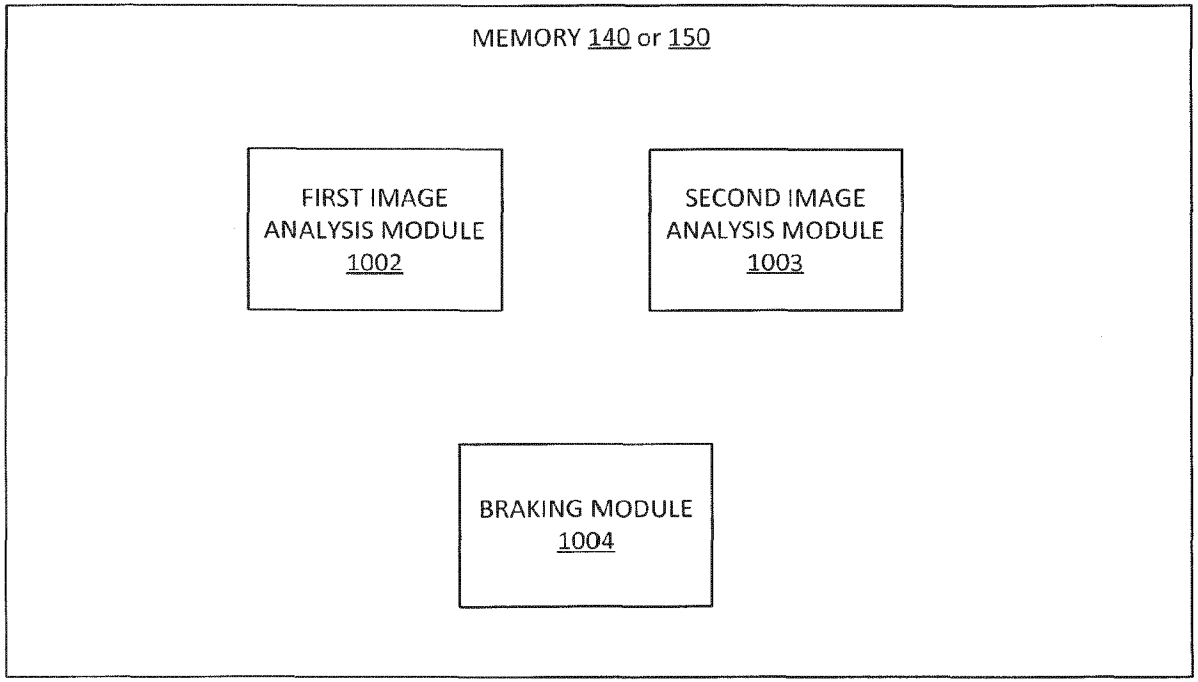


FIG. 10

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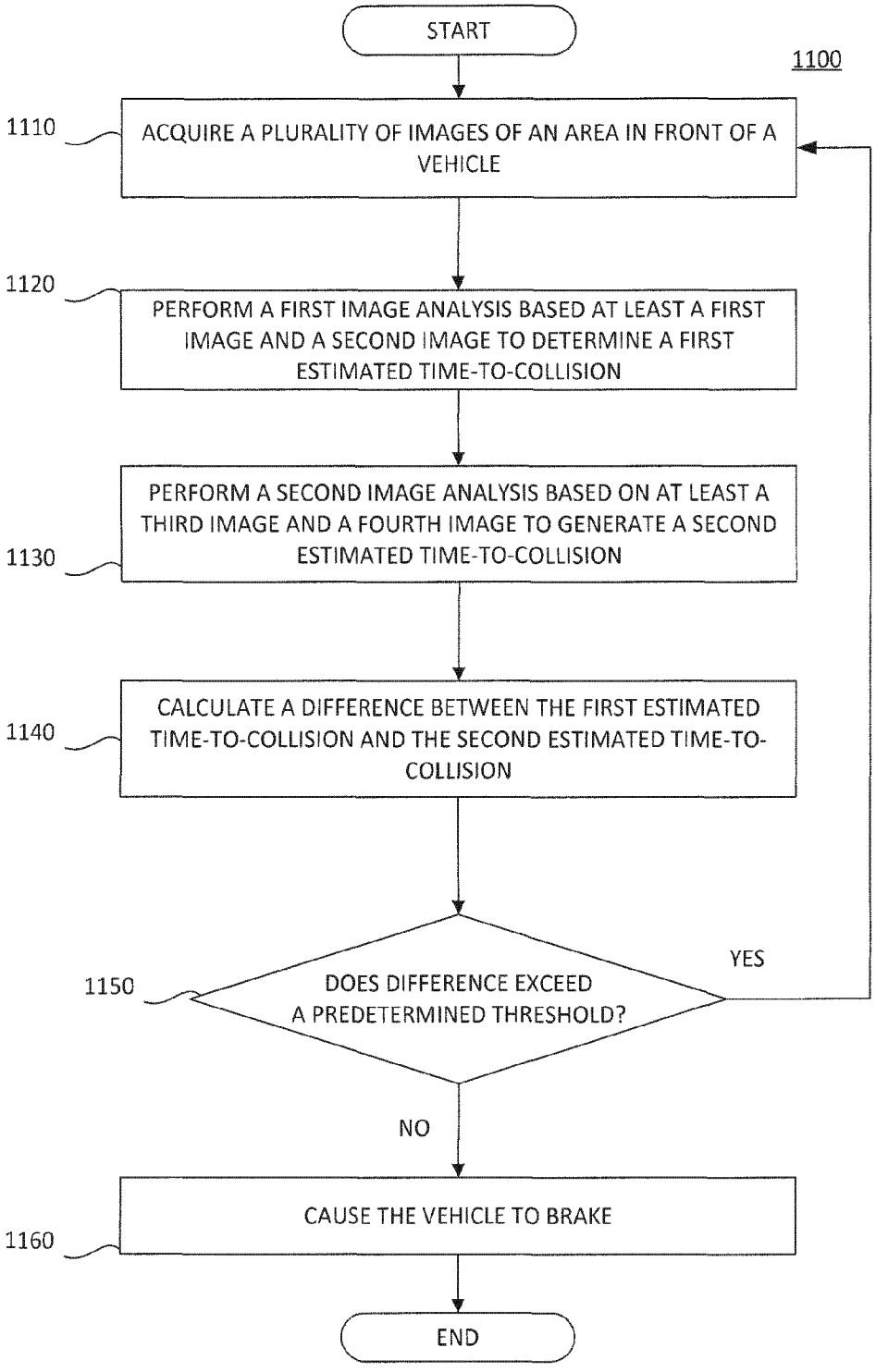


FIG. 11

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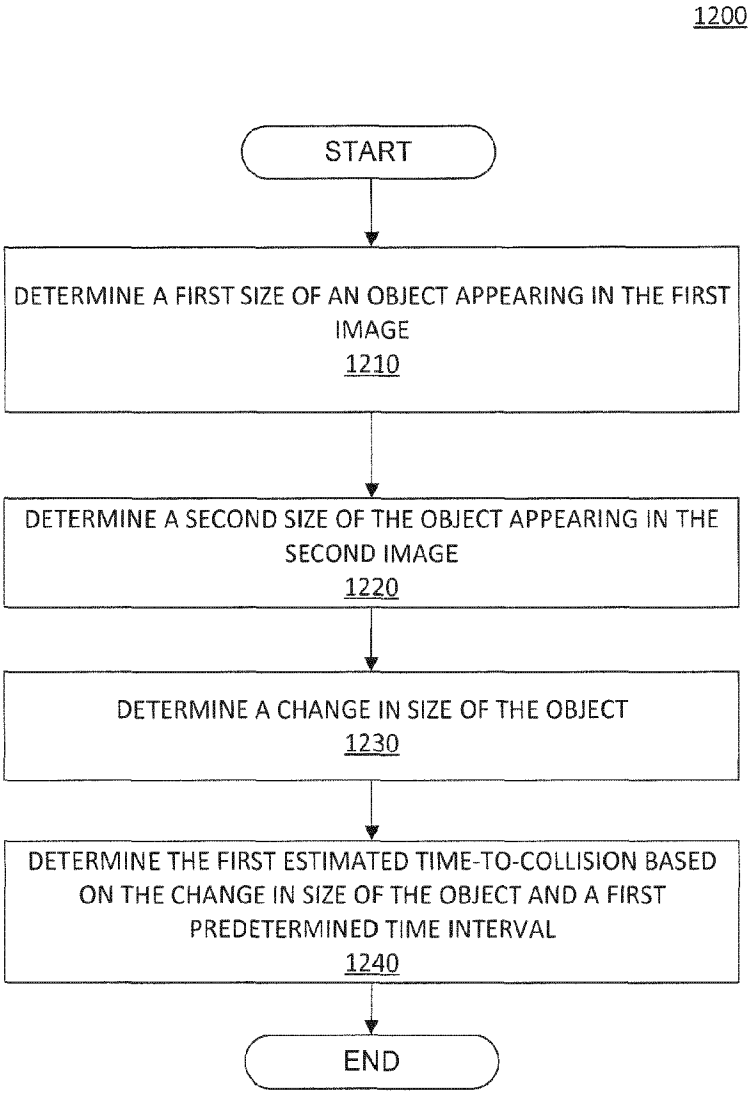


FIG. 12

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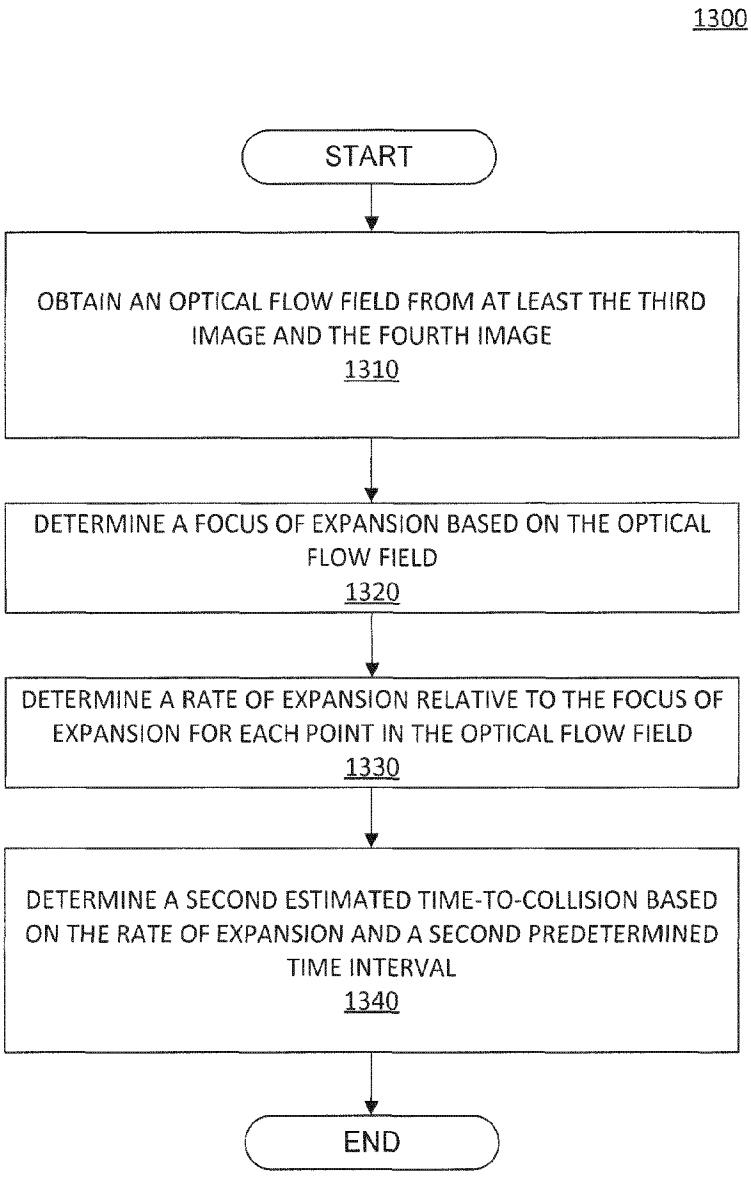


FIG. 13

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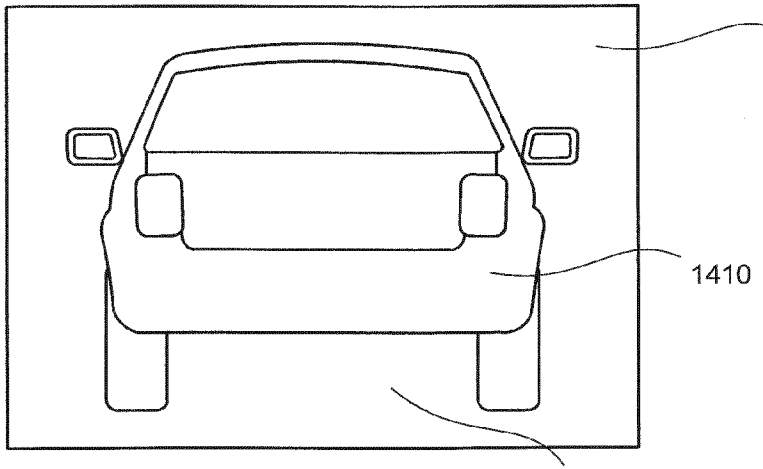


FIG. 14A

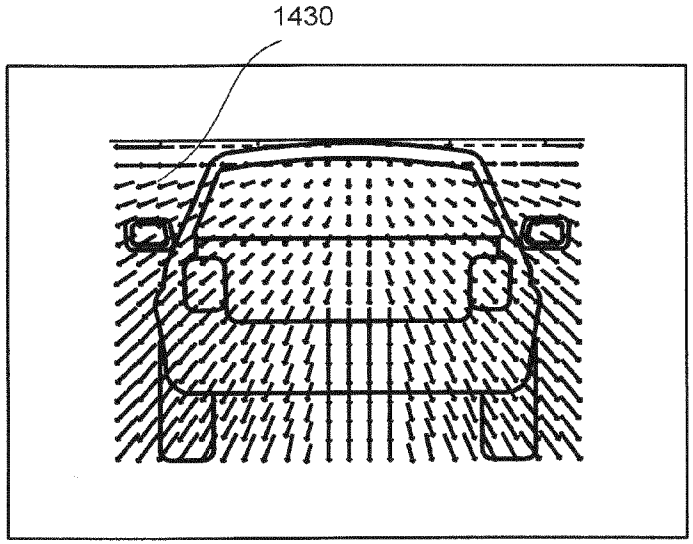


FIG. 14B

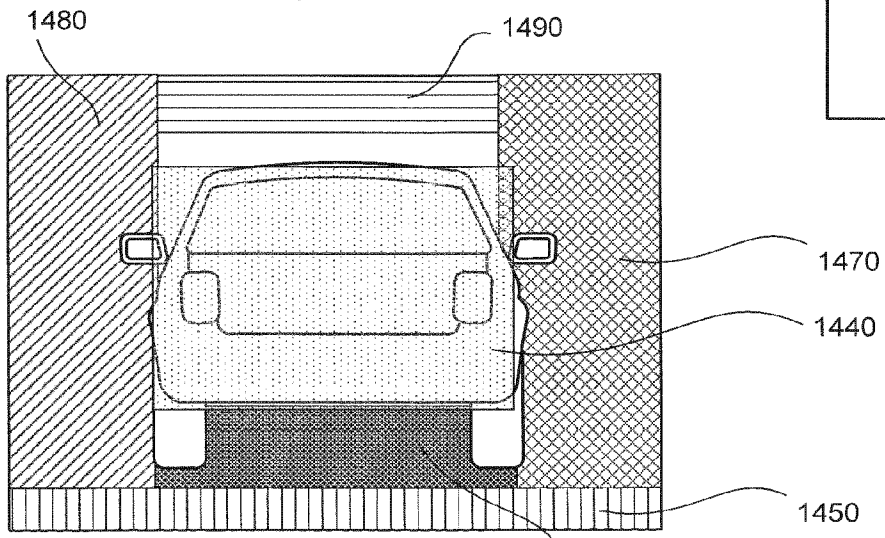


FIG. 14C

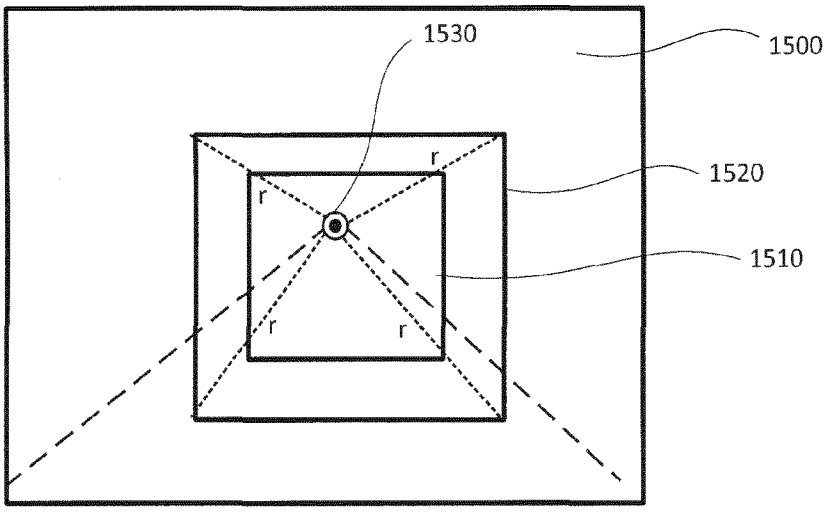


FIG. 15A

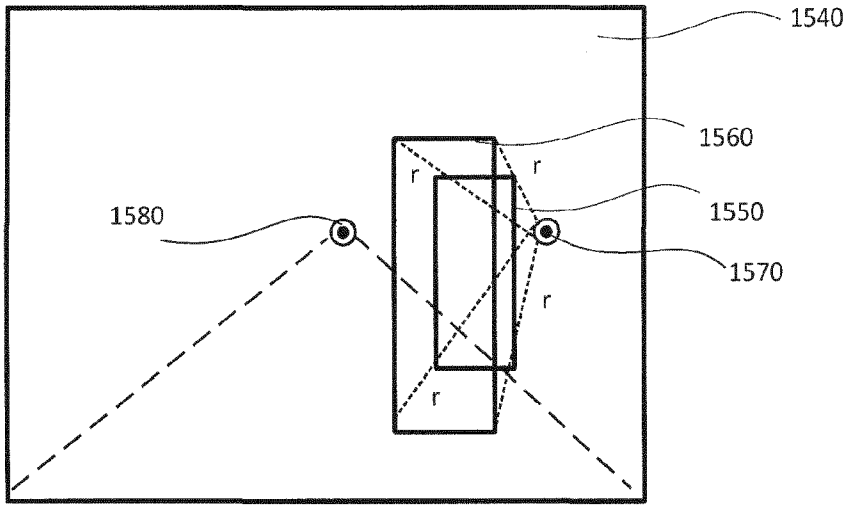


FIG. 15B

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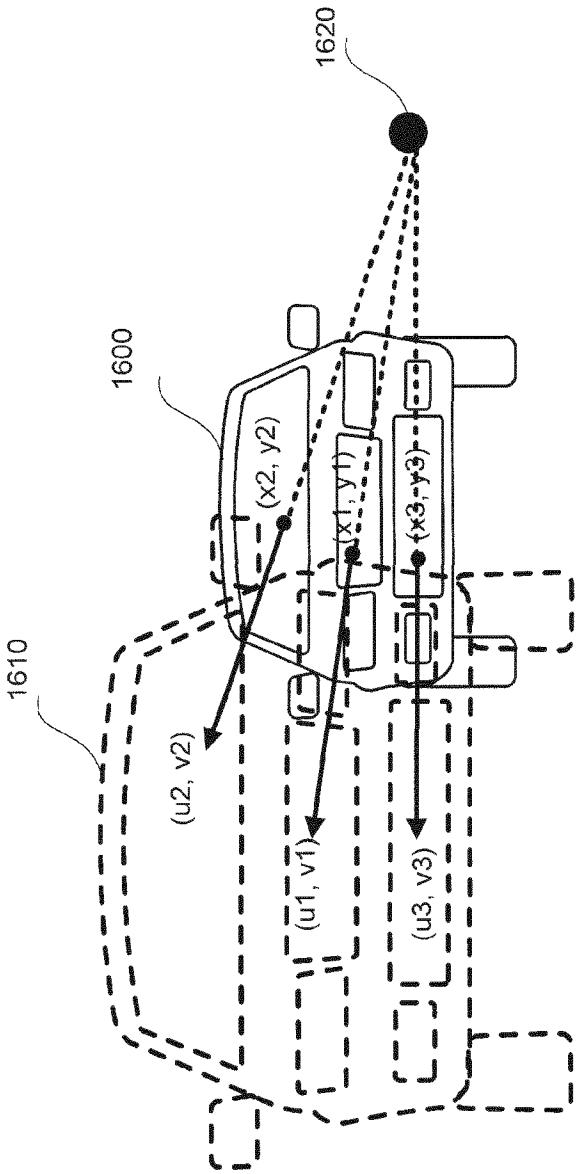


FIG. 16

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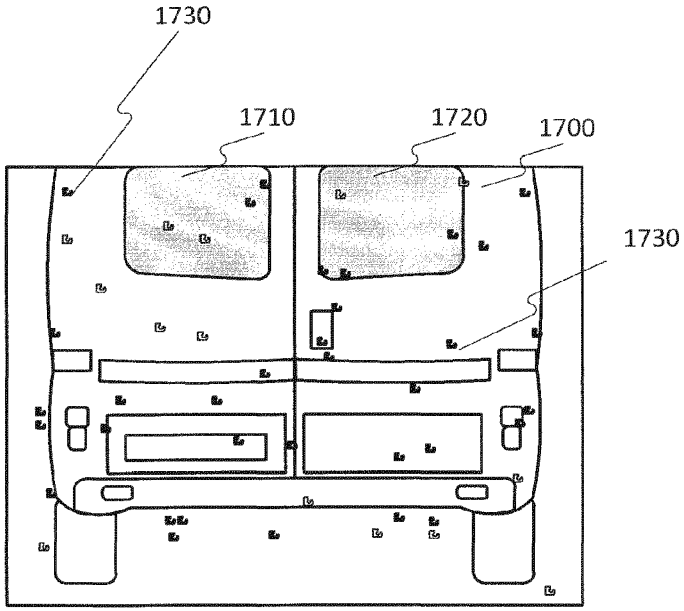


FIG. 17A

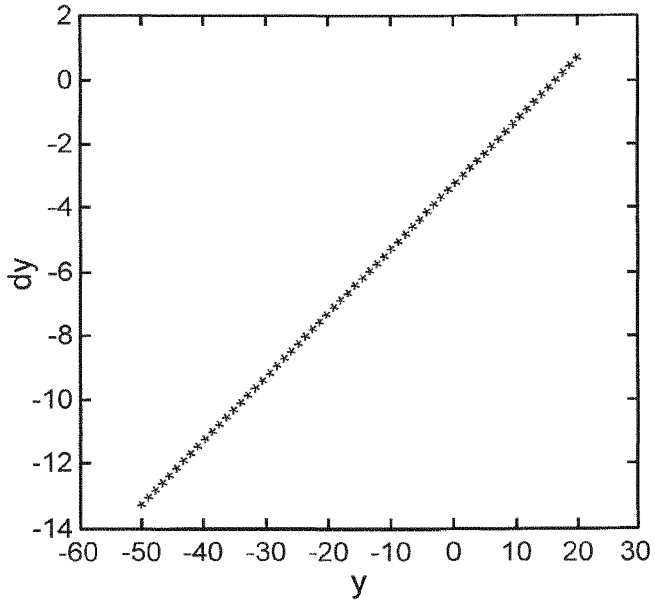


FIG. 17B

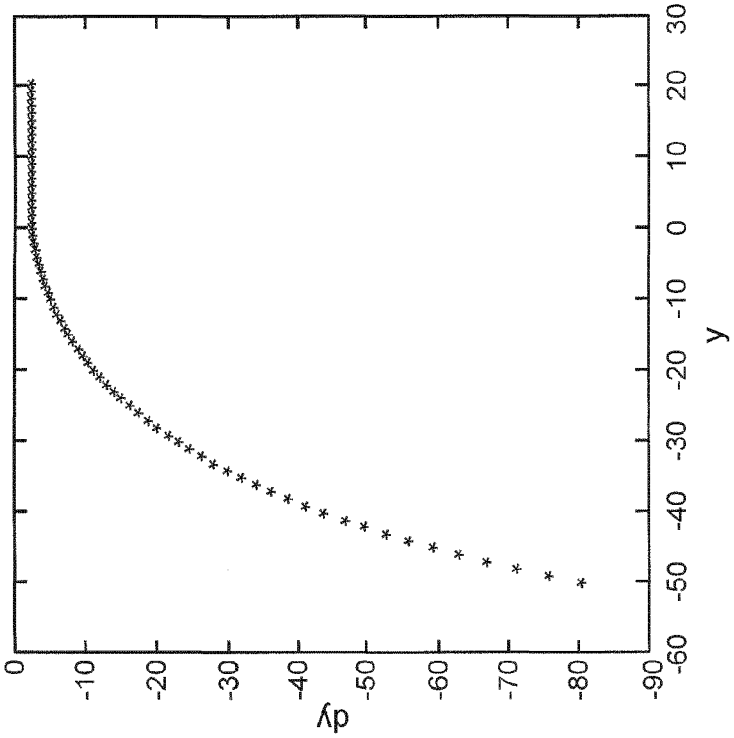


FIG. 18B

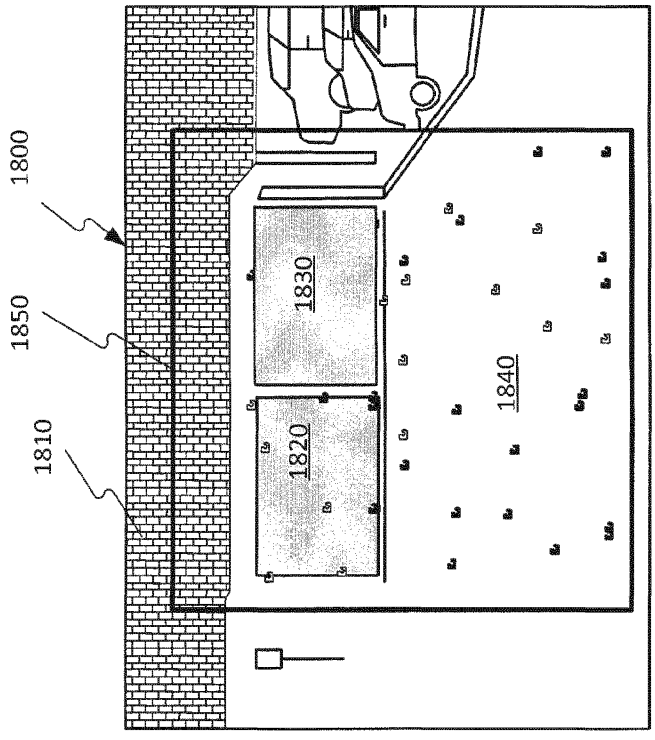


FIG. 18A

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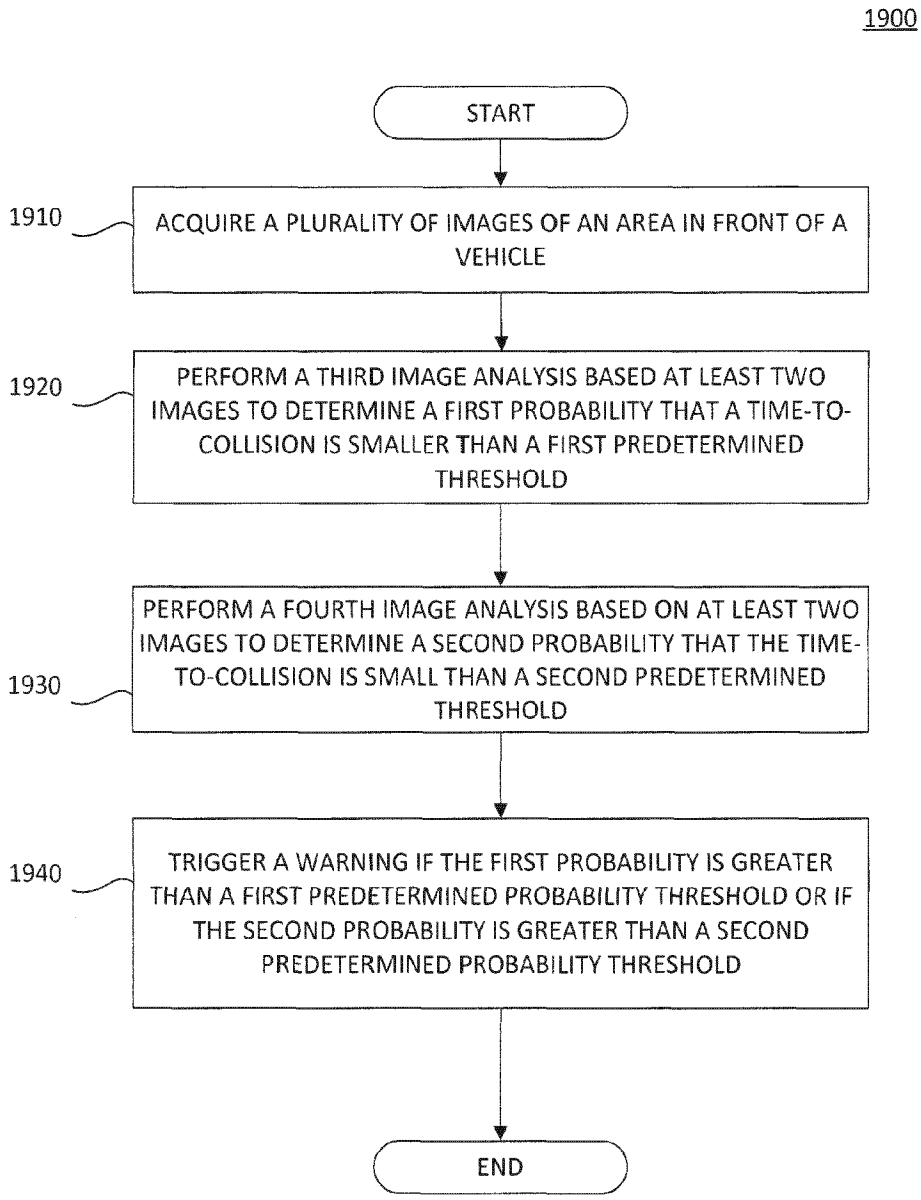


FIG. 19

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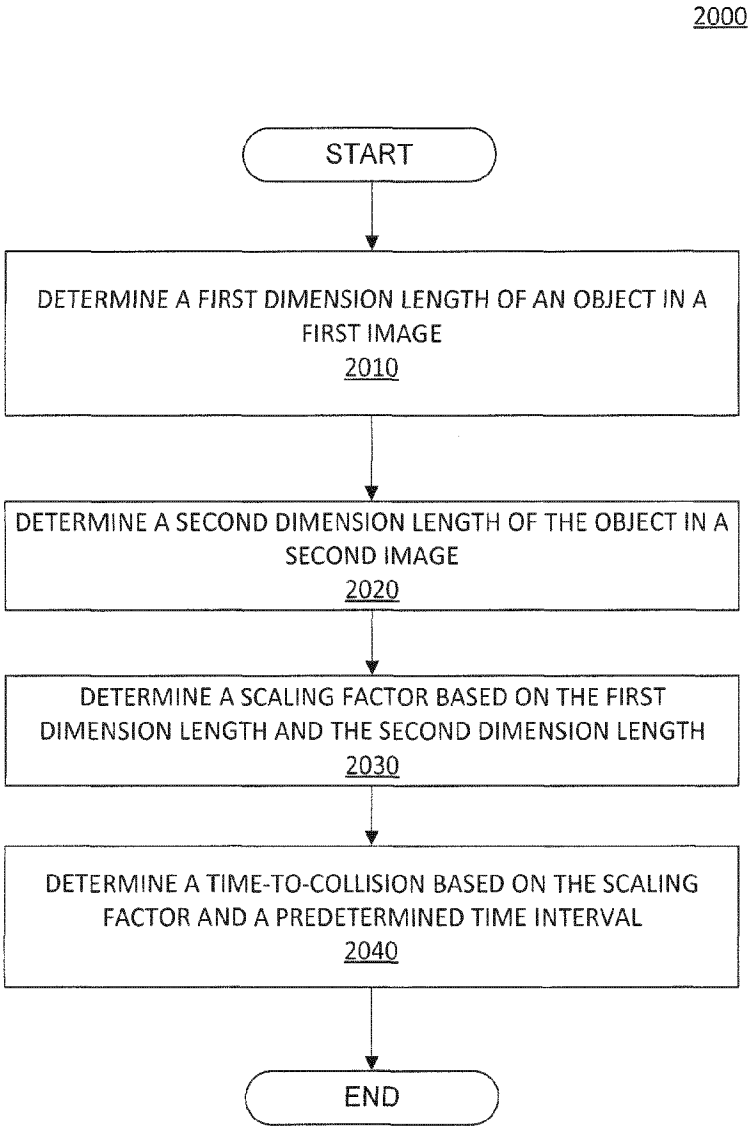


FIG. 20

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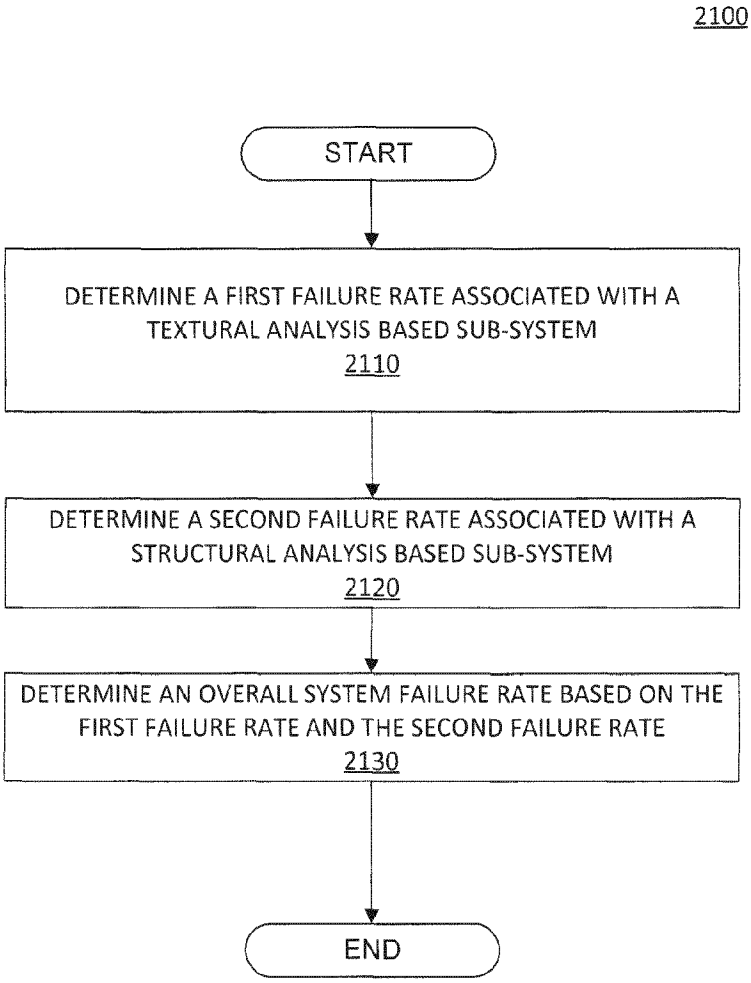


FIG. 21

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Europäisches Patentamt
European Patent Office
Office européen des brevets

EUROPEAN SEARCH REPORT

Application Number
EP 19 21 3374

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
Y	US 2012/314071 A1 (ROSENBAUM DAN [IL] ET AL) 13 December 2012 (2012-12-13) * the whole document * -----	1-13	INV. G06T7/20 G06K9/00
Y	Kyung-Ho Shin ET AL: "A study on the reliability improvement for applying GNSS to railroad system", 8th World Congress on Railway Research, May 18-22, 2008, 18 May 2008 (2008-05-18), pages 1-7, XP055227717, Seoul, Korea Retrieved from the Internet: URL:https://web.archive.org/web/20101125041611/http://www.uic.org/cdrom/2008/11_wcrr2008/pdf/0.1.4.5.3.pdf [retrieved on 2015-11-11] * abstract * * section 5 * -----	1-13	
A	Instruments Group Mtl: "Availability, Reliability, SIL - What's the difference?", , 10 July 2012 (2012-07-10), pages 1-4, XP055660584, Retrieved from the Internet: URL:https://web.archive.org/web/20120710031115/http://www.mtl-inst.com/images/uploads/datasheets/App_Notes/AN9030.pdf [retrieved on 2020-01-22] * the whole document * -----	1-13	TECHNICAL FIELDS SEARCHED (IPC) G06T G06K
A	US 2006/178830 A1 (SHERONY RINI [US]) 10 August 2006 (2006-08-10) * abstract * * page 2 - page 3 * ----- -/--	1-13	

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
Munich	23 January 2020	Katartzis, Antonios

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

EPO FORM 1503 03.82 (P04C01)

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Europäisches Patentamt
European Patent Office
Office européen des brevets

EUROPEAN SEARCH REPORT

Application Number
EP 19 21 3374

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
Y	US 5 559 695 A (DAILY MICHAEL J [US]) 24 September 1996 (1996-09-24) * abstract * * column 6 - column 14 *	1-13	
A	WO 2013/107525 A1 (SICK IVP AB [SE]; FORCHHEIMER ROBERT [SE]; AASTROEM ANDERS [SE]) 25 July 2013 (2013-07-25) * the whole document *	1-13	

TECHNICAL FIELDS SEARCHED (IPC)

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
Munich	23 January 2020	Katartzis, Antonios

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

EPO FORM 1503 03.82 (P04C01)

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ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 19 21 3374

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

23-01-2020

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EPO FORM P0459

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

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REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

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(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

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International Bureau

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1 May 2014 (01.05.2014)

WIPO | PCT

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B01F 13/10 (2006.01) *B01F 15/00* (2006.01)

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(22) International Filing Date:
25 October 2013 (25.10.2013)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
61/719,126 26 October 2012 (26.10.2012) US

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(72) Inventors: **BARTHOLOMEW, Julie, R.**; 823 Smith Avenue, Birmingham, MI 48009 (US). **SCHENA, Michael**; 1148 Clear Creek Drive, Rochester Hills, MI 48306 (US).

(74) Agents: **PURSLEY, Kristen L.** et al.; The Dobrusin Law Firm, P.C., 29 W. Lawrence Street, Suite 210, Pontiac, MI 48342 (US).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

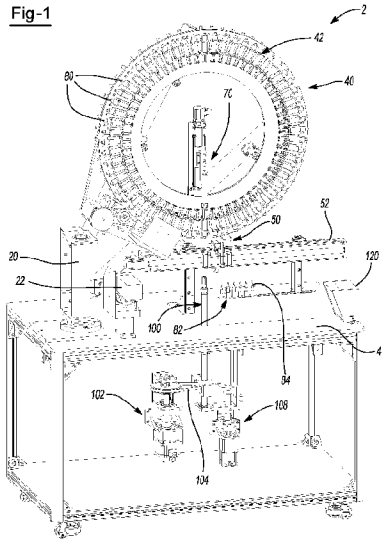
— *with international search report (Art. 21(3))*

— *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))*

(88) Date of publication of the international search report:
26 June 2014

(54) Title: A CUSTOMIZED DISPENSING DEVICE DELIVERY SYSTEM AND METHOD

Fig-1



(57) Abstract: A device for producing a customized formulation comprising: a customized dispending device 2 comprising: (a) a computer; (b) at least one robot arm 50; (c) a housing having at least one transparent panel; (d) at least one robot arm slide 52 that the at least one robot arm is connected to for sliding along the inside of the housing; (e) a rotary wheel 40; (f) a plurality of ingredient containers 80 connected to the rotary wheel; and (g) a package for ingredients to be dispensed into 82; wherein a radio frequency identification device (RFID) is included in the package, on a label of the package, on the packaging for the package, or a combination thereof, wherein the package may be tracked during shipping, signal to a user when the package is delivered, connect to social media to post a message regarding the package, or a combination thereof.

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INTERNATIONAL SEARCH REPORT

International application No
PCT/US2013/066744

A. CLASSIFICATION OF SUBJECT MATTER
INV. B01F13/10 B01F15/00
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
B01F G06Q

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 8 186 872 B2 (BARTHOLOMEW JULIE R [US] ET AL) 29 May 2012 (2012-05-29) cited in the application	8,10,12, 16,17
Y	figure 1 column 1, line 61 - line 63 column 2, line 64 - column 3, line 5 column 3, line 22 - line 28 column 8, line 67 - column 9, line 4 column 22, line 31 - column 23, line 54 column 24, line 30 - line 35	1-7,9
Y	US 2010/148931 A1 (PAPPU RAVIKANTH SRINIVASA [US] ET AL) 17 June 2010 (2010-06-17) paragraph [0002]	1-7,9

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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" doument member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
23 January 2014	06/05/2014

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Krasenbrink, B

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Form PCT/ISA/210 (second sheet) (April 2005)

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2013/066744

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

1-10, 12, 17(completely); 16(partially)

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

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C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	DE 10 2009 040514 A1 (HORNBACH BAUMARKT AG [DE]) 3 March 2011 (2011-03-03) abstract figure 1 pages 22-25, 6	1-10,12, 16,17
X	US 2003/060925 A1 (BARTHOLOMEW JULIE R [US] ET AL) 27 March 2003 (2003-03-27)	8,10,12, 17
Y	figure 1	1-7,9
A	abstract paragraph [0105] - paragraph [0107]	16
A	EP 1 431 890 A1 (VP CREATIVITY LAB LTD [CN]) 23 June 2004 (2004-06-23) abstract figures 1-7 paragraph [0052] - paragraph [0054] claims 12,13,15	1-10,12, 16,17

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2013/066744

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 8186872 B2	29-05-2012	CA 2587098 A1	18-05-2006
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FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-10, 12, 17(completely); 16(partially)

   customized dispensing device and method comprising a RFID included in the package, on a label of the package, on the packaging for the package, or a combination thereof

   ---

2. claim: 11

   method comprising a connection between a RFID tag, a RFID card, a RFID stick, or a combination thereof and a user's handheld device, social media, e-mail, or a combination thereof

   ---

3. claims: 13-15

   method comprising an output device displaying an unique image

   ---

4. claim: 16(partially)

   method comprising a RFID device located on a tester, a mirror, a storefront window, a bracelet, a key fob, or a mobile device

   ---

(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 3 680 818 A1

(12) EUROPEAN PATENT APPLICATION

(43) Date of publication:
15.07.2020 Bulletin 2020/29

(51) Int Cl.:
G06K 9/00 *(2006.01)* ***B60W 30/14*** *(2006.01)*

(21) Application number: **20159461.1**

(22) Date of filing: **04.12.2014**

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA ME

(30) Priority: **04.12.2013 US 201361911490 P**
14.05.2014 US 201461993084 P
14.05.2014 US 201461993111 P
23.06.2014 US 201461015524 P
09.07.2014 US 201462022221 P
21.08.2014 US 201462040224 P
21.08.2014 US 201462040269 P

(62) Document number(s) of the earlier application(s) in accordance with Art. 76 EPC:
19160915.5 / 3 514 032
14843184.4 / 3 092 599

(71) Applicant: **Mobileye Vision Technologies Ltd.**
91450 Jerusalem (IL)

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  Tel Aviv (IL)

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London SE1 9BG (GB)

Remarks:
This application was filed on 26-02-2020 as a divisional application to the application mentioned under INID code 62.

(54) ADJUSTING VELOCITY OF A VEHICLE FOR A CURVE

(57) Systems and methods use cameras to provide autonomous navigation features. In one implementation, a driver assist navigation system is provided for a primary vehicle. The system may include at least one image capture device configured to acquire a plurality of images of an area in a vicinity of the primary vehicle; a data interface; and at least one processing device. The at least one processing device may be configured to: locate in the plurality of images a leading vehicle; determine, based on the plurality of images, at least one action taken by the leading vehicle; and cause the primary vehicle to mimic the at least one action of the leading vehicle.

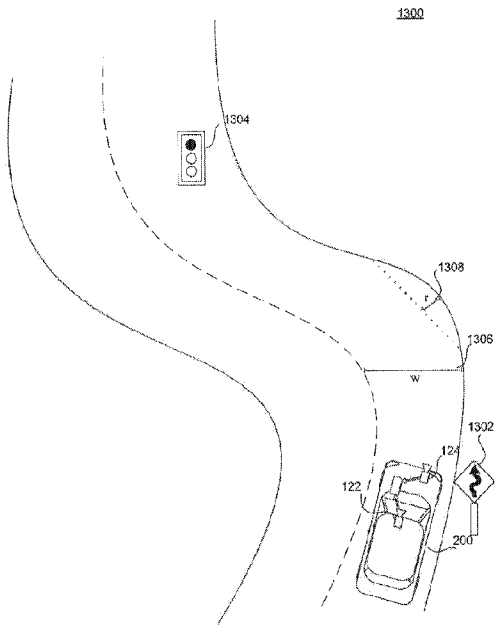


FIG. 13A

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Description

Cross References to Related Applications

[0001] This application claims the benefit of priority of United States Provisional Patent Application No. 61/911,490, filed on December 4, 2013; United States Provisional Patent Application No. 61/993,084, filed on May 14, 2014; United States Provisional Patent Application No. 61/993,111, filed on May 14.2014; United States Provisional Patent Application 62/015,524, filed on June 23, 2014; United States Provisional Patent Application 62/022,221, filed on July 9, 2014; United States Provisional Patent Application No. 62/040,224, filed on August 21, 2014; and United States Provisional Patent Application 62/040,269, filed on August 21, 2014. All of the foregoing applications are incorporated herein by reference in their entirety.

BACKGROUND

I. Technical Field

[0002] The present disclosure relates generally to autonomous vehicle navigation and, more specifically, to systems and methods that use cameras to provide autonomous vehicle navigation features.

II. Background Information

[0003] As technology continues to advance, the goal of a fully autonomous vehicle that is capable of navigating on roadways is on the horizon. Primarily, an autonomous vehicle may be able to identify its environment and navigate without input from a human operator. Autonomous vehicles may also take into account a variety of factors and make appropriate decisions based on those factors to safely and accurately reach an intended destination. For example, various objects-such as other vehicles and pedestrians-are encountered when a vehicle typically travels a roadway. Autonomous driving systems may recognize these objects in a vehicle's environment and take appropriate and timely action to avoid collisions. Additionally, autonomous driving systems may identify other indicators-such as traffic signals, traffic signs, and lane markings-that regulate vehicle movement (e.g., when the vehicle must stop and may go, a speed at which the vehicle must not exceed, where the vehicle must be positioned on the roadway, etc.). Autonomous driving systems may need to determine when a vehicle should change lanes, turn at intersections, change roadways, etc. As is evident from these examples, many factors may need to be addressed in order to provide an autonomous vehicle that is capable of navigating safely and accurately.

SUMMARY

[0004] Embodiments consistent with the present disclosure provide systems and methods for autonomous vehicle navigation. The disclosed embodiments may use cameras to provide autonomous vehicle navigation features. For example, consistent with the disclosed embodiments, the disclosed systems may include one, two, or more cameras that monitor the environment of a vehicle and cause a navigational response based on an analysis of images captured by one or more of the cameras.

[0005] Consistent with a disclosed embodiment, a driver assist navigation system is provided for a vehicle. The system may include at least one image capture device configured to acquire a plurality of images of an area in a vicinity of the vehicle; a data interface; and at least one processing device. The at least one processing device may be configured to: receive the plurality of images via the data interface; determine from the plurality of images a first lane constraint on a first side of the vehicle; determine from the plurality of images a second lane constraint on a second side of the vehicle opposite to the first side of the vehicle, wherein the first and second lane constraints define a lane within which the vehicle travels and wherein a first distance corresponds to a distance between the first side of the vehicle and the first lane constraint and a second distance corresponds to a distance between the second side of the vehicle and the second lane constraint; determine, based on the plurality of images, whether a lane offset condition exists on the first side of the vehicle; if a lane offset condition exists on the first side of the vehicle, cause the vehicle to travel within the first and second lane constraints such that the first distance is greater than the second distance; determine, based on the plurality of images, whether a lane offset condition exists on the second side of the vehicle; and if a lane offset condition exists on the second side of the vehicle, cause the vehicle to travel within the first and second lane constraints such that the first distance is less than the second distance.

[0006] Consistent with the disclosed embodiment, the at least one processing device may be further configured to cause the first distance to be substantially the same as the second distance if, based on the plurality of images, a lane offset condition is determined to exist on both the first and second sides of the vehicle. The at least one processing device may be configured to determine, based on the plurality of images, whether a lane offset condition is substantially non-existent, and if the lane offset condition is substantially non-existent, cause the vehicle to travel within the first and second lane constraints such that the first distance is substantially equal to the second distance. If the driver assist navigation system determines that a lane offset condition exists, the at least one processing device may be configured to cause the first distance to be at least 125 times greater than the second distance. Alternatively, the at least one processing device may be further configured to cause the first

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distance to be at least 2 times greater than the second distance. If the driver assist navigation system determines that the lane offset condition includes a curved road, the at least one processing device may be configured to cause the vehicle to travel within the first and second lane constraints such that the first distance is toward an outside of the curve relative to the vehicle, and the second distance is toward an inside of the curve relative to the vehicle. If the driver assist navigation system determines that the lane offset condition includes a presence of one or more objects on one side of the lane, the at least one processing device may be configured to cause the vehicle to travel within the first and second lane constraints such that the first distance, which is greater than the second distance, is provided toward the one or more objects. The one or more objects may include parked cars, a wall, and/or pedestrians, and may have a height of greater than 10 cm from a road surface. At least one of the first and second lane constraints may include a line marked on a road surface, an edge of a road surface, or a determined midpoint of a road surface width. Determination of whether a lane offset condition exists on the first side of the vehicle may be performed based on a position of a target object on the first side of the vehicle. The causing of the vehicle to travel within the first and second lane constraints such that the first distance is greater than the second distance may be overridden based on input from a driver of the vehicle.

[0007] Consistent with another disclosed embodiment, a vehicle may include a first vehicle side; a second vehicle side opposite the first vehicle side; at least one image capture device configured to acquire a plurality of images of an area in a vicinity of the vehicle; a data interface; and at least one processing device. The at least one processing device may be configured to: receive the plurality of images via the data interface; determine from the plurality of images a first lane constraint on the first vehicle side; determine from the plurality of images a second lane constraint on the second vehicle side, wherein the first and second lane constraints define a lane within which the vehicle travels and wherein a first distance corresponds to a distance between the first vehicle side and the first lane constraint and a second distance corresponds to a distance between the second vehicle side and the second lane constraint; determine, based on the plurality of images, whether a lane offset condition exists on the first vehicle side; if a lane offset condition exists on the first vehicle side, cause the vehicle to travel within the first and second lane constraints such that the first distance is greater than the second distance; determine, based on the plurality of images, whether a lane offset condition exists on the second vehicle side; and if a lane offset condition exists on the second vehicle side, cause the vehicle to travel within the first and second lane constraints such that the first distance is less than the second distance.

[0008] Consistent with the disclosed embodiment, the at least one processing device may be further configured to cause the first distance to be substantially the same as the second distance if, based on the plurality of images, a lane offset condition is determined to exist on both the first and second vehicle sides. The at least one processing device may be configured to determine, based on the plurality of images, whether a lane offset condition is substantially non-existent, and if the lane offset condition is substantially non-existent, cause the vehicle to travel within the first and second lane constraints such that the first distance is substantially equal to the second distance. The lane offset condition may include a curved road, and the at least one processing device may be configured to cause the vehicle to travel within the first and second lane constraints such that the first distance is toward an outside of the curve relative to the vehicle, and the second distance is toward an inside of the curve relative to the vehicle. The lane offset condition may include a presence of one or more objects on one side of the lane, and the at least one processing device may be configured to cause the vehicle to travel within the first and second lane constraints such that the first distance, which is greater than the second distance, is provided toward the one or more objects. At least one of the first and second lane constraints may include an edge of a road surface and/or a determined midpoint of a road surface width. Determination of whether a lane offset condition exists on the first side of the vehicle may be performed based on a position of a target object on the first side of the vehicle. The causing of the vehicle to travel within the first and second lane constraints such that the first distance is greater than the second distance may be overridden based on input from a driver of the vehicle.

[0009] Consistent with another disclosed embodiment, a method is provided for navigating a vehicle. The method may include acquiring, using at least one image capture device, a plurality of images of an area in the vicinity of the vehicle; determining from the plurality of images a first lane constraint on a first side of the vehicle; determining from the plurality of images a second lane constraint on a second side of the vehicle opposite to the first side of the vehicle, wherein the first and second lane constraints define a lane within which the vehicle travels and wherein a first distance corresponds to a distance between the first side of the vehicle and the first lane constraint and a second distance corresponds to a distance between the second side of the vehicle and the second lane constraint; determining, based on the plurality of images, whether a lane offset condition exists on the first side of the vehicle; if a lane offset condition exists on the first side of the vehicle, causing the vehicle to travel within the first and second lane constraints such that the first distance is greater than the second distance; determining, based on the plurality of images, whether a lane offset condition exists on the second side of the vehicle; and if a lane offset condition exists on the second side of the vehicle, causing the vehicle to travel within the first and second lane constraints such that the first

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distance is less than the second distance.

[0010] Consistent with a disclosed embodiment, a driver assist navigation system is provided for a vehicle. The system may include at least one image capture device configured to acquire a plurality of images of an area in a vicinity of the vehicle; a data interface; and at least one processing device. The at least processing device may be configured to: receive the plurality of images via the data interface; determine from the plurality of images a current lane of travel from among a plurality of available travel lanes; and cause the vehicle to change lanes if the current lane of travel is not the same as a predetermined default travel lane.

[0011] Consistent with the disclosed embodiment, the predetermined default travel lane may be a right-most lane among the plurality of available travel lanes. The at least one processing device may be configured to activate a turn signal prior to causing the vehicle to change lanes. The at least one processing device may be configured to cause an audible announcement prior to causing the vehicle to change lanes. The at least one processing device may be configured to cause an audible indicator prior to causing the vehicle to change lanes. The predetermined default travel lane may be determined based on the plurality of images of the area in the vicinity of the vehicle, based on data received from a global positioning system, and/or based on an input received from a user.

[0012] Consistent with another disclosed embodiment, a vehicle may include a body; at least one image capture device configured to acquire a plurality of images of an area in a vicinity of the vehicle; a data interface; and at least one processing device. The at least one processing device may be configured to: receive the plurality of images via the data interface; determine from the plurality of images a current lane of travel from among a plurality of available travel lanes; and cause the vehicle to change lanes if the current lane of travel is not the same as a predetermined default travel lane.

[0013] Consistent with the disclosed embodiment, the predetermined default travel lane may be a right-most lane among the plurality of available travel lanes. The at least one processing device may be configured to activate a turn signal prior to causing the vehicle to change lanes. The at least one processing device may be configured to cause an audible announcement prior to causing the vehicle to change lanes. The at least one processing device may be configured to cause an audible indicator prior to causing the vehicle to change lanes. The predetermined default travel lane may be determined based on the plurality of images of the area in the vicinity of the vehicle, based on data received from a global positioning system, and/or based on an input received from a user.

[0014] Consistent with another disclosed embodiment, a method is provided for navigating a vehicle. The method may include acquiring, using at least one image capture device, a plurality of images of an area in a vicinity of the vehicle; determining from the plurality of images a current lane of travel from among a plurality of available travel lanes; and causing the vehicle to change lanes if the current lane of travel is not the same as a predetermined default travel lane.

[0015] Consistent with the disclosed embodiment, the predetermined default travel lane may be a right-most lane among the plurality of available travel lanes. A turn signal may be activated prior to causing the vehicle to change lanes. The predetermined default travel lane may be determined based on the plurality of images of the area in the vicinity of the vehicle.

[0016] Consistent with a disclosed embodiment, a driver assist navigation system is provided for a vehicle. The system may include at least one image capture device configured to acquire a plurality of images of an area in a vicinity of the vehicle; a data interface; and at least one processing device. The at least one processing device may be configured to: receive the plurality of images via the data interface; recognize a curve to be navigated based on map data and vehicle position information; determine an initial target velocity for the vehicle based on at least one characteristic of the curve as reflected in the map data; adjust a velocity of the vehicle to the initial target velocity; determine, based on the plurality of images, one or more observed characteristics of the curve; determine an updated target velocity based on the one or more observed characteristics of the curve; and adjust the velocity of the vehicle to the updated target velocity.

[0017] Consistent with the disclosed embodiment, the at least one characteristic of the curve may include an expected radius of curvature for the curve as determined from the map data. The initial target velocity may be determined based on the expected radius of curvature for the curve and a lateral acceleration limit. The lateral acceleration limit may be between about 0.2 m/sec^2 and 3.0 m/sec^2. Alternatively, the lateral acceleration limit may be between about 1.5 m/sec^2 and 3.0 m/sec^2. The lateral acceleration limit may be adjusted based on a road width determined based on the plurality of images. The one or more observed characteristics of the curve may include an actual radius of curvature for the curve as determined through analysis of the plurality of images. The updated target velocity may be determined based on the actual radius of curvature for the curve and a lateral acceleration limit The one or more observed characteristics of the curve may include a rate of change in an actual radius of curvature for the curve as determined through analysis of the plurality of images. The one or more observed characteristics of the curve may include a degree of banking associated with the curve as determined through analysis of the plurality of images. The one or more observed characteristics of the curve may include information, determined through analysis of the plurality of images, relating to the curve conveyed by one or more road signs. The initial target velocity may also be based on a focal range of the at least one image capture device. The initial target velocity may also be based

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on whether a traffic light is determined to be located along the curve. The initial target velocity may also be based on whether a traffic light is determined to be located within a predetermined distance after the curve.

[0018] Consistent with another disclosed embodiment, a vehicle may include a body; at least one image capture device configured to acquire a plurality of images of an area in a vicinity of the vehicle; a data interface; and at least one processing device. The at least one processing device may be configured to: receive the plurality of images via the data interface; recognize a curve to be navigated based on map data and vehicle position information; determine an initial target velocity for the vehicle based on at least one characteristic of the curve as reflected in the map data; adjust a velocity of the vehicle to the initial target velocity; determine, based on the plurality of images, one or more observed characteristics of the curve; determine an updated target velocity based on the one or more observed characteristics of the curve; and adjust the velocity of the vehicle to the updated target velocity.

[0019] Consistent with the disclosed embodiment, the at least one characteristic of the curve may include an expected radius of curvature for the curve as determined from the map data. The initial target velocity may be determined based on the expected radius of curvature for the curve and a lateral acceleration limit. The lateral acceleration limit may be adjusted based on a road width determined based on the plurality of images. The one or more observed characteristics of the curve may include an actual radius of curvature for the curve as determined through analysis of the plurality of images. The updated target velocity may be determined based on the actual radius of curvature for the curve and a lateral acceleration limit. The one or more observed characteristics of the curve may include a rate of change in an actual radius of curvature for the curve as determined through analysis of the plurality of images. The one or more observed characteristics of the curve may include a degree of banking associated with the curve as determined through analysis of the plurality of images. The one or more observed characteristics of the curve may include information, determined through analysis of the plurality of images, relating to the curve conveyed by one or more road signs. The initial target velocity may also be based on a focal range of the at least one image capture device. The initial target velocity may also be based on whether a traffic light is determined to be located along the curve. The initial target velocity may also be based on whether a traffic light is determined to be located within a predetermined distance after the curve.

[0020] Consistent with another disclosed embodiment, a method is provided for navigating a vehicle. The method may include acquiring, using at least one image capture device, a plurality of images of an area in a vicinity of the vehicle; recognizing a curve to be navigated based on map data and vehicle position information; determining an initial target velocity for the vehicle based on at least one characteristic of the curve as reflected in the map data; adjusting a velocity of the vehicle to the initial target velocity; determining, based on the plurality of images, one or more observed characteristics of the curve; determining an updated target velocity based on the one or more observed characteristics of the curve; and adjusting the velocity of the vehicle to the updated target velocity.

[0021] Consistent with a disclosed embodiment, a driver assist navigation system is provided for a primary vehicle. The system may include at least one image capture device configured to acquire a plurality of images of an area in a vicinity of the primary vehicle; a data interface; and at least one processing device. The at least one processing device may be configured to: receive the plurality of images via the data interface; determine, from at least some of the plurality of images, a first lane constraint on a first side of the primary vehicle; determine, from at least some of the plurality of images, a second lane constraint on a second side of the primary vehicle opposite to the first side of the primary vehicle, wherein the first and second lane constraints define a lane within which the primary vehicle travels; cause the primary vehicle to travel within the first and second lane constraints; locate in the plurality of images a leading vehicle; determine, based on the plurality of images, at least one action taken by the leading vehicle; and cause the primary vehicle to mimic the at least one action of the leading vehicle.

[0022] Consistent with the disclosed embodiment, at least one of the first and second lane constraints may include a line marked on a road surface. At least one of the first and second lane constraints may include an edge of a road surface. At least one of the first and second lane constraints may include a determined midpoint of a road surface width. The at least one action taken by the leading vehicle may include a turn, and the at least one processing device may cause the primary vehicle to execute a similar turn beginning at a location at which the leading vehicle initiated its turn. The at least one action taken by the leading vehicle may include an acceleration. The at least one action taken by the leading vehicle may include braking. The at least one action taken by the leading vehicle may include providing a first offset distance on a side of the leading vehicle adjacent to the first lane constraint that is different from a second offset distance on a side of the leading vehicle adjacent to the second lane constraint. The at least one processing device may be further configured to determine, based on the plurality of images or based on map data and position information, whether the leading vehicle is turning at an intersection, and if the leading vehicle is determined to be turning at an intersection, decline to mimic the turn of the leading vehicle. The at least one processing device may be configured to determine, based on the plurality of images or based on map data and position information, whether the leading vehicle is turning at an intersection, determine whether the leading vehicle is changing lanes within the intersection, mimic the turn of the leading vehicle if the leading vehicle is determined to be turning at an inter-

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section and not changing lanes within the intersection, and decline to mimic the turn of the leading vehicle if the leading vehicle is determined to be turning at an intersection, but changing lanes within the intersection. The at least one processing device may be configured to acquire a first leading vehicle based on the plurality of images, acquire a second leading vehicle based on the plurality of images, and cause the primary vehicle to mimic the first leading vehicle if, based on the plurality of images, the first leading vehicle is determined to be continuing on a path having less of a turning radius than a path followed by the second leading vehicle. The at least one processing device may be configured to determine position information for the leading vehicle and compare the position information to predetermined map data, create a navigation history for the leading vehicle by tracking movements of the leading vehicle relative to the predetermined map data, and determine whether to cause the primary vehicle to mimic the at least one action of the leading vehicle based on the navigation history of the leading vehicle. The at least one processing device may be configured to cause the primary vehicle to mimic a turn of the leading vehicle, even where no turn is detected based on the plurality of images, when the navigation history indicates that the leading vehicle has successfully navigated at least one prior turn.

[0023] Consistent with another disclosed embodiment, a primary vehicle may include a body; at least one image capture device configured to acquire a plurality of images of an area in a vicinity of the primary vehicle; a data interface; and at least one processing device. The at least one processing device may be configured to: receive the plurality of images via the data interface; determine, from at least some of the plurality of images, a first lane constraint on a first side of the primary vehicle; determine, from at least some of the plurality of images, a second lane constraint on a second side of the primary vehicle opposite to the first side of the primary vehicle, wherein the first and second lane constraints define a lane within which the primary vehicle travels; cause the primary vehicle to travel within the first and second lane constraints; locate in the plurality of images a leading vehicle; determine, based on the plurality of images, at least one action taken by the leading vehicle; and cause the primary vehicle to mimic the at least one action of the leading vehicle.

[0024] Consistent with the disclosed embodiment, at least one of the first and second lane constraints may include a line marked on a road surface. At least one of the first and second lane constraints may include an edge of a road surface. At least one of the first and second lane constraints may include a determined midpoint of a road surface width. The at least one action taken by the leading vehicle may include a turn, and the at least one processing device may cause the primary vehicle to execute a similar turn beginning at a location at which the leading vehicle initiated its turn. The at least one action taken by the leading vehicle may include an acceleration. The at least one action taken by the leading vehicle may include braking. The at least one action taken by the leading vehicle may include providing a first offset distance on a side of the leading vehicle adjacent to the first lane constraint that is different from a second offset distance on a side of the leading vehicle adjacent to the second lane constraint. The at least one processing device may be further configured to determine, based on the plurality of images or based on map data and position information, whether the leading vehicle is turning at an intersection, and if the leading vehicle is determined to be turning at an intersection, decline to mimic the turn of the leading vehicle. The at least one processing device may be configured to determine, based on the plurality of images or based on map data and position information, whether the leading vehicle is turning at an intersection, determine whether the leading vehicle is changing lanes within the intersection, mimic the turn of the leading vehicle if the leading vehicle is determined to be turning at an intersection and not changing lanes within the intersection, and decline to mimic the turn of the leading vehicle if the leading vehicle is determined to be turning at an intersection, but changing lanes within the intersection. The at least one processing device may be configured to acquire a first leading vehicle based on the plurality of images, acquire a second leading vehicle based on the plurality of images, and cause the primary vehicle to mimic the first leading vehicle if, based on the plurality of images, the first leading vehicle is determined to be continuing on a path having less of a turning radius than a path followed by the second leading vehicle. The at least one processing device may be configured to determine position information for the leading vehicle and compare the position information to predetermined map data, create a navigation history for the leading vehicle by tracking movements of the leading vehicle relative to the predetermined map data, and determine whether to cause the primary vehicle to mimic the at least one action of the leading vehicle based on the navigation history of the leading vehicle. The at least one processing device may be configured to cause the primary vehicle to mimic a turn of the leading vehicle, even where no turn is detected based on the plurality of images, when the navigation history indicates that the leading vehicle has successfully navigated at least one prior turn.

[0025] Consistent with another disclosed embodiment, a method is provided for navigating a primary vehicle. The method ma include acquiring, using at least one image capture device, a plurality of images of an area in a vicinity of the primary vehicle; determining, from at least some of the plurality of images, a first lane constraint on a first side of the primary vehicle; determining, from at least some of the plurality of images, a second lane constraint on a second side of the primary vehicle opposite to the first side of the primary vehicle, wherein the first and second lane constraints define a lane within which the primary vehicle travels; causing the primary vehicle to travel within the first and second lane constraints; lo-

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cating in the plurality of images a leading vehicle; determining, based on the plurality of images, at least one action taken by the leading vehicle; and causing the primary vehicle to mimic the at least one action of the leading vehicle.

[0026] Consistent with a disclosed embodiment, a driver assist navigation system is provided for a user vehicle. They system may include at least one image capture device configured to acquire a plurality of images of an area in a vicinity of the user vehicle; a data interface; and at least one processing device. The at least one processing device may be configured to: receive the plurality of images via the data interface; determine from the plurality of images a first lane constraint on a first side of the user vehicle; determine from the plurality of images a second lane constraint on a second side of the user vehicle opposite to the first side of the user vehicle, wherein the first and second lane constraints define a lane within which the user vehicle travels: acquire, based on the plurality of images, a target vehicle; enable the user vehicle to pass the target vehicle if the target vehicle is determined to be in a lane different from the lane in which the user vehicle is traveling; monitor a position of the target vehicle based on the plurality of images; and cause the user vehicle to abort the pass before completion of the pass, if the target vehicle is determined to be entering the lane in which the user vehicle is traveling.

[0027] Consistent with the disclosed embodiment, causing the user vehicle to abort the pass may include causing an application of brakes in the user vehicle. Causing the user vehicle to abort the pass may include causing an audible announcement. Causing the user vehicle to abort the pass may include causing the user vehicle to stop accelerating. Monitoring the position of the target vehicle may include estimating a speed of the target vehicle. At least one of the first and second lane constraints may include a line marked on a road surface, an edge of a road surface, and/or a determined midpoint of a road surface width.

[0028] Consistent with another disclosed embodiment, a user vehicle may include at least one image capture device configured to acquire a plurality of images of an area in a vicinity of the user vehicle; a data interface; and at least one processing device. The at least one processing device may be configured to: receive the plurality of images via the data interface; determine from the plurality of images a first lane constraint on a first side of the user vehicle; determine from the plurality of images a second lane constraint on a second side of the user vehicle opposite to the first side of the user vehicle, wherein the first and second lane constraints define a lane within which the user vehicle travels; acquire, based on the plurality of images, a target vehicle: enable the user vehicle to pass the target vehicle if the target vehicle is determined to be in a lane different from the lane in which the user vehicle is traveling; monitor a position of the target vehicle based on the plurality of images; and cause the user vehicle to abort the pass before completion of the pass, if the target vehicle is determined to be entering the lane in which the user vehicle is traveling.

[0029] Consistent with the disclosed embodiment, causing the user vehicle to abort the pass may include causing an application of brakes in the user vehicle. Causing the user vehicle to abort the pass may include causing an audible announcement. Causing the user vehicle to abort the pass may include causing the user vehicle to stop accelerating. Monitoring the position of the target vehicle may include estimating a speed of the target vehicle. At least one of the first and second lane constraints may include a line marked on a road surface, an edge of a road surface, and/or a determined midpoint of a road surface width.

[0030] Consistent with another disclosed embodiment, a method is provided for navigating a user vehicle. The method may include acquiring, using at least one image capture device, a plurality of images of an area in a vicinity of the user vehicle; determining from the plurality of images a first lane constraint on a first side of the user vehicle; determining from the plurality of images a second lane constraint on a second side of the user vehicle opposite to the first side of the user vehicle, wherein the first and second lane constraints define a lane within which the user vehicle travels; acquiring, based on the plurality of images, a target vehicle; enabling the user vehicle to pass the target vehicle if the target vehicle is determined to be in a lane different from the lane in which the user vehicle is traveling; monitoring a position of the target vehicle based on the plurality of images; and causing the user vehicle to abort the pass before completion of the pass, if the target vehicle is determined to be entering the lane in which the user vehicle is traveling.

[0031] Consistent with the disclosed embodiment, causing the user vehicle to abort the pass may include causing an application of brakes in the user vehicle. Causing the user vehicle to abort the pass may include causing the user vehicle to stop accelerating. At least one of the first and second lane constraints may include a line marked on a road surface, an edge of a road surface, and/or a determined midpoint of a road surface width.

[0032] Consistent with a disclosed embodiment, a driver assist navigation system is provided for a user vehicle. The system may include at least one image capture device configured to acquire a plurality of images of an area in a vicinity of the user vehicle; a data interface; and at least one processing device. The at least one processing device may be configured to: receive the plurality of images via the data interface; determine from the plurality of images a first lane constraint on a first side of the user vehicle; determine from the plurality of images a second lane constraint on a second side of the user vehicle opposite to the first side of the user vehicle, wherein the first and second lane constraints define a lane within which the user vehicle travels; determine, based on the plurality of images, whether an encroaching vehicle is approaching from a side of the user vehicle; and cause

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the user vehicle to maintain a current velocity and to travel within the first and second lane constraints such that a first distance, on the side of the user vehicle that the encroaching vehicle is approaching from, is greater than a second distance.

[0033] Consistent with the disclosed embodiment, the at least one processing device may be further configured to cause the user vehicle to take evasive action if analysis of the plurality of images indicates that the encroaching vehicle has crossed at least one collision threshold. The evasive action may include changing lanes, altering course, and/or braking. The at least one collision threshold may include a minimum predetermined distance to maintain between the user vehicle and the encroaching vehicle. The at least one collision threshold may include a time to collision. The at least one processing device may be configured to cause the user vehicle to return to a center of the lane, within which the user vehicle originally traveled, after completion of the evasive action. The at least one image capture device may have a field of view of at least 140 degrees. The at least one processing device may be configured to cause the user vehicle to resume a preset speed after braking in response to an encroaching vehicle. The at least one processing device may be configured to cause the user vehicle to return to a lane location within the first and second lane constraints such that the first distance between the user vehicle and the first lane constraint is substantially equal to the second distance between the user vehicle and the second lane constraint after altering course in response to an encroaching vehicle.

[0034] Consistent with another disclosed embodiment, a user vehicle may include at least one image capture device configured to acquire a plurality of images of an area in a vicinity of the user vehicle; a data interface; and at least one processing device. The at least one processing device may be configured to: receive the plurality of images via the data interface; determine from the plurality of images a first lane constraint on a first side of the user vehicle; determine from the plurality of images a second lane constraint on a second side of the user vehicle opposite to the first side of the user vehicle, wherein the first and second lane constraints define a lane within which the user vehicle travels; determine, based on the plurality of images, whether an encroaching vehicle is approaching from a side of the user vehicle; and cause the user vehicle to maintain a current velocity and to travel within the first and second lane constraints such that a first distance, on the side of the user vehicle that the encroaching vehicle is approaching from, is greater than a second distance.

[0035] Consistent with the disclosed embodiment, the at least one processing device may be further configured to cause the user vehicle to take evasive action if analysis of the plurality of images indicates that the encroaching vehicle has crossed at least one collision threshold. The evasive action may include changing lanes, altering course, and/or braking. The at least one collision threshold may include a minimum predetermined distance to maintain between the user vehicle and the encroaching vehicle. The at least one collision threshold may include a time to collision. The at least one processing device may be configured to cause the user vehicle to return to a center of the lane, within which the user vehicle originally traveled, after completion of the evasive action. The at least one image capture device may have a field of view of at least 140 degrees. The at least one processing device may be configured to cause the user vehicle to resume a preset speed after braking in response to an encroaching vehicle. The at least one processing device may be configured to cause the user vehicle to return to a lane location within the first and second lane constraints such that the first distance between the user vehicle and the first lane constraint is substantially equal to the second distance between the user vehicle and the second lane constraint after altering course in response to an encroaching vehicle.

[0036] Consistent with another disclosed embodiment, a method for navigating a user vehicle is provided. The method may include acquiring, using at least one image capture device, a plurality of images of an area in a vicinity of the user vehicle; determining from the plurality of images a first lane constraint on a first side of the user vehicle; determining from the plurality of images a second lane constraint on a second side of the user vehicle opposite to the first side of the user vehicle, wherein the first and second lane constraints define a lane within which the user vehicle travels; determining, based on the plurality of images, whether an encroaching vehicle is approaching from a side of the user vehicle; and causing the user vehicle to maintain a current velocity and to travel within the first and second lane constraints such that a first distance, on the side of the user vehicle that the encroaching vehicle is approaching from, is greater than a second distance.

[0037] Consistent with a disclosed embodiment, a driver assist navigation system is provided for a primary vehicle. They system may include at least one image capture device configured to acquire a plurality of images of an area in a vicinity of the primary vehicle; a data interface; and at least one processing device. The at least processing device may be configured to: receive the plurality of images via the data interface; identify a target object within the plurality of images; monitor, via the plurality of images, a motion of the target object and a distance between the primary vehicle and the target object; determine an indicator of an intercept time between the primary vehicle and the target object based on the monitored motion and the distance between the primary vehicle and the target object; and cause a response in the primary vehicle based on a comparison of the intercept time to a plurality of predetermined intercept thresholds.

[0038] Consistent with the disclosed embodiment, the target object may be a target vehicle traveling in a lane different from the primary vehicle. The intercept time may be based on an indicator of speed of the tracked object,

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as determined based on the plurality of images. The intercept time may be based on an indicator of an acceleration of the tracked object, as determined based on the plurality of images. The at least one processing device may be further configured to determine whether the target object is traveling in the same lane as the primary vehicle, and forego the response in the primary vehicle if the target object is determined to be traveling in a lane different from the primary vehicle. Determination of whether the target object is traveling in the same lane as the primary vehicle may be based on the plurality of images. Determination of whether the target object is traveling in the same lane as the primary vehicle may be based on at least one of predetermined map data or yaw rate of the primary vehicle. The response may be based on an averaged motion profile associated with the target object if the indicator of intercept time indicates that the target object is outside a first intercept threshold relative to the vehicle. The response may be based on actual motion of the target object if the indicator of intercept time indicates that the target object is between the first intercept threshold and a second intercept threshold relative to the vehicle. The response may include an emergency avoidance action if the indicator of intercept time indicates that the target object is within the second intercept threshold. The emergency avoidance action may include changing lanes and/or emergency braking.

[0039] Consistent with another disclosed embodiment, a primary vehicle may include a body; at least one image capture device configured to acquire a plurality of images of an area in a vicinity of the primary vehicle; a data interface; and at least one processing device. The at least one processing device may be configured to: receive the plurality of images via the data interface; identify a target object within the plurality of images; monitor, via the plurality of images, a motion of the target object and a distance between the primary vehicle and the target object; determine an indicator of an intercept time between the primary vehicle and the target object based on the monitored motion and the distance between the primary vehicle and the target object; and cause a response in the primary vehicle based on a comparison of the intercept time to a plurality of predetermined intercept thresholds.

[0040] Consistent with the disclosed embodiment, the target object may be a target vehicle traveling in a lane different from the primary vehicle. The intercept time may be based on an indicator of speed of the tracked object, as determined based on the plurality of images. The intercept time may be based on an indicator of an acceleration of the tracked object, as determined based on the plurality of images. The at least one processing device may be further configured to determine whether the target object is traveling in the same lane as the primary vehicle, and forego the response in the primary vehicle if the target object is determined to be traveling in a lane different from the primary vehicle. Determination of whether the target object is traveling in the same lane as the primary vehicle may be based on the plurality of images. Determination of whether the target object is traveling in the same lane as the primary vehicle may be based on at least one of predetermined map data or yaw rate of the primary vehicle. The response may be based on an averaged motion profile associated with the target object if the indicator of intercept time indicates that the target object is outside a first intercept threshold relative to the vehicle. The response may be based on actual motion of the target object if the indicator of intercept time indicates that the target object is between the first intercept threshold and a second intercept threshold relative to the vehicle. The response may include an emergency avoidance action if the indicator of intercept time indicates that the target object is within the second intercept threshold. The emergency avoidance action may include changing lanes and/or emergency braking.

[0041] Consistent with another disclosed embodiment, a method for navigating a primary vehicle may include acquiring, via at least one image capture device, a plurality of images of an area in a vicinity of the primary vehicle; identifying a target object within the plurality of images; monitoring, based on the plurality of images, a motion of the target object and a distance between the primary vehicle and the target object; determining an indicator of an intercept time between the primary vehicle and the target object based on the monitored motion and the distance between the primary vehicle and the target object; and causing a response in the primary vehicle based on a comparison of the intercept time to a plurality of predetermined intercept thresholds.

[0042] Consistent with a disclosed embodiment, a driver assist navigation system is provided for a vehicle. The system may include at least one image capture device configured to acquire a plurality of images of an area in a vicinity of the vehicle; a data interface; and at least one processing device. The at least one processing device may be configured to: receive the plurality of images via the data interface; identify, based on analysis of the plurality of images, a trigger for stopping the vehicle; and based on the identified trigger, cause the vehicle to stop according to a braking profile including a first segment associated with a first deceleration rate, a second segment which includes a second deceleration rate less than the first deceleration rate, and a third segment in which a level of braking is decreased as a target stopping location is approached, as determined based on the analysis of the plurality of images.

[0043] Consistent with the disclosed embodiment, reaching of the target stopping location may be accompanied by a release in braking pressure. The trigger may include an object. The object may include another vehicle in front of the vehicle. The trigger may include a traffic light signal, a stop sign, and/or a speed limit sign. The at least one processing device may be further configured to provide an audible announcement identifying the trigger. The at least one processing device may be configured to cause an audible announcement indicating that the vehicle is braking.

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[0044] Consistent with another disclosed embodiment, a vehicle may include a body; at least one image capture device configured to acquire a plurality of images of an area in a vicinity of the vehicle; a data interface; and at least one processing device. The at least one processing device may be configured to: receive the plurality of images via the data interface; identify, based on analysis of the plurality of images, a trigger for stopping the vehicle; and based on the identified trigger, cause the vehicle to stop according to a braking profile including a first segment associated with a first deceleration rate, a second segment which includes a second deceleration rate less than the first deceleration rate, and a third segment in which a level of braking is decreased as a target stopping location is approached, as determined based on the analysis of the plurality of images.

[0045] Consistent with the disclosed embodiment, reaching of the target stopping location may be accompanied by a release in braking pressure. The trigger may include an object. The object may include another vehicle in front of the vehicle. The trigger may include a traffic light signal, a stop sign, and/or a speed limit sign. The at least one processing device may be further configured to provide an audible announcement identifying the trigger. The at least one processing device may be configured to cause an audible announcement indicating that the vehicle is braking.

[0046] Consistent with another disclosed embodiment, a method is provided for navigating a vehicle. The method may include acquiring, via at least one image capture plurality of images of an area in a vicinity of the vehicle; identifying, based on analysis of the plurality of images, a trigger for stopping the vehicle; and based on the identified trigger, causing the vehicle to stop according to a braking profile including a first segment associated with a first deceleration rate, a second segment which includes a second deceleration rate less than the first deceleration rate, and a third segment in which a level of braking is decreased as a target stopping location is approached, as determined based on the analysis of the plurality of images.

[0047] Consistent with other disclosed embodiments, non-transitory computer-readable storage media may store program instructions, which are executed by at least one processing device and perform any of the methods described herein.

[0048] The foregoing general description and the following detailed description are exemplary and explanatory only and are not restrictive of the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0049] The accompanying drawings, which are incorporated in and constitute a part of this disclosure, illustrate various disclosed embodiments. In the drawings:

FIG. 1 is a diagrammatic representation of an exemplary system consistent with the disclosed embodiments.

FIG. 2A is a diagrammatic side view representation of an exemplary vehicle including a system consistent with the disclosed embodiments.

FIG. 2B is a diagrammatic top view representation of the vehicle and system shown in FIG. 2A consistent with the disclosed embodiments.

FIG. 2C is a diagrammatic top view representation of another embodiment of a vehicle including a system consistent with the disclosed embodiments.

FIG. 2D is a diagrammatic top view representation of yet another embodiment of a vehicle including a system consistent with the disclosed embodiments.

FIG. 2E is a diagrammatic top view representation of yet another embodiment of a vehicle including a system consistent with the disclosed embodiments.

FIG. 2F is a diagrammatic representation of exemplary vehicle control systems consistent with the disclosed embodiments.

FIG. 3A is a diagrammatic representation of an interior of a vehicle including a rearview mirror and a user interface for a vehicle imaging system consistent with the disclosed embodiments.

FIG. 3B is an illustration of an example of a camera mount that is configured to be positioned behind a rearview mirror and against a vehicle windshield consistent with the disclosed embodiments.

FIG. 3C is an illustration of the camera mount shown in FIG. 3B from a different perspective consistent with the disclosed embodiments.

FIG. 3D is an illustration of an example of a camera mount that is configured to be positioned behind a rearview mirror and against a vehicle windshield consistent with the disclosed embodiments.

FIG. 4 is an exemplary block diagram of a memory configured to store instructions for performing one or more operations consistent with the disclosed embodiments.

FIG. 5A is a flowchart showing an exemplary process for causing one or more navigational responses based on monocular image analysis consistent with disclosed embodiments.

FIG. 5B is a flowchart showing an exemplary process for detecting one or more vehicles and/or pedestrians in a set of images consistent with the disclosed embodiments.

FIG. 5C is a flowchart showing an exemplary process for detecting road marks and/or lane geometry information in a set of images consistent with the disclosed embodiments.

FIG. 5D is a flowchart showing an exemplary process for detecting traffic lights in a set of images consistent with the disclosed embodiments.

FIG. 5E is a flowchart showing an exemplary process for causing one or more navigational responses based on a vehicle path consistent with the disclosed embodiments.

FIG. 5F is a flowchart showing an exemplary process

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for determining whether a leading vehicle is changing lanes consistent with the disclosed embodiments.

FIG. 6 is a flowchart showing an exemplary process for causing one or more navigational responses based on stereo image analysis consistent with the disclosed embodiments.

FIG. 7 is a flowchart showing an exemplary process for causing one or more navigational responses based on an analysis of three sets of images consistent with the disclosed embodiments.

FIG. 8A is a diagrammatic representation of an exemplary vehicle traveling within a first and a second lane constraint in which a lane offset condition exists on the first vehicle side consistent with the disclosed embodiments.

FIG. 8B is a diagrammatic representation of an exemplary vehicle traveling within a first and a second lane constraint in which a lane offset condition exists on the second vehicle side consistent with the disclosed embodiments.

FIG. 8C is a diagrammatic representation of an exemplary vehicle traveling within a first and a second lane constraint on a curved road consistent with the disclosed embodiments.

FIG. 8D is a diagrammatic representation of an exemplary vehicle traveling within a first and a second lane constraint in which a lane offset condition exists on both the first vehicle side and on the second vehicle side consistent with the disclosed embodiments.

FIG. 9 is a diagrammatic representation of the memory of an exemplary navigation system consistent with the disclosed embodiments.

FIG. 10 is a flowchart of an exemplary method for navigating a vehicle consistent with the disclosed embodiments.

FIG 11 is a diagrammatic representation of an exemplary vehicle including a navigation system traveling within a default lane consistent with the disclosed embodiments.

FIG 12A is a diagrammatic representation of the memory of an exemplary navigation system consistent with the disclosed embodiments.

FIG 12B is a flowchart of an exemplary process for navigating a vehicle consistent with the disclosed embodiments.

FIGS. 13A and 13B arc diagrammatic representations of an exemplary vehicle approaching, and navigating, a curve with one or more characteristics consistent with the disclosed embodiments.

FIG. 14 is an exemplary block diagram of a memory configured to store instructions for performing one or more operations consistent with the disclosed embodiments.

FIG. 15 is a flow chart showing an exemplary process for controlling the velocity of a vehicle based on a detected curve and observed characteristics of the curve consistent with disclosed embodiments.

FIGS. 16A-16D are diagrammatic representations of a primary vehicle mimicking one or more actions of a leading vehicle consistent with the disclosed embodiments.

FIG. 17 is an exemplary block diagram of a memory configured to store instructions for performing one or more operations consistent with the disclosed embodiments.

FIG. 18 is a flow chart showing an exemplary process for causing a primary vehicle to mimic one or more actions of a leading vehicle consistent with disclosed embodiments.

FIG. 19 is a flow chart showing an exemplary process for causing a primary vehicle to decline to mimic a turn of a leading vehicle consistent with disclosed embodiments.

FIG. 20 is a flow chart showing an exemplary process for causing a primary vehicle to mimic or decline a turn of a leading vehicle consistent with disclosed embodiments.

FIG. 21 is a flow chart showing another exemplary process for causing a primary vehicle to mimic one or more actions of a leading vehicle consistent with disclosed embodiments.

FIG. 22 is a flow chart showing an exemplary process for causing a primary vehicle to mimic one or more actions of a leading vehicle based on a navigation history consistent with disclosed embodiments.

FIG. 23 is a diagrammatic representation of an exemplary vehicle traveling within a first and a second lane constraint on a roadway along on which another vehicle is traveling consistent with the disclosed embodiments.

FIG. 24A is a diagrammatic representation of a memory storing instructions for navigating a vehicle among encroaching vehicles consistent with the disclosed embodiments.

FIG. 24B is a flowchart of an exemplary process for navigating a vehicle among encroaching vehicles consistent with the disclosed embodiments.

FIG. 25 is a diagrammatic representation of an exemplary vehicle traveling within a first and a second lane constraint on a roadway along on which another vehicle is traveling consistent with the disclosed embodiments.

FIG. 26 is a diagrammatic representation of a memory storing instructions for detecting and responding to traffic laterally encroaching on a vehicle consistent with the disclosed embodiments.

FIG. 27 is a flowchart of an exemplary process for detecting and responding to traffic laterally encroaching on a vehicle consistent with the disclosed embodiments.

FIGS. 28A and 28B are diagrammatic representations of causing a response in a primary vehicle consistent with the disclosed embodiments.

FIG. 29 is an exemplary block diagram of a memory

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configured to store instructions for performing one or more operations consistent with the disclosed embodiments.

FIG. 30 is a flow chart showing an exemplary process for causing a response in a primary vehicle consistent with disclosed embodiments.

FIG. 31 is a flow chart showing an exemplary process for declining to cause a response in a primary vehicle consistent with disclosed embodiments.

FIG. 32A is a diagrammatic representation of an exemplary vehicle in which an object is present in the vicinity of vehicle consistent with the disclosed embodiments.

FIG. 32B illustrates an exemplary braking profile, consistent with the disclosed embodiments.

FIG. 33 is a diagrammatic representation of the memory of an exemplary navigation system consistent with the disclosed embodiments.

FIG. 34 is a flowchart of an exemplary method for implementing a braking profile while navigating a vehicle consistent with the disclosed embodiments.

DETAILED DESCRIPTION

[0050] The following detailed description refers to the accompanying drawings. Wherever possible, the same reference numbers are used in the drawings and the following description to refer to the same or similar parts. While several illustrative embodiments are described herein, modifications, adaptations and other implementations are possible. For example, substitutions, additions or modifications may be made to the components illustrated in the drawings, and the illustrative methods described herein may be modified by substituting, reordering, removing, or adding steps to the disclosed methods. Accordingly, the following detailed description is not limited to the disclosed embodiments and examples. Instead, the proper scope is defined by the appended claims.

[0051] Disclosed embodiments provide systems and methods that use cameras to provide autonomous navigation features. In various embodiments, the system may include one, two or more cameras that monitor the environment of a vehicle. In one embodiment, the system may monitor and adjust the free space between a vehicle and the boundaries of the lane within which the vehicle is traveling. In another embodiment, the system may select a particular lane as a default lane for the vehicle to use while traveling. In another embodiment, the system may control the speed of the vehicle in different scenarios, such as while making a turn. In yet another embodiment, the system may mimic the actions of a leading vehicle. In yet another embodiment, the system may monitor a target vehicle and enable the vehicle to pass the target vehicle under certain conditions (e.g., if the target vehicle is traveling in a lane different from the lane within which the vehicle is traveling. In still yet another embodiment, the system may produce a natural feeling response to a laterally encroaching vehicle, such as a vehicle attempting to move into the lane within which the vehicle is traveling.

[0052] FIG. 1 is a block diagram representation of a system 100 consistent with the exemplary disclosed embodiments. System 100 may include various components depending on the requirements of a particular implementation. In some embodiments, system 100 may include a processing unit 110, an image acquisition unit 120, a position sensor 130, one or more memory units 140, 150, a map database 160, and a user interface 170. Processing unit 110 may include one or more processing devices. In some embodiments, processing unit 110 may include an applications processor 180, an image processor 190, or any other suitable processing device. Similarly, image acquisition unit 120 may include any number of image acquisition devices and components depending on the requirements of a particular application. In some embodiments, image acquisition unit 120 may include one or more image capture devices (e.g., cameras), such as image capture device 122, image capture device 124, and image capture device 126. System 100 may also include a data interface 128 communicatively connecting processing device 110 to image acquisition device 120. For example, data interface 128 may include any wired and/or wireless link or links for transmitting image data acquired by image accusation device 120 to processing unit 110.

[0053] Both applications processor 180 and image processor 190 may include various types of processing devices. For example, either or both of applications processor 180 and image processor 190 may include a microprocessor, preprocessors (such as an image preprocessor), graphics processors, a central processing unit (CPU), support circuits, digital signal processors, integrated circuits, memory, or any other types of devices suitable for running applications and for image processing and analysis. In some embodiments, applications processor 180 and/or image processor 190 may include any type of single or multi-core processor, mobile device microcontroller, central processing unit, etc. Various processing devices may be used, including, for example, processors available from manufacturers such as Intel®, AMD®, etc. and may include various architectures (e.g., x86 processor, ARM®, etc.).

[0054] In some embodiments, applications processor 180 and/or image processor 190 may include any of the EyeQ series of processor chips available from Mobileye®. These processor designs each include multiple processing units with local memory and instruction sets. Such processors may include video inputs for receiving image data from multiple image sensors and may also include video out capabilities. In one example, the EyeQ2® uses 90nm-micron technology operating at 332Mhz. The EyeQ2® architecture consists of two floating point, hyper-thread 32-bit RJSC CPUs (MIPS32® 34K® cores), five Vision Computing Engines (VCE), three Vector Microcode Processors (VMP®), Denali 64-

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bit Mobile DDR Controller, 128-bit internal Sonics Interconnect, dual 16-bit Video input and 18-bit Video output controllers, 16 channels DMA and several peripherals. The MIPS34K CPU manages the five VCEs, three VMP™ and the DMA, the second MIPS34K CPU and the multi-channel DMA as well as the other peripherals. The five VCEs, three VMP® and the MIPS34K CPU can perform intensive vision computations required by multi-function bundle applications. In another example, the EyeQ3®, which is a third generation processor and is six times more powerful that the EyeQ2®, may be used in the disclosed embodiments.

[0055] While FIG. 1 depicts two separate processing devices included in processing unit 110, more or fewer processing devices may be used. For example, in some embodiments, a single processing device may be used to accomplish the tasks of applications processor 180 and image processor 190. In other embodiments, these tasks may be performed by more than two processing devices.

[0056] Processing unit 110 may comprise various types of devices. For example, processing unit 110 may include various devices, such as a controller, an image preprocessor, a central processing unit (CPU), support circuits, digital signal processors, integrated circuits, memory, or any other types of devices for image processing and analysis. The image preprocessor may include a video processor for capturing, digitizing and processing the imagery from the image sensors. The CPU may comprise any number of microcontrollers or microprocessors. The support circuits may be any number of circuits generally well known in the art, including cache, power supply, clock and input-output circuits. The memory may store software that, when executed by the processor, controls the operation of the system. The memory may include databases and image processing software. The memory may comprise any number of random access memories, read only memories, flash memories, disk drives, optical storage, tape storage, removable storage and other types of storage. In one instance, the memory may be separate from the processing unit 110. In another instance, the memory may be integrated into the processing unit 110.

[0057] Each memory 140, 150 may include software instructions that when executed by a processor (e.g., applications processor 180 and/or image processor 190), may control operation of various aspects of system 100. These memory units may include various databases and image processing software. The memory units may include random access memory, read only memory, flash memory, disk drives, optical storage, tape storage, removable storage and/or any other types of storage. In some embodiments, memory units 140, 150 may be separate from the applications processor 180 and/or image processor 190. In other embodiments, these memory units may be integrated into applications processor 180 and/or image processor 190.

[0058] Position sensor 130 may include any type of device suitable for determining a location associated with at least one component of system 100. In some embodiments, position sensor 130 may include a GPS receiver. Such receivers can determine a user position and velocity by processing signals broadcasted by global positioning system satellites. Position information from position sensor 130 may be made available to applications processor 180 and/or image processor 190.

[0059] User interface 170 may include any device suitable for providing information to or for receiving inputs from one or more users of system 100. In some embodiments, user interface 170 may include user input devices, including, for example, a touchscreen, microphone, keyboard, pointer devices, track wheels, cameras, knobs, buttons, etc. With such input devices, a user may be able to provide information inputs or commands to system 100 by typing instructions or information, providing voice commands, selecting menu options on a screen using buttons, pointers, or eye-tracking capabilities, or through any other suitable techniques for communicating information to system 100.

[0060] User interface 170 may be equipped with one or more processing devices configured to provide and receive information to or from a user and process that information for use by, for example, applications processor 180. In some embodiments, such processing devices may execute instructions for recognizing and tracking eye movements, receiving and interpreting voice commands, recognizing and interpreting touches and/or gestures made on a touchscreen, responding to keyboard entries or menu selections, etc. In some embodiments, user interface 170 may include a display, speaker, tactile device, and/or any other devices for providing output information to a user.

[0061] Map database 160 may include any type of database for storing map data useful to system 100. In some embodiments, map database 160 may include data relating to the position, in a reference coordinate system, of various items, including roads, water features, geographic features, businesses, points of interest, restaurants, gas stations, etc. Map database 160 may store not only the locations of such items, but also descriptors relating to those items, including, for example, names associated with any of the stored features. In some embodiments, map database 160 may be physically located with other components of system 100. Alternatively or additionally, map database 160 or a portion thereof may be located remotely with respect to other components of system 100 (e.g., processing unit 110). In such embodiments, information from map database 160 may be downloaded over a wired or wireless data connection to a network (e.g., over a cellular network and/or the Internet, etc.).

[0062] Image capture devices 122, 124, and 126 may each include any type of device suitable for capturing at least one image from an environment. Moreover, any number of image capture devices may be used to acquire images for input to the image processor. Some embod-

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iments may include only a single image capture device, while other embodiments may include two, three, or even four or more image capture devices. Image capture devices 122, 124, and 126 will be further described with reference to FIGS. 2B-2E, below.

[0063] System 100, or various components thereof, may be incorporated into various different platforms. In some embodiments, system 100 may be included on a vehicle 200, as shown in FIG. 2A. For example, vehicle 200 may be equipped with a processing unit 110 and any of the other components of system 100, as described above relative to FIG. 1. While in some embodiments vehicle 200 may be equipped with only a single image capture device (e.g., camera), in other embodiments, such as those discussed in connection with FIGS. 2B-2E, multiple image capture devices may be used. For example, either of image capture devices 122 and 124 of vehicle 200, as shown in FIG. 2A, may be part of an ADAS (Advanced Driver Assistance Systems) imaging set.

[0064] The image capture devices included on vehicle 200 as part of the image acquisition unit 120 may be positioned at any suitable location. In some embodiments, as shown in FIGS. 2A-2E and 3A-3C, image capture device 122 may be located in the vicinity of the rearview mirror. This position may provide a line of sight similar to that of the driver of vehicle 200, which may aid in determining what is and is not visible to the driver. Image capture device 122 may be positioned at any location near the rearview mirror, but placing image capture device 122 on the driver side of the mirror may further aid in obtaining images representative of the driver's field of view and/or line of sight.

[0065] Other locations for the image capture devices of image acquisition unit 120 may also be used. For example, image capture device 124 may be located on or in a bumper of vehicle 200. Such a location may be especially suitable for image capture devices having a wide field of view. The line of sight of bumper-located image capture devices can be different from that of the driver and, therefore, the bumper image capture device and driver may not always see the same objects. The image capture devices (e.g., image capture devices 122, 124, and 126) may also be located in other locations. For example, the image capture devices may be located on or in one or both of the side mirrors of vehicle 200, on the roof of vehicle 200, on the hood of vehicle 200, on the trunk of vehicle 200, on the sides of vehicle 200, mounted on, positioned behind, or positioned in front of any of the windows of vehicle 200, and mounted in or near light figures on the front and/or back of vehicle 200, etc.

[0066] In addition to image capture devices, vehicle 200 may include various other components of system 100. For example, processing unit 110 may be included on vehicle 200 either integrated with or separate from an engine control unit (ECU) of the vehicle. Vehicle 200 may also be equipped with a position sensor 130, such as a GPS receiver and may also include a map database 160 and memory units 140 and 150.

[0067] FIG. 2A is a diagrammatic side view representation of an exemplary vehicle imaging system consistent with the disclosed embodiments. FIG. 2B is a diagrammatic top view illustration of the embodiment shown in FIG. 2A. As illustrated in FIG. 2B, the disclosed embodiments may include a vehicle 200 including in its body a system 100 with a first image capture device 122 positioned in the vicinity of the rearview mirror and/or near the driver of vehicle 200, a second image capture device 124 positioned on or in a bumper region (e.g., one of bumper regions 210) of vehicle 200, and a processing unit 110.

[0068] As illustrated in FIG. 2C, image capture devices 122 and 124 may both be positioned in the vicinity of the rearview mirror and/or near the driver of vehicle 200. Additionally, while two image capture devices 122 and 124 are shown in FIGS. 2B and 2C, it should be understood that other embodiments may include more than two image capture devices. For example, in the embodiments shown in FIGS. 2D and 2E, first, second, and third image capture devices 122, 124, and 126, are included in the system 100 of vehicle 200.

[0069] As illustrated in FIG. 2D, image capture device 122 may be positioned in the vicinity of the rearview mirror and/or near the driver of vehicle 200, and image capture devices 124 and 126 may be positioned on or in a bumper region (e.g., one of bumper regions 210) of vehicle 200. And as shown in FIG. 2E, image capture devices 122, 124, and 126 may be positioned in the vicinity of the rearview mirror and/or near the driver seat of vehicle 200. The disclosed embodiments are not limited to any particular number and configuration of the image capture devices, and the image capture devices may be positioned in any appropriate location within and/or on vehicle 200.

[0070] It is to be understood that the disclosed embodiments are not limited to vehicles and could be applied in other contexts. It is also to be understood that disclosed embodiments are not limited to a particular type of vehicle 200 and may be applicable to all types of vehicles including automobiles, trucks, trailers, and other types of vehicles.

[0071] The first image capture device 122 may include any suitable type of image capture device. Image capture device 122 may include an optical axis. In one instance, the image capture device 122 may include an Aptina M9V024 WVGA sensor with a global shutter. In other embodiments, image capture device 122 may provide a resolution of 1280x960 pixels and may include a rolling shutter. Image capture device 122 may include various optical elements. In some embodiments one or more lenses may be included, for example, to provide a desired focal length and field of view for the image capture device. In some embodiments, image capture device 122 may be associated with a 6mm lens or a 12mm lens. In some embodiments, image capture device 122 may be configured to capture images having a desired field-of-view

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(FOV) 202, as illustrated in FIG. 2D. For example, image capture device 122 may be configured to have a regular FOV, such as within a range of 40 degrees to 56 degrees, including a 46 degree FOV, 50 degree FOV, 52 degree FOV, or greater. Alternatively, image capture device 122 may be configured to have a narrow FOV in the range of 23 to 40 degrees, such as a 28 degree FOV or 36 degree FOV. In addition, image capture device 122 may be configured to have a wide FOV in the range of 100 to 180 degrees. In some embodiments, image capture device 122 may include a wide angle bumper camera or one with up to a 180 degree FOV.

[0072] The first image capture device 122 may acquire a plurality of first images relative to a scene associated with the vehicle 200. Each of the plurality of first images may be acquired as a series of image scan lines, which may be captured using a rolling shutter. Each scan line may include a plurality of pixels.

[0073] The first image capture device 122 may have a scan rate associated with acquisition of each of the first series of image scan lines. The scan rate may refer to a rate at which an image sensor can acquire image data associated with each pixel included in a particular scan line.

[0074] Image capture devices 122, 124, and 126 may contain any suitable type and number of image sensors, including CCD sensors or CMOS sensors, for example. In one embodiment, a CMOS image sensor may be employed along with a rolling shutter, such that each pixel in a row is read one at a time, and scanning of the rows proceeds on a row-by-row basis until an entire image frame has been captured. In some embodiments, the rows may be captured sequentially from top to bottom relative to the frame.

[0075] The use of a rolling shutter may result in pixels in different rows being exposed and captured at different times, which may cause skew and other image artifacts in the captured image frame. On the other hand, when the image capture device 122 is configured to operate with a global or synchronous shutter, all of the pixels may be exposed for the same amount of time and during a common exposure period. As a result, the image data in a frame collected from a system employing a global shutter represents a snapshot of the entire FOV (such as FOV 202) at a particular time. In contrast, in a rolling shutter application, each row in a frame is exposed and data is capture at different times. Thus, moving objects may appear distorted in an image capture device having a rolling shutter. This phenomenon will be described in greater detail below.

[0076] The second image capture device 124 and the third image capturing device 126 may be any type of image capture device. Like the first image capture device 122, each of image capture devices 124 and 126 may include an optical axis. In one embodiment, each of image capture devices 124 and 126 may include an Aptina M9V024 WVGA sensor with a global shutter. Alternatively, each of image capture devices 124 and 126 may include a rolling shutter. Like image capture device 122, image capture devices 124 and 126 may be configured to include various tenses and optical elements. In some embodiments, lenses associated with image capture devices 124 and 126 may provide FOVs (such as FOVs 204 and 206) that are the same as, or narrower than, a FOV (such as FOV 202) associated with image capture device 122. For example, image capture devices 124 and 126 may have FOVs of 40 degrees, 30 degrees, 26 degrees, 23 degrees, 20 degrees, or less.

[0077] Image capture devices 124 and 126 may acquire a plurality of second and third images relative to a scene associated with the vehicle 200. Each of the plurality of second and third images may be acquired as a second and third series of image scan lines, which may be captured using a rolling shutter. Each scan line or row may have a plurality of pixels. Image capture devices 124 and 126 may have second and third scan rates associated with acquisition of each of image scan lines included in the second and third series.

[0078] Each image capture device 122, 124, and 126 may be positioned at any suitable position and orientation relative to vehicle 200. The relative positioning of the image capture devices 122, 124, and 126 may be selected to aid in fusing together the information acquired from the image capture devices. For example, in some embodiments, a FOV (such as FOV 204) associated with image capture device 124 may overlap partially or fully with a FOV (such as FOV 202) associated with image capture device 122 and a FOV (such as FOV 206) associated with image capture device 126.

[0079] Image capture devices 122, 124, and 126 may be located on vehicle 200 at any suitable relative heights. In one instance, there may be a height difference between the image capture devices 122, 124, and 126, which may provide sufficient parallax information to enable stereo analysis. For example, as shown in FIG. 2A, the two image capture devices 122 and 124 are at different heights. There may also be a lateral displacement difference between image capture devices 122, 124, and 126, giving additional parallax information for stereo analysis by processing unit 110, for example. The difference in the lateral displacement may be denoted by d_x, as shown in FIGS. 2C and 2D. In some embodiments, fore or aft displacement (e.g., range displacement) may exist between image capture devices 122, 124, and 126. For example, image capture device 122 may be located 0.5 to 2 meters or more behind image capture device 124 and/or image capture device 126. This type of displacement may enable one of the image capture devices to cover potential blind spots of the other image capture device(s).

[0080] Image capture devices 122 may have any suitable resolution capability (e.g., number of pixels associated with the image sensor), and the resolution of the image sensor(s) associated with the image capture device 122 may be higher, lower, or the same as the resolution of the image sensor(s) associated with image cap-

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ture devices 124 and 126. In some embodiments, the image sensor(s) associated with image capture device 122 and/or image capture devices 124 and 126 may have a resolution of 640 x 480, 1024 x 768, 1280 x 960, or any other suitable resolution.

[0081] The frame rate (e.g., the rate at which an image capture device acquires a set of pixel data of one image frame before moving on to capture pixel data associated with the next image frame) may be controllable. The frame rate associated with image capture device 122 may be higher, lower, or the same as the frame rate associated with image capture devices 124 and 126. The frame rate associated with image capture devices 122, 124, and 126 may depend on a variety of factors that may affect the timing of the frame rate. For example, one or more of image capture devices 122, 124, and 126 may include a selectable pixel delay period imposed before or after acquisition of image data associated with one or more pixels of an image sensor in image capture device 122, 124, and/or 126. Generally, image data corresponding to each pixel may be acquired according to a clock rate for the device (e.g., one pixel per clock cycle). Additionally, in embodiments including a rolling shutter, one or more of image capture devices 122, 124, and 126 may include a selectable horizontal blanking period imposed before or after acquisition of image data associated with a row of pixels of an image sensor in image capture device 122, 124, and/or 126. Further, one or more of image capture devices 122, 124, and/or 126 may include a selectable vertical blanking period imposed before or after acquisition of image data associated with an image frame of image capture device 122, 124, and 126.

[0082] These timing controls may enable synchronization of frame rates associated with image capture devices 122, 124, and 126, even where the line scan rates of each are different. Additionally, as will be discussed in greater detail below, these selectable timing controls, among other factors (e.g., image sensor resolution, maximum line scan rates, etc.) may enable synchronization of image capture from an area where the FOV of image capture device 122 overlaps with one or more FOVs of image capture devices 124 and 126, even where the field of view of image capture device 122 is different from the FOVs of image capture devices 124 and 126.

[0083] Frame rate timing in image capture device 122, 124, and 126 may depend on the resolution of the associated image sensors. For example, assuming similar line scan rates for both devices, if one device includes an image sensor having a resolution of 640 x 480 and another device includes an image sensor with a resolution of 1280 x 960, then more time will be required to acquire a frame of image data from the sensor having the higher resolution.

[0084] Another factor that may affect the timing of image data acquisition in image capture devices 122, 124, and 126 is the maximum line scan rate. For example, acquisition of a row of image data from an image sensor included in image capture device 122, 124, and 126 will require some minimum amount of time. Assuming no pixel delay periods are added, this minimum amount of time for acquisition of a row of image data will be related to the maximum line scan rate for a particular device. Devices that offer higher maximum line scan rates have the potential to provide higher frame rates than devices with lower maximum line scan rates. In some embodiments, one or more of image capture devices 124 and 126 may have a maximum line scan rate that is higher than a maximum line scan rate associated with image capture device 122. In some embodiments, the maximum line scan rate of image capture device 124 and/or 126 may be 1.25, 1.5, 1.75, or 2 times or more than a maximum line scan rate of image capture device 122.

[0085] In another embodiment, image capture devices 122, 124, and 126 may have the same maximum line scan rate, but image capture device 122 may be operated at a scan rate less than or equal to its maximum scan rate. The system may be configured such that one or more of image capture devices 124 and 126 operate at a line scan rate that is equal to the line scan rate of image capture device 122. In other instances, the system may be configured such that the line scan rate of image capture device 124 and/or image capture device 126 may be 1.25, 1.5, 1.75, or 2 times or more than the line scan rate of image capture device 122.

[0086] In some embodiments, image capture devices 122, 124, and 126 may be asymmetric. That is, they may include cameras having different fields of view (FOV) and focal lengths. The fields of view of image capture devices 122, 124, and 126 may include any desired area relative to an environment of vehicle 200, for example. In some embodiments, one or more of image capture devices 122, 124, and 126 may be configured to acquire image data from an environment in front of vehicle 200, behind vehicle 200, to the sides of vehicle 200, or combinations thereof.

[0087] Further, the focal length associated with each image capture device 122, 124, and/or 126 may be selectable (e.g., by inclusion of appropriate lenses etc.) such that each device acquires images of objects at a desired distance range relative to vehicle 200. For example, in some embodiments image capture devices 122, 124, and 126 may acquire images of close-up objects within a few meters from the vehicle. Image capture devices 122, 124, and 126 may also be configured to acquire images of objects at ranges more distant from the vehicle (e.g., 25 m, 50 m, 100 m, 150 m, or more). Further, the focal lengths of image capture devices 122, 124, and 126 may be selected such that one image capture device (e.g., image capture device 122) can acquire images of objects relatively close to the vehicle (e.g., within 10 m or within 20 m) while the other image capture devices (e.g., image capture devices 124 and 126) can acquire images of more distant objects (e.g., greater than 20 m, 50 m, 100 m, 150 m, etc.) from vehicle 200.

[0088] According to some embodiments, the FOV of one or more image capture devices 122, 124, and 126

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may have a wide angle. For example, it may be advantageous to have a FOV of 140 degrees, especially for image capture devices 122, 124, and 126 that may be used to capture images of the area in the vicinity of vehicle 200. For example, image capture device 122 may be used to capture images of the area to the right or left of vehicle 200 and, in such embodiments, it may be desirable for image capture device 122 to have a wide FOV (e.g., at least 140 degrees).

[0089] The field of view associated with each of image capture devices 122, 124, and 126 may depend on the respective focal lengths. For example, as the focal length increases, the corresponding field of view decreases.

[0090] Image capture devices 122, 124, and 126 may be configured to have any suitable fields of view. In one particular example, image capture device 122 may have a horizontal FOV of 46 degrees, image capture device 124 may have a horizontal FOV of 23 degrees, and image capture device 126 may have a horizontal FOV in between 23 and 46 degrees. In another instance, image capture device 122 may have a horizontal FOV of 52 degrees, image capture device 124 may have a horizontal FOV of 26 degrees, and image capture device 126 may have a horizontal FOV in between 26 and 52 degrees. In some embodiments, a ratio of the FOV of image capture device 122 to the FOVs of image capture device 124 and/or image capture device 126 may vary from 1.5 to 2.0. In other embodiments, this ratio may vary between 1.25 and 2.25.

[0091] System 100 may be configured so that a field of view of image capture device 122 overlaps, at least partially or fully, with a field of view of image capture device 124 and/or image capture device 126. In some embodiments, system 100 may be configured such that the fields of view of image capture devices 124 and 126, for example, fall within (e.g., are narrower than) and share a common center with the field of view of image capture device 122. In other embodiments, the image capture devices 122, 124, and 126 may capture adjacent FOVs or may have partial overlap in their FOVs. In some embodiments, the fields of view of image capture devices 122, 124, and 126 may be aligned such that a center of the narrower FOV image capture devices 124 and/or 126 may be located in a lower half of the field of view of the wider FOV device 122.

[0092] FIG. 2F is a diagrammatic representation of exemplary vehicle control systems, consistent with the disclosed embodiments. As indicated in FIG. 2F, vehicle 200 may include throttling system 220, braking system 230, and steering system 240. System 100 may provide inputs (e.g., control signals) to one or more of throttling system 220, braking system 230, and steering system 240 over one or more data links (e.g., any wired and/or wireless link or links for transmitting data). For example, based on analysis of images acquired by image capture devices 122, 124, and/or 126, system 100 may provide control signals to one or more of throttling system 220, braking system 230, and steering system 240 to navigate vehicle 200 (e.g., by causing an acceleration, a turn, a lane shift, etc.). Further, system 100 may receive inputs from one or more of throttling system 220, braking system 230, and steering system 24 indicating operating conditions of vehicle 200 (e.g., speed, whether vehicle 200 is braking and/or turning, etc.). Further details are provided in connection with FIGS. 4-7, below.

[0093] As shown in FIG. 3A, vehicle 200 may also include a user interface 170 for interacting with a driver or a passenger of vehicle 200. For example, user interface 170 in a vehicle application may include a touch screen 320, knobs 330, buttons 340, and a microphone 350. A driver or passenger of vehicle 200 may also use handles (e.g., located on or near the steering column of vehicle 200 including, for example, turn signal handles), buttons (e.g., located on the steering wheel of vehicle 200), and the like, to interact with system 100. In some embodiments, microphone 350 may be positioned adjacent to a rearview mirror 310. Similarly, in some embodiments, image capture device 122 may be located near rearview mirror 310. In some embodiments, user interface 170 may also include one or more speakers 360 (e.g., speakers of a vehicle audio system). For example, system 100 may provide various notifications (e.g., alerts) via speakers 360.

[0094] FIGS. 3B-3D are illustrations of an exemplary camera mount 370 configured to be positioned behind a rearview mirror (e.g., rearview mirror 310) and against a vehicle windshield, consistent with disclosed embodiments. As shown in FIG. 3B, camera mount 370 may include image capture devices 122, 124, and 126. Image capture devices 124 and 126 may be positioned behind a glare shield 380, which may be flush against the vehicle windshield and include a composition of film and/or anti-reflective materials. For example, glare shield 380 may be positioned such that it aligns against a vehicle windshield having a matching slope. In some embodiments, each of image capture devices 122, 124, and 126 may be positioned behind glare shield 380, as depicted, for example, in FIG. 3D. The disclosed embodiments are not limited to any particular configuration of image capture devices 122, 124, and 126, camera mount 370, and glare shield 380. FIG. 3C is an illustration of camera mount 370 shown in FIG. 3B from a front perspective.

[0095] As will be appreciated by a person skilled in the art having the benefit of this disclosure, numerous variations and/or modifications may be made to the foregoing disclosed embodiments. For example, not all components are essential for the operation of system 100. Further, any component may be located in any appropriate part of system 100 and the components may be rearranged into a variety of configurations while providing the functionality of the disclosed embodiments. Therefore, the foregoing configurations are examples and, regardless of the configurations discussed above, system 100 can provide a wide range of functionality to analyze the surroundings of vehicle 200 and navigate vehicle 200 in response to the analysis.

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[0096] As discussed below in further detail and consistent with various disclosed embodiments, system 100 may provide a variety of features related to autonomous driving and/or driver assist technology. For example, system 100 may analyze image data, position data (e.g., GPS location information), map data, speed data, and/or data from sensors included in vehicle 200. System 100 may collect the data for analysis from, for example, image acquisition unit 120, position sensor 130, and other sensors. Further, system 100 may analyze the collected data to determine whether or not vehicle 200 should take a certain action, and then automatically take the determined action without human intervention. For example, when vehicle 200 navigates without human intervention, system 100 may automatically control the braking, acceleration, and/or steering of vehicle 200 (e.g., by sending control signals to one or more of throttling system 220, braking system 230, and steering system 240). Further, system 100 may analyze the collected data and issue warnings and/or alerts to vehicle occupants based on the analysis of the collected data.

[0097] Further, consistent with disclosed embodiments, the functionality provided by system 100 may cause vehicle 200 to take different actions to navigate vehicle 200 within a lane and/or relative to other vehicles and/or objects. For example, system 100 may adjust the positioning of vehicle 200 relative to a lane within which vehicle 200 is traveling and/or relative to objects positioned near vehicle 200, select a particular lane for vehicle 200 to use while traveling, and take action in response to an encroaching vehicle, such as a vehicle attempting to move into the lane within which vehicle 200 is traveling. Additionally, system 100 may control the speed of vehicle 200 in different scenarios, such as when vehicle 200 is making a turn. System 100 may further cause vehicle 200 to mimic the actions of a leading vehicle or monitor a target vehicle and navigate vehicle 200 so that it passes the target vehicle. Additional details regarding the various embodiments that are provided by system 100 are provided below.

Forward-Facing Multi-Imaging System

[0098] As discussed above, system 100 may provide drive assist functionality that uses a multi-camera system. The multi-camera system may use one or more cameras facing in the forward direction of a vehicle. In other embodiments, the multi-camera system may include one or more cameras facing to the side of a vehicle or to the rear of the vehicle. In one embodiment, for example, system 100 may use a two-camera imaging system, where a first camera and a second camera (e.g., image capture devices 122 and 124) may be positioned at the front and/or the sides of a vehicle (e.g., vehicle 200). The first camera may have a field of view that is greater than, less than, or partially overlapping with, the field of view of the second camera. In addition, the first camera may be connected to a first image processor to perform monocular image analysis of images provided by the first camera, and the second camera may be connected to a second image processor to perform monocular image analysis of images provided by the second camera. The outputs (e.g., processed information) of the first and second image processors may be combined. In some embodiments, the second image processor may receive images from both the first camera and second camera to perform stereo analysis. In another embodiment, system 100 may use a three-camera imaging system where each of the cameras has a different field of view. Such a system may, therefore, make decisions based on information derived from objects located at varying distances both forward and to the sides of the vehicle. References to monocular image analysis may refer to instances where image analysis is performed based on images captured from a single point of view (e.g., from a single camera). Stereo image analysis may refer to instances where image analysis is performed based on two or more images captured with one or more variations of an image capture parameter. For example, captured images suitable for performing stereo image analysis may include images captured: from two or more different positions, from different fields of view, using different focal lengths, along with parallax information, etc.

[0099] For example, in one embodiment, system 100 may implement a three camera configuration using image capture devices 122-126. In such a configuration, image capture device 122 may provide a narrow field of view (e.g., 34 degrees, or other values selected from a range of about 20 to 45 degrees, etc.), image capture device 124 may provide a wide field of view (e.g., 150 degrees or other values selected from a range of about 100 to about 180 degrees), and image capture device 126 may provide an intermediate field of view (e.g., 46 degrees or other values selected from a range of about 35 to about 60 degrees). In some embodiments, image capture device 126 may act as a main or primary camera. Image capture devices 122-126 may be positioned behind rearview mirror 310 and positioned substantially side-by-side (e.g., 6 cm apart). Further, in some embodiments, as discussed above, one or more of image capture devices 122-126 may be mounted behind glare shield 380 that is flush with the windshield of vehicle 200. Such shielding may act to minimize the impact of any reflections from inside the car on image capture devices 122-126.

[0100] In another embodiment, as discussed above in connection with FIGS. 3B and 3C, the wide field of view camera (e.g., image capture device 124 in the above example) may be mounted lower than the narrow and main field of view cameras (e.g., image devices 122 and 126 in the above example). This configuration may provide a free line of sight from the wide field of view camera. To reduce reflections, the cameras may be mounted close to the windshield of vehicle 200, and may include polarizers on the cameras to damp reflected light.

[0101] A three camera system may provide certain per-

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formance characteristics. For example, some embodiments may include an ability to validate the detection of objects by one camera based on detection results from another camera. In the three camera configuration discussed above, processing unit 110 may include, for example, three processing devices (e.g., three EyeQ series of processor chips, as discussed above), with each processing device dedicated to processing images captured by one or more of image capture devices 122-126.

[0102] In a three camera system, a first processing device may receive images from both the main camera and the narrow field of view camera, and perform vision processing of the narrow FOV camera to, for example, detect other vehicles, pedestrians, lane marks, traffic signs, traffic lights, and other road objects. Further, the first processing device may calculate a disparity of pixels between the images from the main camera and the narrow camera and create a 3D reconstruction of the environment of vehicle 200. The first processing device may then combine the 3D reconstruction with 3D map data or with 3D information calculated based on information from another camera.

[0103] The second processing device may receive images from main camera and perform vision processing to detect other vehicles, pedestrians, lane marks, traffic signs, traffic lights, and other road objects. Additionally, the second processing device may calculate a camera displacement and, based on the displacement, calculate a disparity of pixels between successive images and create a 3D reconstruction of the scene (e.g., a structure from motion). The second processing device may send the structure from motion based 3D reconstruction to the first processing device to be combined with the stereo 3D images.

[0104] The third processing device may receive images from the wide FOV camera and process the images to detect vehicles, pedestrians, lane marks, traffic signs, traffic lights, and other road objects. The third processing device may further execute additional processing instructions to analyze images to identify objects moving in the image, such as vehicles changing lanes, pedestrians, etc.

[0105] In some embodiments, having streams of image-based information captured and processed independently may provide an opportunity for providing redundancy in the system. Such redundancy may include, for example, using a first image capture device and the images processed from that device to validate and/or supplement information obtained by capturing and processing image information from at least a second image capture device.

[0106] In some embodiments, system 100 may use two image capture devices (e.g., image capture devices 122 and 124) in providing navigation assistance for vehicle 200 and use a third image capture device (e.g., image capture device 126) to provide redundancy and validate the analysis of data received from the other two image capture devices. For example, in such a configuration, image capture devices 122 and 124 may provide images for stereo analysis by system 100 for navigating vehicle 200, while image capture device 126 may provide images for monocular analysis by system 100 to provide redundancy and validation of information obtained based on images captured from image capture device 122 and/or image capture device 124. That is, image capture device 126 (and a corresponding processing device) may be considered to provide a redundant sub-system for providing a check on the analysis derived from image capture devices 122 and 124 (e.g., to provide an automatic emergency braking (AEB) system).

[0107] One of skill in the art will recognize that the above camera configurations, camera placements, number of cameras, camera locations, etc., are examples only. These components and others described relative to the overall system may be assembled and used in a variety of different configurations without departing from the scope of the disclosed embodiments. Further details regarding usage of a multi-camera system to provide driver assist and/or autonomous vehicle functionality follow below.

[0108] FIG. 4 is an exemplary functional block diagram of memory 140 and/or 150, which may be stored/programmed with instructions for performing one or more operations consistent with the disclosed embodiments. Although the following refers to memory 140, one of skill in the art will recognize that instructions may be stored in memory 140 and/or 150.

[0109] As shown in FIG. 4, memory 140 may store a monocular image analysis module 402, a stereo image analysis module 404, a velocity and acceleration module 406, and a navigational response module 408. The disclosed embodiments are not limited to any particular configuration of memory 140. Further, application processor 180 and/or image processor 190 may execute the instructions stored in any of modules 402-408 included in memory 140. One of skill in the art will understand that references in the following discussions to processing unit 110 may refer to application processor 180 and image processor 190 individually or collectively. Accordingly, steps of any of the following processes may be performed by one or more processing devices.

[0110] In one embodiment, monocular image analysis module 402 may store instructions (such as computer vision software) which, when executed by processing unit 110, performs monocular image analysis of a set of images acquired by one of image capture devices 122, 124, and 126. In some embodiments, processing unit 110 may combine information from a set of images with additional sensory information (e.g., information from radar) to perform the monocular image analysis. As described in connection with FIGS. 5A-5D below, monocular image analysis module 402 may include instructions for detecting a set of features within the set of images, such as lane markings, vehicles, pedestrians, road signs, highway exit ramps, traffic lights, hazardous objects, and any other feature associated with an environment of a vehicle.

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Based on the analysis, system 100 (e.g., via processing unit 110) may cause one or more navigational responses in vehicle 200, such as a turn, a lane shift, a change in acceleration, and the like, as discussed below in connection with navigational response module 408.

[0111] In one embodiment, stereo image analysis module 404 may store instructions (such as computer vision software) which, when executed by processing unit 110, performs stereo image analysis of first and second sets of images acquired by a combination of image capture devices selected from any of image capture devices 122, 124, and 126. In some embodiments, processing unit 110 may combine information from the first and second sets of images with additional sensory information (e.g., information from radar) to perform the stereo image analysis. For example, stereo image analysis module 404 may include instructions for performing stereo image analysis based on a first set of images acquired by image capture device 124 and a second set of images acquired by image capture device 126. As described in connection with FIG. 6 below, stereo image analysis module 404 may include instructions for detecting a set of features within the first and second sets of images, such as lane markings, vehicles, pedestrians, road signs, highway exit ramps, traffic lights, hazardous objects, and the like. Based on the analysis, processing unit 110 may cause one or more navigational responses in vehicle 200, such as a turn, a lane shift, a change in acceleration, and the like, as discussed below in connection with navigational response module 408.

[0112] In one embodiment, velocity and acceleration module 406 may store software configured to analyze data received from one or more computing and electromechanical devices in vehicle 200 that are configured to cause a change in velocity and/or acceleration of vehicle 200. For example, processing unit 110 may execute instructions associated with velocity and acceleration module 406 to calculate a target speed for vehicle 200 based on data derived from execution of monocular image analysis module 402 and/or stereo image analysis module 404. Such data may include, for example, a target position, velocity, and/or acceleration, the position and/or speed of vehicle 200 relative to a nearby vehicle, pedestrian, or road object, position information for vehicle 200 relative to lane markings of the road, and the like. In addition, processing unit 110 may calculate a target speed for vehicle 200 based on sensory input (e.g., information from radar) and input from other systems of vehicle 200, such as throttling system 220, braking system 230, and/or steering system 240 of vehicle 200. Based on the calculated target speed, processing unit 110 may transmit electronic signals to throttling system 220, braking system 230, and/or steering system 240 of vehicle 200 to trigger a change in velocity and/or acceleration by, for example, physically depressing the brake or easing up off the accelerator of vehicle 200.

[0113] In one embodiment, navigational response module 408 may store software executable by processing unit 110 to determine a desired navigational response based on data derived from execution of monocular image analysis module 402 and/or stereo image analysis module 404. Such data may include position and speed information associated with nearby vehicles, pedestrians, and road objects, target position information for vehicle 200, and the like. Additionally, in some embodiments, the navigational response may be based (partially or fully) on map data, a predetermined position of vehicle 200, and/or a relative velocity or a relative acceleration between vehicle 200 and one or more objects detected from execution of monocular image analysis module 402 and/or stereo image analysis module 404. Navigational response module 408 may also determine a desired navigational response based on sensory input (e.g., information from radar) and inputs from other systems of vehicle 200, such as throttling system 220, braking system 230, and steering system 240 of vehicle 200. Based on the desired navigational response, processing unit 110 may transmit electronic signals to throttling system 220, braking system 230, and steering system 240 of vehicle 200 to trigger a desired navigational response by, for example, turning the steering wheel of vehicle 200 to achieve a rotation of a predetermined angle. In some embodiments, processing unit 110 may use the output of navigational response module 408 (e.g., the desired navigational response) as an input to execution of velocity and acceleration module 406 for calculating a change in speed of vehicle 200.

[0114] FIG. 5A is a flowchart showing an exemplary process 500A for causing one or more navigational responses based on monocular image analysis, consistent with disclosed embodiments. At step 510, processing unit 110 may receive a plurality of images via data interface 128 between processing unit 110 and image acquisition unit 120. For instance, a camera included in image acquisition unit 120 (such as image capture device 122 having field of view 202) may capture a plurality of images of an area forward of vehicle 200 (or to the sides or rear of a vehicle, for example) and transmit them over a data connection (e.g., digital, wired, USB, wireless, Bluetooth, etc.) to processing unit 110. Processing unit 110 may execute monocular image analysis module 402 to analyze the plurality of images at step 520, as described in further detail in connection with FIGS. SB-SD below. By performing the analysis, processing unit 110 may detect a set of features within the set of images, such as lane markings, vehicles, pedestrians, road signs, highway exit ramps, traffic lights, and the like.

[0115] Processing unit 110 may also execute monocular image analysis module 402 to detect various road hazards at step 520, such as, for example, parts of a truck tire, fallen road signs, loose cargo, small animals, and the like. Road hazards may vary in structure, shape, size, and color, which may make detection of such hazards more challenging. In some embodiments, processing unit 110 may execute monocular image analysis module 402 to perform multi-frame analysis on the plurality

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of images to detect road hazards. For example, processing unit 110 may estimate camera motion between consecutive image frames and calculate the disparities in pixels between the frames to construct a 3D-map of the road. Processing unit 110 may then use the 3D-map to detect the road surface, as well as hazards existing above the road surface.

[0116] At step 530, processing unit 110 may execute navigational response module 408 to cause one or more navigational responses in vehicle 200 based on the analysis performed at step 520 and the techniques as described above in connection with FIG. 4. Navigational responses may include, for example, a turn, a lane shift, a change in acceleration, and the like. In some embodiments, processing unit 110 may use data derived from execution of velocity and acceleration module 406 to cause the one or more navigational responses. Additionally, multiple navigational responses may occur simultaneously, in sequence, or any combination thereof. For instance, processing unit 110 may cause vehicle 200 to shift one lane over and then accelerate by, for example, sequentially transmitting control signals to steering system 240 and throttling system 220 of vehicle 200. Alternatively, processing unit 110 may cause vehicle 200 to brake while at the same time shifting lanes by, for example, simultaneously transmitting control signals to braking system 230 and steering system 240 of vehicle 200.

[0117] FIG. 5B is a flowchart showing an exemplary process 500B for detecting one or more vehicles and/or pedestrians in a set of images, consistent with disclosed embodiments. Processing unit 110 may execute monocular image analysis module 402 to implement process 500B. At step 540, processing unit 110 may determine a set of candidate objects representing possible vehicles and/or pedestrians. For example, processing unit 110 may scan one or more images, compare the images to one or more predetermined patterns, and identify within each image possible locations that may contain objects of interest (e.g., vehicles, pedestrians, or portions thereof). The predetermined patterns may be designed in such a way to achieve a high rate of "false hits" and a low rate of "misses." For example, processing unit 110 may use a low threshold of similarity to predetermined patterns for identifying candidate objects as possible vehicles or pedestrians. Doing so may allow processing unit 110 to reduce the probability of missing (e.g., not identifying) a candidate object representing a vehicle or pedestrian.

[0118] At step 542, processing unit 110 may filter the set of candidate objects to exclude certain candidates (e.g., irrelevant or less relevant objects) based on classification criteria. Such criteria may be derived from various properties associated with object types stored in a database (e.g., a database stored in memory 140). Properties may include object shape, dimensions, texture, position (e.g., relative to vehicle 200), and the like. Thus, processing unit 110 may use one or more sets of criteria to reject false candidates from the set of candidate objects.

[0119] At step 544, processing unit 110 may analyze multiple frames of images to determine whether objects in the set of candidate objects represent vehicles and/or pedestrians. For example, processing unit 110 may track a detected candidate object across consecutive frames and accumulate frame-by-frame data associated with the detected object (e.g., size, position relative to vehicle 200, etc.). Additionally, processing unit 110 may estimate parameters for the detected object and compare the object's frame-by-frame position data to a predicted position.

[0120] At step 546, processing unit 110 may construct a set of measurements for the detected objects. Such measurements may include, for example, position, velocity, and acceleration values (relative to vehicle 200) associated with the detected objects. In some embodiments, processing unit 110 may construct the measurements based on estimation techniques using a series of time-based observations such as Kalman filters or linear quadratic estimation (LQE), and/or based on available modeling data for different object types (e.g., cars, trucks, pedestrians, bicycles, road signs, etc.). The Kalman filters may be based on a measurement of an object's scale, where the scale measurement is proportional to a time to collision (e.g., the amount of time for vehicle 200 to reach the object). Thus, by performing steps 540-546, processing unit 110 may identify vehicles and pedestrians appearing within the set of captured images and derive information (e.g., position, speed, size) associated with the vehicles and pedestrians. Based on the identification and the derived information, processing unit 110 may cause one or more navigational responses in vehicle 200, as described in connection with FIG. 5A, above.

[0121] At step 548, processing unit 110 may perform an optical flow analysis of one or more images to reduce the probabilities of detecting a "false hit" and missing a candidate object that represents a vehicle or pedestrian. The optical flow analysis may refer to, for example, analyzing motion patterns relative to vehicle 200 in the one or more images associated with other vehicles and pedestrians, and that are distinct from road surface motion. Processing unit 110 may calculate the motion of candidate objects by observing the different positions of the objects across multiple image frames, which are captured at different times. Processing unit 110 may use the position and time values as inputs into mathematical models for calculating the motion of the candidate objects. Thus, optical flow analysis may provide another method of detecting vehicles and pedestrians that are nearby vehicle 200. Processing unit 110 may perform optical flow analysis in combination with steps 540-546 to provide redundancy for detecting vehicles and pedestrians and increase the reliability of system 100.

[0122] FIG. 5C is a flowchart showing an exemplary process 500C for detecting road marks and/or lane geometry information in a set of images, consistent with disclosed embodiments. Processing unit 110 may execute monocular image analysis module 402 to implement

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process 500C. At step 550, processing unit 110 may detect a set of objects by scanning one or more images. To detect segments of lane markings, lane geometry information, and other pertinent road marks, processing unit 110 may filter the set of objects to exclude those determined to be irrelevant (e.g., minor potholes, small rocks, etc.). At step 552, processing unit 110 may group together the segments detected in step 550 belonging to the same road mark or lane mark. Based on the grouping, processing unit 110 may develop a model to represent the detected segments, such as a mathematical model.

[0123] At step 554. processing unit 110 may construct a set of measurements associated with the detected segments. In some embodiments, processing unit 110 may create a projection of the detected segments from the image plane onto the real-world plane. The projection may be characterized using a 3rd-degree polynomial having coefficients corresponding to physical properties such as the position, slope, curvature, and curvature derivative of the detected road. In generating the projection, processing unit 110 may take into account changes in the road surface, as well as pitch and roll rates associated with vehicle 200. In addition, processing unit 110 may model the road elevation by analyzing position and motion cues present on the road surface. Further, processing unit 110 may estimate the pitch and roll rates associated with vehicle 200 by tracking a set of feature points in the one or more images.

[0124] At step 556, processing unit 110 may perform multi-frame analysis by, for example, tracking the detected segments across consecutive image frames and accumulating frame-by-frame data associated with detected segments. As processing unit 110 performs multi-frame analysis, the set of measurements constructed at step 554 may become more reliable and associated with an increasingly higher confidence level. Thus, by performing steps 550-556, processing unit 110 may identify road marks appearing within the set of captured images and derive lane geometry information. Based on the identification and the derived information, processing unit 110 may cause one or more navigational responses in vehicle 200, as described in connection with FIG. 5A, above.

[0125] At step 558, processing unit 110 may consider additional sources of information to further develop a safety model for vehicle 200 in the context of its surroundings. Processing unit 110 may use the safety model to define a context in which system 100 may execute autonomous control of vehicle 200 in a safe manner. To develop the safety model, in some embodiments, processing unit 110 may consider the position and motion of other vehicles, the detected road edges and barriers, and/or general road shape descriptions extracted from map data (such as data from map database 160). By considering additional sources of information, processing unit 110 may provide redundancy for detecting road marks and lane geometry and increase the reliability of system 100.

[0126] FIG. 5D is a flowchart showing an exemplary process 500D for detecting traffic lights in a set of images, consistent with disclosed embodiments. Processing unit 110 may execute monocular image analysis module 402 to implement process 500D. At step 560, processing unit 110 may scan the set of images and identify objects appearing at locations in the images likely to contain traffic lights. For example, processing unit 110 may filter the identified objects to construct a set of candidate objects, excluding those objects unlikely to correspond to traffic lights. The filtering may be done based on various properties associated with traffic lights, such as shape, dimensions, texture, position (e.g., relative to vehicle 200), and the like. Such properties may be based on multiple examples of traffic lights and traffic control signals and stored in a database. In some embodiments, processing unit 110 may perform multi-frame analysis on the set of candidate objects reflecting possible traffic lights. For example, processing unit 110 may track the candidate objects across consecutive image frames, estimate the real-world position of the candidate objects, and filter out those objects that are moving (which are unlikely to be traffic lights). In some embodiments, processing unit 110 may perform color analysis on the candidate objects and identify the relative position of the detected colors appearing inside possible traffic lights.

[0127] At step 562, processing unit 110 may analyze the geometry of a junction. The analysis may be based on any combination of: (i) the number of lanes detected on either side of vehicle 200, (ii) markings (such as arrow marks) detected on the road, and (iii) descriptions of the junction extracted from map data (such as data from map database 160). Processing unit 110 may conduct the analysis using information derived from execution of monocular analysis module 402. In addition, Processing unit 110 may determine a correspondence between the traffic lights detected at step 560 and the lanes appearing near vehicle 200.

[0128] As vehicle 200 approaches the junction, at step 564, processing unit 110 may update the confidence level associated with the analyzed junction geometry and the detected traffic lights. For instance, the number of traffic lights estimated to appear at the junction as compared with the number actually appearing at the junction may impact the confidence level. Thus, based on the confidence level, processing unit 110 may delegate control to the driver of vehicle 200 in order to improve safety conditions. By performing steps 560-564, processing unit 110 may identify traffic lights appearing within the set of captured images and analyze junction geometry information. Based on the identification and the analysis, processing unit 110 may cause one or more navigational responses in vehicle 200, as described in connection with FIG. 5A, above.

[0129] FIG. 5E is a flowchart showing an exemplary process 500E for causing one or more navigational responses in vehicle 200 based on a vehicle path, consistent with the disclosed embodiments. At step 570, processing unit 110 may construct an initial vehicle path

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associated with vehicle 200. The vehicle path may be represented using a set of points expressed in coordinates (x, z), and the distance d, between two points in the set of points may fall in the range of l to 5 meters. In one embodiment, processing unit 110 may construct the initial vehicle path using two polynomials, such as left and right road polynomials. Processing unit 110 may calculate the geometric midpoint between the two polynomials and offset each point included in the resultant vehicle path by a predetermined offset (e.g., a smart lane offset), if any (an offset of zero may correspond to travel in the middle of a lane). The offset may be in a direction perpendicular to a segment between any two points in the vehicle path. In another embodiment, processing unit 110 may use one polynomial and an estimated lane width to offset each point of the vehicle path by half the estimated lane width plus a predetermined offset (e.g., a smart lane offset).

[0130] At step 572, processing unit 110 may update the vehicle path constructed at step 570. Processing unit 110 may reconstruct the vehicle path constructed at step 570 using a higher resolution, such that the distance d_k between two points in the set of points representing the vehicle path is less than the distance d_f described above. For example, the distance d_i may fall in the range of 0.1 to 0.3 meters. Processing unit 110 may reconstruct the vehicle path using a parabolic spline algorithm, which may yield a cumulative distance vector S corresponding to the total length of the vehicle path (i.e., based on the set of points representing the vehicle path).

[0131] At step 574, processing unit 110 may determine a look-ahead point (expressed in coordinates as (x_l, z_l)) based on the updated vehicle path constructed at step 572. Processing unit 110 may extract the look-ahead point from the cumulative distance vector S, and the look-ahead point may be associated with a look-ahead distance and look-ahead time. The look-ahead distance, which may have a lower bound ranging from 10 to 20 meters, may be calculated as the product of the speed of vehicle 200 and the look-ahead time. For example, as the speed of vehicle 200 decreases, the look-ahead distance may also decrease (e.g., until it reaches the lower bound). The look-ahead time, which may range from 0.5 to 1.5 seconds, may be inversely proportional to the gain of one or more control loops associated with causing a navigational response in vehicle 200, such as the heading error tracking control loop. For example, the gain of the heading error tracking control loop may depend on the bandwidth of a yaw rate loop, a steering actuator loop, car lateral dynamics, and the like. Thus, the higher the gain of the heading error tracking control loop, the lower the look-ahead time.

[0132] At step 576, processing unit 110 may determine a heading error and yaw rate command based on the look-ahead point determined at step 574. Processing unit 110 may determine the heading error by calculating the arctangent of the look-ahead point, e.g., arctan (x_l/z_l). Processing unit 110 may determine the yaw rate command as the product of the heading error and a high-level control gain. The high-level control gain may be equal to: (2 / look-ahead time), if the look-ahead distance is not at the lower bound. Otherwise, the high-level control gain may be equal to: (2 * speed of vehicle 200 / look-ahead distance).

[0133] FIG. 5F is a flowchart showing an exemplary process 500F for determining whether a leading vehicle is changing lanes, consistent with the disclosed embodiments. At step 580, processing unit 110 may determine navigation information associated with a leading vehicle (e.g., a vehicle traveling ahead of vehicle 200). For example, processing unit 110 may determine the position, velocity (e.g., direction and speed), and/or acceleration of the leading vehicle, using the techniques described in connection with FIGS. 5A and 5B, above. Processing unit 110 may also determine one or more road polynomials, a look-ahead point (associated with vehicle 200), and/or a snail trail (e.g., a set of points describing a path taken by the leading vehicle), using the techniques described in connection with FIG. 5E, above.

[0134] At step 582, processing unit 110 may analyze the navigation information determined at step 580. In one embodiment, processing unit 110 may calculate the distance between a snail trail and a road polynomial (e.g., along the trail). If the variance of this distance along the trail exceeds a predetermined threshold (for example, 0.1 to 0.2 meters on a straight road, 0.3 to 0.4 meters on a moderately curvy road, and 0.5 to 0.6 meters on a road with sharp curves), processing unit 110 may determine that the leading vehicle is likely changing lanes. In the case where multiple vehicles are detected traveling ahead of vehicle 200, processing unit 110 may compare the snail trails associated with each vehicle. Based on the comparison, processing unit 110 may determine that a vehicle whose snail trail does not match with the snail trails of the other vehicles is likely changing lanes. Processing unit 110 may additionally compare the curvature of the snail trail (associated with the leading vehicle) with the expected curvature of the road segment in which the leading vehicle is traveling. The expected curvature may be extracted from map data (e.g., data from map database 160), from road polynomials, from other vehicles' snail trails, from prior knowledge about the road, and the like. If the difference in curvature of the snail trail and the expected curvature of the road segment exceeds a predetermined threshold, processing unit 110 may determine that the leading vehicle is likely changing lanes.

[0135] In another embodiment, processing unit 110 may compare the leading vehicle's instantaneous position with the look-ahead point (associated with vehicle 200) over a specific period of time (e.g., 0.5 to 1.5 seconds). If the distance between the leading vehicle's instantaneous position and the look-ahead point varies during the specific period of time, and the cumulative sum of variation exceeds a predetermined threshold (for example, 0.3 to 0.4 meters on a straight road, 0.7 to 0.8

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meters on a moderately curvy road, and 1.3 to 1.7 meters on a road with sharp curves), processing unit 110 may determine that the leading vehicle is likely changing lanes. In another embodiment, processing unit 110 may analyze the geometry of the snail trail by comparing the lateral distance traveled along the trail with the expected curvature of the snail trail. The expected radius of curvature may be determined according to the calculation: $(\delta_z^2 + \delta_x^2)/2/(\delta_x)$, where δ_x represents the lateral distance traveled and δ_x represents the longitudinal distance traveled. If the difference between the lateral distance traveled and the expected curvature exceeds a predetermined threshold (e.g., 500 to 700 meters), processing unit 110 may determine that the leading vehicle is likely changing lanes. In another embodiment, processing unit 110 may analyze the position of the leading vehicle. If the position of the leading vehicle obscures a road polynomial (e.g., the leading vehicle is overlaid on top of the road polynomial), then processing unit 110 may determine that the leading vehicle is likely changing lanes. In the case where the position of the leading vehicle is such that, another vehicle is detected ahead of the leading vehicle and the snail trails of the two vehicles are not parallel, processing unit 110 may determine that the (closer) leading vehicle is likely changing lanes.

[0136] At step 584, processing unit 110 may determine whether or not leading vehicle 200 is changing lanes based on the analysis performed at step 582. For example, processing unit 110 may make the determination based on a weighted average of the individual analyses performed at step 582. Under such a scheme, for example, a decision by processing unit 110 that the leading vehicle is likely changing lanes based on a particular type of analysis may be assigned a value of "1" (and "0" to represent a determination that the leading vehicle is not likely changing lanes). Different analyses performed at step 582 may be assigned different weights, and the disclosed embodiments are not limited to any particular combination of analyses and weights.

[0137] FIG. 6 is a flowchart showing an exemplary process 600 for causing one or more navigational responses based on stereo image analysis, consistent with disclosed embodiments. At step 610, processing unit 110 may receive a first and second plurality of images via data interface 128. For example, cameras included in image acquisition unit 120 (such as image capture devices 122 and 124 having fields of view 202 and 204) may capture a first and second plurality of images of an area forward of vehicle 200 and transmit them over a digital connection (e.g., USB, wireless, Bluetooth, etc.) to processing unit 110. In some embodiments, processing unit 110 may receive the first and second plurality of images via two or more data interfaces. The disclosed embodiments are not limited to any particular data interface configurations or protocols.

[0138] At step 620, processing unit 110 may execute stereo image analysis module 404 to perform stereo image analysis of the first and second plurality of images to create a 3D map of the road in front of the vehicle and detect features within the images, such as lane markings, vehicles, pedestrians, road signs, highway exit ramps, traffic lights, road hazards, and the like. Stereo image analysis may be performed in a manner similar to the steps described in connection with FIGS. 5A-5D, above. For example, processing unit 110 may execute stereo image analysis module 404 to detect candidate objects (e.g., vehicles, pedestrians, road marks, traffic lights, road hazards, etc.) within the first and second plurality of images, filter out a subset of the candidate objects based on various criteria, and perform multi-frame analysis, construct measurements, and determine a confidence level for the remaining candidate objects. In performing the steps above, processing unit 110 may consider information from both the first and second plurality of images, rather than information from one set of images alone. For example, processing unit 110 may analyze the differences in pixel-level data (or other data subsets from among the two streams of captured images) for a candidate object appearing in both the first and second plurality of images. As another example, processing unit 110 may estimate a position and/or velocity of a candidate object (e.g., relative to vehicle 200) by observing that the object appears in one of the plurality of images but not the other or relative to other differences that may exist relative to objects appearing if the two image streams. For example, position, velocity, and/or acceleration relative to vehicle 200 may be determined based on trajectories, positions, movement characteristics, etc. of features associated with an object appearing in one or both of the image streams.

[0139] At step 630, processing unit 110 may execute navigational response module 408 to cause one or more navigational responses in vehicle 200 based on the analysis performed at step 620 and the techniques as described above in connection with FIG. 4. Navigational responses may include, for example, a turn, a lane shift, a change in acceleration, a change in velocity, braking, and the like. In some embodiments, processing unit 110 may use data derived from execution of velocity and acceleration module 406 to cause the one or more navigational responses. Additionally, multiple navigational responses may occur simultaneously, in sequence, or any combination thereof.

[0140] FIG. 7 is a flowchart showing an exemplary process 700 for causing one or more navigational responses based on an analysis of three sets of images, consistent with disclosed embodiments. At step 710, processing unit 110 may receive a first, second, and third plurality of images via data interface 128. For instance, cameras included in image acquisition unit 120 (such as image capture devices 122, 124, and 126 having fields of view 202, 204, and 206) may capture a first, second, and third plurality of images of an area forward and/or to the side of vehicle 200 and transmit them over a digital connection (e.g., USB, wireless, Bluetooth, etc.) to processing unit 110. In some embodiments, processing

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unit 110 may receive the first, second, and third plurality of images via three or more data interfaces. For example, each of image capture devices 122, 124, 126 may have an associated data interface for communicating data to processing unit 110. The disclosed embodiments are not limited to any particular data interface configurations or protocols.

[0141] At step 720, processing unit 110 may analyze the first, second, and third plurality of images to detect features within the images, such as lane markings, vehicles, pedestrians, road signs, highway exit ramps, traffic lights, road hazards, and the like. The analysis may be performed in a manner similar to the steps described in connection with FIGS. 5A-5D and 6, above. For instance, processing unit 110 may perform monocular image analysis (e.g., via execution of monocular image analysis module 402 and based on the steps described in connection witb FIGS. 5A-5D, above) on each of the first, second, and third plurality of images. Alternatively, processing unit 110 may perform stereo image analysis (e.g., via execution of stereo image analysis module 404 and based on the steps described in connection with FIG. 6, above) on the first and second plurality of images, the second and third plurality of images, and/or the first and third plurality of images. The processed information corresponding to the analysis of the first, second, and/or third plurality of images may be combined. In some embodiments, processing unit 110 may perform a combination of monocular and stereo image analyses. For example, processing unit 110 may perform monocular image analysis (e.g., via execution of monocular image analysis module 402) on the first plurality of images and stereo image analysis (e.g., via execution of stereo image analysis module 404) on the second and third plurality of images. The configuration of image capture devices 122, 124, and 126-including their respective locations and fields of view 202, 204, and 206 may influence the types of analyses conducted on the first, second, and third plurality of images. The disclosed embodiments are not limited to a particular configuration of image capture devices 122, 124, and 126, or the types of analyses conducted on the first, second, and third plurality of images.

[0142] In some embodiments, processing unit 110 may perform testing on system 100 based on the images acquired and analyzed at steps 710 and 720. Such testing may provide an indicator of the overall performance of system 100 for certain configurations of image capture devices 122, 124, and 126. For example, processing unit 110 may determine the proportion of "false hits" (e.g., cases where system 100 incorrectly determined the presence of a vehicle or pedestrian) and "misses."

[0143] At step 730, processing unit 110 may cause one or more navigational responses in vehicle 200 based on information derived from two of the first, second, and third plurality of images. Selection of two of the first, second, and third plurality of images may depend on various factors, such as, for example, the number, types, and sizes of objects detected in each of the plurality of images. Processing unit 110 may also make the selection based on image quality and resolution, the effective field of view reflected in the images, the number of captured frames, the extent to which one or more objects of interest actually appear in the frames (e.g., the percentage of frames in which an object appears, the proportion of the object that appears in each such frame, etc.), and the like.

[0144] In some embodiments, processing unit 110 may select information derived from two of the first, second, and third plurality of images by determining the extent to which information derived from one image source is consistent with information derived from other image sources. For example, processing unit 110 may combine the processed information derived from each of image capture devices 122, 124, and 126 (whether by monocular analysis, stereo analysis, or any combination of the two) and determine visual indicators (e.g., lane markings, a detected vehicle and its location and/or path, a detected traffic light, etc.) that are consistent across the images captured from each of image capture devices 122, 124, and 126. Processing unit 110 may also exclude information that is inconsistent across the captured images (e.g., a vehicle changing lanes, a lane model indicating a vehicle that is too close to vehicle 200, etc.). Thus, processing unit 110 may select information derived from two of the first, second, and third plurality of images based on the determinations of consistent and inconsistent information.

[0145] Navigational responses may include, for example, a turn, a lane shift, a change in acceleration, and the like. Processing unit 110 may cause the one or more navigational responses based on the analysis performed at step 720 and the techniques as described above in connection with FIG. 4. Processing unit 110 may also use data derived from execution of velocity and acceleration module 406 to cause the one or more navigational responses. In some embodiments, processing unit 110 may cause the one or more navigational responses based on a relative position, relative velocity, and/or relative acceleration between vehicle 200 and an object detected within any of the first, second, and third plurality of images. Multiple navigational responses may occur simultaneously, in sequence, or any combination thereof.

Smart Lane Offset

[0146] System 100 may provide driver assist functionality that monitors and adjusts the free space between vehicle 200 and boundaries (e.g., lane boundaries) within which vehicle 200 is traveling. A lane may refer to a designated or intended travel path of a vehicle and may have marked (e.g., lines on a road) or unmarked boundaries (e.g., an edge of a road, a road barrier, guard rail, parked vehicles, etc.). For instance, as a default, system 100 may maximize or increase the free space between vehicle 200 and the current lane boundaries. Further, under certain conditions, system 100 may offset vehicle 200 toward one side of the current lane of travel without leav-

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ing the lane. For example, where vehicle 200 is traveling around a curve, system 100 may decrease the offset towards the inside of the curve (e.g., adjust the position of vehicle 200 so that it is closer to the inside of the curve). As another example, where obstacles-such as parked cars, pedestrians, or cyclists-are present on one side of the lane, system 100 may increase the offset on the side of vehicle 200 where the obstacles are located (e.g., adjust the position of vehicle 200 so that it is further from the obstacles).

[0147] FIG. 8A illustrates vehicle 200 traveling on a roadway 800 in which the disclosed systems and methods for identifying lane constraints and operating vehicle 200 within the lane constraints may be used. As shown, vehicle 200 may have a first vehicle side 802, which may be a first distance 805 from a first lane constraint 810. Similarly, vehicle 200 may have a second vehicle side 812 opposite from first vehicle side 802, and second vehicle side 812 may be a second distance 815 from second lane constraint 820. In this manner, first lane constraint 810 and second lane constraint 820 may define a lane within which vehicle 200 may travel.

[0148] Processing unit 110 may be configured to determine first lane constraint 810 and second lane constraint 820 based on a plurality of images acquired by image capture device 122-126 that processing unit 110 may receive via data interface 128. According to some embodiments, first lane constraint 810 and/or second lane constraint 820 may be identified by visible lane boundaries, such as dashed or solid lines marked on a road surface. Additionally or alternatively, first lane constraint 810 and/or second lane constraint 820 may include an edge of a road surface or a barrier. Additionally or alternatively, first lane constraint 810 and/or second lane constrain 820 may include markers (e.g., Botts' dots). According to some embodiments, processing unit 110 may determine first lane constraint 810 and/or second lane constraint 820 by identifying a midpoint of a road surface width. According to some embodiments, if processing unit 110 identifies only first lane constraint 810, processing unit 110 may estimate second lane constraint 820, such as based on an estimated lane width or road width. Processing unit 110 may identify lane constraints in this manner when, for example, lines designating road lanes are not painted or otherwise labeled.

[0149] Detection of first lane constraint 810 and/or second lane constraint 820 may include processing unit 110 determining their 3D models in camera coordinate system. For example, the 3D models of first lane constraint 810 and/or second lane constraint 820 may be described by a third-degree polynomial. In addition to 3D modeling of first lane constraint 810 and/or second lane constraint 820, processing unit 110 may perform multi-frame estimation of host motion parameters, such as the speed, yaw and pitch rates, and acceleration of vehicle 200. Optionally, processing unit 110 may detect static and moving vehicles and their position, heading, speed, and acceleration, all relative to vehicle 200. Processing unit 110 may further determine a road elevation model to transform all of the information acquired from the plurality of images into 3D space.

[0150] Generally, as a default condition, vehicle 200 may travel relatively centered within first and second lane constraints 810 and/or 820. However, in some circumstances, environmental factors may make this undesirable or unfeasible, such as when objects or structures are present on one side of the road. Thus, there may be circumstances in which it may be desirable or advantageous for vehicle 200 to be closer to one lane constraint or the other. Processing unit 110 may also be configured to determine whether such circumstances, called lane offset conditions, exist based on the plurality of images.

[0151] To determine whether lane offset conditions exist, processing unit 110 may be configured to determine the presence of one or more objects 825 in the vicinity of vehicle 200. For example object 825 may comprise another vehicle, such as a car, truck or motorcycle traveling on roadway 800. Processing unit 110 may determine, for each object 825, an offset profile. The offset profile may include a determination of whether in its current and predicted position object 825 will be within a predefined range of vehicle 200. If processing unit 110 determines that object 825 is or will be within a predefined range of vehicle 200, processing unit 110 may determine whether there is enough space within first lane constraint 810 and second lane constraint 820, for vehicle 200 to bypass object 825. If there is not enough space, processing unit 110 may execute a lane change. If there is enough space, processing unit 110 may determine whether there is enough time to bypass object 825 before the distance between vehicle 200 and object 825 closes. If there is enough time, processing unit 110 may initiate and or activate the offset maneuver to bypass object 825. The offset maneuver may be executed by processing unit 110 so that the movement of vehicle 200 is smooth and comfortable for the driver. For example, the offset slew rate may be approximately 0.15 to 0.75 m/sec. The offset maneuver may be executed so that the maximum amplitude of the offset maneuver will occur when the gap between vehicle 200 and object 825 closes. If there is not enough time, processing unit 110 may initiate braking (e.g., by transmitting electronic signals to braking system 230) and then initiate offset maneuver.

[0152] After each offset profile is set for each object 825, processing unit may combine offset profiles such that the maximum lateral distance is kept from each object 825 that vehicle 200 is bypassing. That is, offset maneuvers may be modified and/or executed such that the lateral distance between vehicle 200 and each object 825 that vehicle 200 is bypassing is maximized.

[0153] Additionally or alternatively, object 825 may be a parked or stationary vehicle, a wall, or a person, such as pedestrian or cycling traffic. Processing unit 110 may determine a lane offset condition exists based on certain characteristics of object 825. For example, processing unit 110 may determine object 825 constitutes a lane

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offset condition if the height of object 825 exceeds a predetermined threshold, such as 10 cm from a road surface. In this manner, processing unit 110 may be configured to filter out objects that would not present a lane offset condition, such as small pieces of debris.

[0154] Additionally or alternatively, processing unit 110 may be configured to determine whether a lane offset condition exists on first vehicle side 802 based on a position of a target objcct 830 on vehicle first side 802. Target object 830 may include one or more objects that constitute a lane offset condition. Additionally or alternatively, target object 830 may not constitute a lane offset condition. For example, target object 830 may be a street sign or other object a sufficient distance from the travel lane or occurring with sufficient infrequency to not constitute a lane offset condition. Processing unit 110 may be configured to conclude a lane offset condition does not exist if such a target object 830 is detected.

[0155] Processing unit 110 may be configured to cause vehicle 200 to travel such that first distance 805 and second distance 810 are substantially different to avoid or stay farther away from object 825. For example, if a lane offset condition exists on first vehicle side 802, processing unit 110 may be configured to cause vehicle 200 to travel within first lane constraint 810 and second lane constraint 820 such that first distance 805 is greater than second distance 815. This is illustrated, for example, in FIG. 8A. Alternatively, if a lane offset condition exists on second vehicle side 812, processing unit 110 may create or execute an offset profile that is configured to cause vehicle 200 to travel within first lane constraint 810 and second lane constraint 820 such that first distance 805 is less than second distance 815. This is illustrated, for example, in FIG 8B.

[0156] As another example, a parked vehicle may be located on one side of vehicle 200 and a pedestrian may be located on the other side of vehicle 200. In such a situation, system 100 may determine that is desirable to reduce the distance between vehicle 200 and the parked vehicle, in order to provide more space between vehicle 200 and the pedestrian. Accordingly, processing unit 110 may cause vehicle 200 to travel such that the distance between the parked vehicle is reduced.

[0157] The identity of first vehicle side 802 and second vehicle side 812 need not be static, such that at different points in time, processing unit 110 may identify first vehicle side 802 as the driver's side or as the passenger's side of vehicle 200. For example, the identity of first vehicle side 802 may change depending on the presence of one or more objects 825 on that side of vehicle 200, such that if one lane offset condition exists based on object 825, it exists on first vehicle side 802. In such circumstances, processing unit 110 may create or execute an offset profile that is configured to cause vehicle 200 to travel within first lane constraint 810 and second lane constraint 820 such that first distance 805, which is greater than second distance 815, is provided toward object 825.

[0158] According to some embodiments, when a lane offset condition exists on first vehicle side 802, processing unit 110 may create an offset profile configured to cause vehicle 200 to travel within first lane constraint 810 and second lane constraint 820 such that first distance 805 is at least 1.25 times greater than second distance 815. Additionally or alternatively, when a lane offset condition exists on first vehicle side 802, processing unit 110 may create an offset profile that is configured to cause vehicle 200 to travel within first lane constraint 810 and second lane constraint 820 such that first distance 805 is at least 2 times greater than second distance 815.

[0159] In some embodiments, as shown in FIG. 8C, processing unit 110 may determine a lane offset condition exists on both first vehicle side 802 and on second vehicle side 812. Processing unit 110 may then create an offset profile for this offset condition that is configured to cause vehicle 200 to travel within first lane constraint 810 and second lane constraint 820 such that first distance 805 is substantially the same as second distance 815.

[0160] Processing unit 110 may be configured so that the offset profiles for moving objects 825 as well as stationary objects 825 are prioritized. For example, processing unit 110 may prioritize offset profiles to keep a predefined distance between vehicle 200 and moving objects 825 and/or static objects 825. Processing unit 200 may prioritize these offset conditions over those offset conditions based on certain lane characteristics, such as a curve. The last priority lane offset condition may include mimicking a lead vehicle.

[0161] Processing unit 110 may factor offset profiles or offset conditions into a desired look-ahead point, which may be located at the middle of the lane defined by first lane constraint 810 and second lane constraint 820. Processing unit 110 may compute and implement a yaw rate command based on the look-ahead point and the offset profiles. The yaw rate command may be used to compute a torque command based on the yaw rate command and the yaw rate of vehicle 200 measured by using a gyroscope. Processing unit 110 may transmit the torque command to a steering system (e.g., steering system 240) of vehicle 200.

[0162] According to some embodiments, input from a driver of vehicle 200, such as via user interface 170, may override processing unit 110. For example, a user input may override the control of processing unit 110 to cause vehicle 200 to travel within first lane constraint 810 and second lane constraint 820 such that first distance 805 is greater than second distance 815.

[0163] Additionally or alternatively, processing unit 110 may be configured to determine, based on the plurality of images captured by image capture device 122, whether a lane offset condition is substantially non-existent. This may include circumstances in which one or more objects 825 below a certain size threshold are detected, one or more objects 825 detected are outside of a predetermined distance from the lane constraint, and/or

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when no objects 825 are detected. Under such circumstances, processing unit 110 may be configured to cause vehicle 200 to travel within first lane constraint 810 and second lane constraint 820 such that first distance 805 is equal to or substantially equal to second distance 815.

[0164] A lane offset condition may include a curved road, as illustrated in FIG. 8D. Processing unit 110 may be configured to cause vehicle 200 to travel within first lane constraint 810 and second lane constraint 820 such that first distance 805 is toward the outside of the curved road relative to vehicle 200 and second distance 815 is toward an inside of the curved road relative to vehicle 200. For example, first distance 805 may be less than second distance 815.

[0165] FIG. 9 is an exemplary block diagram of memory 140 and/or 150, which may store instructions for performing one or more operations consistent with disclosed embodiments. As illustrated in FIG. 9, memory 140 may store one or more modules for performing the lane offset condition detection and responses described herein. For example, memory 140 may store a lane constraint module 910 and a lane offset module 920. Application processor 180 and/or image processor 190 may execute the instructions stored in any of modules 910 and 920 included in memory 140. One of skill in the art will understand that references in the following discussions to processing unit 110 may refer to application processor 180 and image processor 190 individually or collectively. Accordingly, steps of any of the following processes may be performed by one or more processing devices.

[0166] Lane constraint module 910 may store instructions which, when executed by processing unit 110, may detect and define first lane constraint 810 and second lane constraint 820. For example, lane offset module 910 may process the plurality of images received from at least one image capture device 122-124 to detect first lane constraint 810 and second lane constraint 820. As discussed above, this may include identifying painted lane lines and/or measuring a midpoint of a road surface.

[0167] Lane offset module 920 may store instructions which, when executed by processing unit 110, may detect the presence of a lane offset condition and/or identify whether lane offset condition is present on first vehicle side 802 and/or second vehicle side 812. For example, lane offset module 920 may process the plurality of images to detect the presence of object(s) 825 on first vehicle side 802 and/or second vehicle side 812. Lane offset module 920 may process the plurality of images to detect a curve in the road on which vehicle 200 is traveling. Additionally or alternatively, lane offset module 920 may receive information from another module or other system indicative of the presence of object(s) 825 and/or a curved lane. Lane offset module 920 may execute control to change the position of vehicle 200 to first lane constraint 810 and/or second lane constraint 820. For example, if lane offset module 920 determines a lane offset condition only on first vehicle side 802, lane offset module 920 may move vehicle 200 closer to second lane constraint 820. On the other hand, if lane offset module 920 determines a lane offset condition only on first vehicle side 812, lane offset module 920 may move vehicle 200 closer to first lane constraint 810.

[0168] Fig. 10 illustrates a process 1000 for navigating vehicle 200, consistent with disclosed embodiments. Process 1000 may identify lane constraints that define a lane of travel for vehicle travel. Process 1000 include causing vehicle 200 to travel closer to one or the other lane constraint, such as first lane constraint 810 or second lane constraint 820, in response to detecting a lane offset condition. In this manner, process 1000 may be used to drive vehicle 200 within lane constraints as well as account for environmental factors that may make it more desirable to shift vehicle 200 within first lane constraint 810 and second lane constraint 820.

[0169] At step 1010, process 1000 may include acquiring, using at least one image capture device 122, 124, and/or 126, a plurality of images of an area in the vicinity of vehicle 200. For example, processing unit 110 may receive the plurality of images may through data interface 128. For example, processing unit 110 may be configured to determine the presence of one or more objects 825 on the side of the road. For example, object 825 may be a parked or stationary vehicle, a wall, or a person, such as pedestrian or cycling traffic. Processing unit 110 may determine if a lane offset condition exists based on certain characteristics of object 825. For example, processing unit 110 may determine that object 825 constitutes a lane offset condition if the height of object 825 exceeds a predetermined threshold, such as 10 cm from a road surface. In this manner, processing unit 110 may be configured to filter out objects that would not present a lane offset condition, such as small pieces of debris.

[0170] Additionally or alternatively, processing unit 110 may be configured to determine whether a lane offset condition exists on first vehicle side 802 based on a position of a target object 830 on vehicle first side 802. Target object 830 may be one or more objects that constitute a lane offset condition. Additionally or alternatively, target object 830 may not constitute a lane offset condition. For example, target object 830 may be a road barrier or a street sign. Processing unit 110 may be configured to conclude a lane offset condition does not exist if such a target object 830 is detected.

[0171] At step 1020, process 1000 may determine from the plurality of images a first lane constraint on first vehicle side 802 and a second lane constraint on second vehicle side 812. For example, processing unit 110 may be configured to determine first lane constraint 810 and second lane constraint 820 based on the plurality of images received via data interface 128.

[0172] At step 1030, process 1000 may determine whether a lane offset condition exists on first vehicle side 802. If a lane offset condition does exist on first vehicle side 802, at step 1040, process 1000 may include causing vehicle 200 to travel within first lane constraint 810 and second lane constraint 820 such that second dis-

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tance 815 is less than first distance 805. Processing unit 110 may be configured to cause vehicle 200 to travel such that first distance 805 and second distance 810 are substantially different to avoid or stay farther away from object 825. For example, if a lane offset condition exists on first vehicle side 802, processing unit 110 may be configured to cause vehicle 200 to travel within first lane constraint 810 and second lane constraint 820 such that first distance 805 is greater than second distance 815. This is illustrated, for example, in FIG. 8A. Alternatively, if a lane offset condition exists on second vehicle side 812, processing unit 110 may be configured to cause vehicle 200 to travel within first lane constraint 810 and second lane constraint 820 such that first distance 805 is less than second distance 815. This is illustrated, for example, in FIG 8B. For example, to navigate vehicle 200 according to process 1000, processing unit 110 may transmit electronic signals to one or more of throttling system 220, braking system 230, and/or steering system 240 of vehicle 200.

[0173] If a lane offset condition does not exist on first vehicle side 802, in step 1050, method may include determining whether lane offset condition exists on second vehicle side 812. If a lane offset condition exists on second vehicle side 812, the method may include causing vehicle 200 to travel between first lane constraint 810 and second lane constraint 820 such that first distance 805 is less than second distance 815.

Navigating a Vehicle to a Default Lane

[0174] System 100 may provide driver assist functionality that monitors the location of vehicle 200 in a current lane of travel and moves vehicle 200 into a predetermined default travel lane if the current lane of travel is not the predetermined default travel lane. The predetermined default travel lane may be defined by a user input and/or as a result of processing images received from at least one image capture device 122-126.

[0175] System 100 may also provide notification of an impending lane change of vehicle 200 to the predetermined default travel lane to the driver and passengers of vehicle 200 and/or other drivers. For example, system 100 may activate a turn signal positioned at or near one of bumper regions 210. Additionally or alternatively, system 100 may sound an audible notification, such as through speakers 360. Vehicle 200 may use system 100 to select a particular lane as predetermined default travel lane when vehicle is traveling. When the current lane within which vehicle 200 is traveling-e.g., the current lane of travel-differs from the predetermined default travel lane, system 100 may cause vehicle 200 to make a lane change, e.g., into the predetermined default travel lane.

[0176] FIG. 11 illustrates vehicle 200 traveling in a current lane of travel 1110 of roadway 800. According to some embodiments, vehicle 200 may have a predetermined default travel lane 1120. For example, predetermined default travel lane 1120 may be the right-most lane of roadway 800. Navigation system 100 may be configured to determine whether vehicle 200 is traveling in predetermined default travel lane 1120 and, if not, cause vehicle 200 to change to predetermined default travel lane 1120. For example, processing unit 110 may be configured to compare current lane of travel 1110 with predetermined default travel lane 1120 and cause vehicle 200 to return to predetermined default travel lane 1120.

[0177] According to some embodiments, processing unit 110 may detect an object 1130 in predetermined default travel lane 1120 based on a plurality of images acquired by one or more of image capture devices 122-126. Processing unit 110 may detect the position and speed of vehicle 200 relative to object 1130 by analyzing the images using techniques described in connection with FIGS. 5A-5D, above. According to some embodiments, processing unit 110 may determine whether vehicle 200 should pass object 1130. This may be desirable if, for example, the speed and/or acceleration of vehicle 200 relative to object 1130 exceeds a certain threshold.

[0178] FIG. 12A is an exemplary block diagram of memory 140, which may store instructions for performing one or more operations consistent with disclosed embodiments. As illustrated in FIG. 12A, memory 140 may store one or more modules for performing the default travel lane and current travel lane detection and responses described herein. For example, memory 140 may store a current lane detection module 1210, a default lane detection module 1220, and an action module 1230.

[0179] Current lane detection module 1210 may store instructions which, when executed by processing unit 110, may detect and define current lane of travel 1110. For example, processing unit 110 may execute current lane detection module 1212 to process the plurality of images received from at least one image capture device 122-124 and detect current lane of travel 1110. This may include detecting the relative position of vehicle 200 with respect to the edge of roadway 800, a midpoint of roadway 800, and/or lane markers, such as painted lane lines. Processing unit 110 may detect the position of vehicle 200 relative to roadway 800 by analyzing the images using techniques described in connection with FIGS. 5A-5D, above.

[0180] Default lane detection module 1220 may store instructions which, when executed by processing unit 110, may identify predetermined default travel lane 1120 and compare default lane detection module 1220 to current lane of travel 1110 identified by current lane detection module 1210. Default lane detection module 1220 may identify predetermined default travel lane 1120 based upon a user input and/or the plurality of images received from at least one image capture device 122-124. For example, a user may select a default lane through voice commands received by speakers 360 or by making a selection on a menu displayed on touch screen 320.

[0181] In some embodiments, predetermined default travel lane 1120 may be the right-most travel lane, or it

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may be the lane that has the more desirable features. For example, default lane detection module 1220 may include instructions to select the lane with less traffic, the lane in which vehicles are traveling closest to speed of vehicle 200, and/or a lane closest to an approaching exit or street to which vehicle 200 will turn. In some embodiments, predetermined default travel lane 1120 may be determined based on data received from position sensor 130, such as a global positioning system.

[0182] Action module 1230 may store instructions which, when executed by processing unit 110, may cause a response to the identification of current lane of travel 1110 and predetermined default travel lane 1120. For example, processing unit 110 may execute action module 1230 to cause vehicle 200 to change lanes if current lane of travel 1110 is not the same as predetermined default travel lane 1120. Additionally or alternatively, action module 1230 may initiate a notification of the lane change, such as activating turn signal 210 and or causing an audible announcement.

[0183] Action module 1230 may include instructions that cause processing unit 110 to determine whether vehicle 200 should move out of predetermined default travel lane 1120. For example, action module 1230 may determine that object 1130 in predetermined default travel lane 1120 should be bypassed by vehicle 200.

[0184] Action module 1230 may further include instructions that cause processing unit 110 to determine whether it is safe to make a lane change. For example, prior to executing a lane change, processing unit 110 may evaluate determine one or more characteristics of roadway 800 based on, for example, analysis of the plurality of images conducted using techniques described in connection with FIGS. 5A-5D, above. If the analysis indicates conditions are not safe to change lanes, processing unit 110 may determine that vehicle 200 should stay in the current lane.

[0185] Action module 1230 may include additional instructions for manipulating vehicle 200 to maneuver out of and return to predetermined default travel lane 1120, such as for bypassing object 1130. When executing these instructions, processing unit 110 may estimate a location of predetermined default travel lane 1120 using estimated motion of vehicle 200. This may be advantageous in circumstances in which predetermined default travel lane 1120 does not remain detectable by image capture devices 122-124.

[0186] Processing unit 110 may be configured to execute an offset profile that offsets vehicle 200 from predetermined default travel lane 1120 by a full lane width, which may be estimated based on the distance between detected lane markers. The offset maneuver defined by offset profile may be executed by processing unit 110 so that the movement of vehicle 200 is smooth and comfortable for the driver. For example, the offset slew rate may be approximately 0.15 to 0.75 m/sec. During the offset maneuver, processing unit 110 may execute instructions from action module 1230 that switch to following the center of current lane of travel 1110. These instructions may include gradually transitioning from following the predicted lane with offset to following current lane of travel 1110. A gradual transition may be accomplished by defining desired look-ahead point so that it is not allowed to change in time more than the recommended slew rate, which may be around 0.25 m/sec.

[0187] The instructions for transitioning vehicle 200 from predetermined default travel lane 1120 may be used to transition vehicle 200 back into predetermined default travel lane. For example, processing unit 110 may be configured to execute an offset profile that offsets vehicle 200 from current lane of travel 1110 by a full lane width, which may be estimated based on the distance between detected lane markers. The offset maneuver defined by offset profile may be executed by processing unit 110 so that the movement of vehicle 200 is smooth and comfortable for the driver. For example, the offset slew rate may be approximately 0.15 to 0.75 m/sec. During the offset maneuver, processing unit 110 may execute instructions from action module 1230 that switch to following the center of predetermined default travel lane 1120. These instructions may include gradually transitioning from following the predicted lane with offset to following predetermined default travel lane 1120. A gradual transition may be accomplished by defining desired look-ahead point so that it is not allowed to change in time more than the recommended slew rate, which may be around 0.25 m/sec.

[0188] At one or more of the steps for transitioning vehicle 200 between two lanes, processing unit 110 may compute and implement a yaw rate command based on the look-ahead point and the offset profiles. The yaw rate command may be used to compute a torque command based on the yaw rate command and the yaw rate of vehicle 200 measured using a gyroscope. Processing unit 110 may transmit a torque command to a steering system (e.g., steering system 240) of vehicle 200.

[0189] FIG. 12B illustrates a process 1250 for navigating vehicle 200 to a default lane consistent with disclosed embodiments. According to some embodiments, process 1250 may be implemented by one or more components of navigation system 100, such as at least one processing unit 110. Process 1250 may identify current lane of travel 1110 of vehicle 200 and compare it with predetermined default travel lane 1120 to determine whether vehicle 200 is traveling within predetermined default travel lane 1120. If vehicle 200 is not travel ing in predetermined default travel lane 1120, processing unit 110 may cause vehicle 200 to change lanes so that it navigates to default travel lane 1120.

[0190] At step 1260, one or more of image capture devices 122-124 may acquire a plurality of images of an area in a vicinity of vehicle 200. Processing unit 110 may receive the plurality of images via data interface 128.

[0191] At step 1270, processing unit 110 may execute current lane detection module 1210 detect and define current lane of travel 1110. For example, processing unit

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110 may process the plurality of images to, for example, detect the relative position of vehicle 200 with respect to the edge of roadway 100, a midpoint of roadway 100, and/or painted lane markers. Processing unit 110 may detect the position of vehicle 200 relative to roadway 800 by analyzing the images using techniques described in connection with FIGS. 5A-5D, above.

[0192] At step 1280, processing unit 110 may execute default lane detection module 1220 to identify predetermined default travel lane 1120 and compare default lane detection module 1220 to current lane of travel 1110 identified by current lane detection module 1210. Default lane detection module 1220 may identify predetermined default travel lane 1120 based upon a user input and/or the plurality of images received from at least one image capture device 122-124.

[0193] For example, as discussed above, processing unit 110 may determine predetermined default travel lane 1120 based on any number of factors. Predetermined default travel lane 1120 may be the right-most lane among the plurality of travel lanes 1110 and 1120. Additionally or alternatively, predetermined default travel lane 1120 may be determined based on an input received from a user via user interface 170, by processing the plurality of images, and/or based on data received from position sensor 130, such as a global positioning system. Predetermined default travel lane 1120 may be determined once, once per vehicle trip, or on regular intervals. For example, predetermined default travel lane 1120 may be determined dynamically in response to conditions at a given location.

[0194] If current lane 1110 is not the same as predetermined default travel lane 1120, processing unit 110 may execute action module 1230 to cause vehicle 100 to navigate to default travel lane 1120. For example, processing unit 110 may transmit electronic signals to one or more of throttling system 220, braking system 230, and/or steering system 240 of vehicle 200 to trigger the desired response. For example, processing unit 110 may cause steering system 240 to turn the steering wheel of vehicle 200 to achieve a rotation of a predetermined angle.

[0195] Further, prior to executing a lane change, processing unit 110 may determine whether it is safe (e.g., there are no vehicles or objects in the way) to change lanes. As discussed above, processing unit 110 may evaluate one or more characteristics of roadway 800 based on, for example, analysis of the plurality of images conducted using techniques described in connection with FIGS. 5A-5D, above. If conditions are not safe to change lanes, processing unit 110 may determine that vehicle 200 should stay in the current lane.

[0196] In some embodiments, execution of action module 1230 may initiate a notification of the lane change. For example, processing unit 110 may cause a signal to activate a turn signal and/or cause an audible announcement via speakers 360. Accordingly, such notification may occur prior to vehicle 200 changing lanes. In other embodiments, execution of action module 1230 may initiate a notification to a driver of vehicle 200 that vehicle 200 is not traveling in a default lane without causing the lane change to occur. Accordingly, in such an embodiment, the driver of vehicle 200 may determine whether to manually take action and steer vehicle 200 to change lanes.

[0197] In some embodiments, system 100 may notify the user of vehicle 200 and/or other drivers in the vicinity of vehicle 200 that vehicle 200 will be changing lanes if vehicle 200 will be moved to predetermined default travel lane 1120. For example, processing unit 110 may activate a turn signal of vehicle 200 prior to causing vehicle 200 to change lanes. Additionally or alternatively, an audible announcement to notify other drivers in the vicinity may be caused by processing unit 110. The audible announcement may be transmitted via, for example, Bluetooth, to receivers included in other nearby vehicles. Additionally or alternatively, at least one processing unit 110 may cause an audible indicator to notify the driver of vehicle 200 prior to causing vehicle 200 to switch lanes. In this manner, driver of vehicle 200 can anticipate the control system 100 will exert on vehicle 200.

Controlling Velocity of a Turning Vehicle

[0198] System 100 may provide driver assist functionality that controls the velocity (i.e., speed and/or direction) of vehicle 200 in different scenarios, such as while making a turn (e.g., through a curve). For example, system 100 may be configured to use a combination of map, position, and/or visual data to control the velocity of vehicle 200 when turning. In particular, system 100 may control the velocity of vehicle 200 as it approaches a curve, while navigating a curve, and/or as it exits a curve. System 100 may consider different factors to control the velocity depending on the position of vehicle 200 relative to the curve at a given time. For example, system 100 may initially cause vehicle 200 to slow down in response to learning that a curve is located a certain distance ahead of vehicle 200. While vehicle 200 turns through the curve, however, system 100 may cause vehicle 200 to accelerate and/or charge direction based on an analysis of the characteristics of the curve.

[0199] FIGS. 13A and 13B are diagrammatic representations of a vehicle (e.g., vehicle 200) approaching, and navigating, a curve with one or more characteristics on road 1300, consistent with the disclosed embodiments. As illustrated in FIG. 13A, visual indicators, such as road sign 1302 located near road 1300, may inform vehicle 200 that a curve lies ahead. In response to the warning provided by road sign 1302, a driver of vehicle 200 and/or a system 100 providing driver assist functionality of vehicle 200 may adjust the velocity of vehicle 200 (e.g., by slowing down and/or steering) to safely navigate the curve.

[0200] As vehicle 200 approaches the curve, system 100 may detect the lane width 1306 and the curve radius

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1308 by using image capture devices 122 and/or 124 (which may be cameras) of vehicle 200. Based on the curve radius 1308, the lane width 1306, and other characteristics associated with the curve detected using image capture devices 122 and/or 124, system 100 may adjust the velocity of vehicle 200. Specifically, system 100 may adjust the velocity as vehicle 200 approaches the curve and/or while vehicle 200 navigates the curve. System 100 may also adjust the velocity as vehicle 200 exits the curve, in response to, for example, traffic light 1304 appearing after the curve. Further detail regarding adjustments to the velocity of vehicle 200 and detection of the lane width 1306, the radius of curvature or curve radius 1308, and characteristics associated with the curve are described in connection with FIGS. 14 and 15, below.

[0201] In some embodiments, system 100 may recognize a curve to be navigated based on map data and/or vehicle position information (e.g., GPS data). System 100 may determine an initial target velocity for the vehicle based on one or more characteristics of the curve as reflected in the map data. System 100 may adjust a velocity of the vehicle to the initial target velocity and determine, based on one or more images acquired by one or more of image capture devices 122-126, one or more observed characteristics of the curve. System 100 may determine an updated target velocity based on the one or more observed characteristics of the curve and adjust the velocity of the vehicle to the updated target velocity.

[0202] FIG. 14 is an exemplary block diagram of a memory configured to store instructions for performing one or more operations consistent with the disclosed embodiments. As indicated in FIG. 14, memory 140 may store a curve recognition module 1402, a characteristic observation module 1404, and a velocity module 1406. The disclosed embodiments are not limited to any particular configuration of memory 140. Further, processing unit 110 may execute the instructions stored in any of modules 1402-1406 included in memory 140.

[0203] In one embodiment, curve recognition module 1402 may store software instructions (such as computer vision software) which, when executed by processing unit 110, detects a curve by, for example, analyzing one or more sets of images and/or using map and/or position data (e.g., data stored in map database 160). The image sets may be acquired by one or more of image capture devices 122, 124, and 126. Based on the analysis, system 100 (e.g., via processing unit 110) may cause a change in velocity of vehicle 200. For example, processing unit 110 may cause vehicle 200 to reduce its speed by a predetermined amount and/or adjust its direction by a particular angle if processing unit 110 detects the presence of a curve located within a minimum threshold distance ahead of vehicle 200.

[0204] In one embodiment, characteristic observation module 1404 may store software instructions (such as computer vision software) which, when executed by processing unit 110, observes characteristics associated with a curve detected by system 100 (e.g., via execution of curve recognition module 1402). Processing unit 110 may observe characteristics associated with a detected curve by analyzing one or more sets of images acquired by one or more of image capture devices 122, 124, and 126 and/or using map and/or position data (e.g., data stored in map database 160). The analysis may yield information associated with the curve, such as curve radius 1308, lane width 1306, a degree of curvature, a rate of change in curvature, a degree of banking, a length or arc length of the curve, and the like. These characteristics may include estimated values (e.g., curve characteristics calculated using preexisting data and/or mathematical models based on such data) and actual values (e.g., curve characteristics calculated by analyzing captured images of the curve). Based on the analysis, processing unit 110 may cause a change in velocity of vehicle 200. For example, processing unit 110 may cause vehicle 200 to reduce its speed and/or adjust its direction by a particular angle in view of a high rate of change in curvature associated with a curve located 25 meters ahead of vehicle 200.

[0205] In one embodiment, velocity module 1406 may store software instructions configured to analyze data from one or more computing and electromechanical devices configured to determine a target velocity and cause a change in velocity of vehicle 200 to the target velocity. For example, processing unit 110 may execute velocity module 1406 to calculate a target velocity for vehicle 200 based on data derived from execution of curve recognition module 1402 and characteristic observation module 1404. Such data may include, for example, an initial target position and initial velocity, an updated target position and updated velocity, a final target position and final velocity, and the like. In addition, processing unit 110 may calculate a velocity for vehicle 200 based on input from other systems of vehicle 200, such as a throttling system 220, braking system 230, and/or steering system 240 of vehicle 200. Based on the calculated target velocity, processing unit 110 may transmit electronic signals (e.g., via a controller area network bus ("CAN bus")) to throttling system 220, braking system 230, and/or steering system 240 of vehicle 200 to trigger a change in the speed and/or direction of vehicle 200 by, for example, physically depressing the brake, easing up off the accelerator of vehicle 200, or steering vehicle 200 in a particular direction (e.g., at a particular angle). An increase in speed may be associated with a corresponding acceleration (e.g., between 0.2 m/sec^2 and 3.0 m/sec^2). Conversely, a decrease in speed may be associated with a corresponding deceleration. In addition, the acceleration or deceleration may be based on the road type (e.g., highway, city street, country road, etc.), the presence of any speed constraints nearby (e.g., sharp curves, traffic lights), as well as a road width or lane width 1306. For purposes of this disclosure, deceleration may refer to an acceleration having a negative value.

[0206] FIG. 15 is a flow chart showing an exemplary

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process 1500 for controlling the velocity of a vehicle based on a detected curve and observed characteristics of the curve and/or map data regarding the curve consistent with disclosed embodiments. At step 1510, processing unit 110 may receive a plurality of images via data interface 128 between processing unit 110 and image acquisition unit 120. For instance, a camera included in image acquisition unit 120 (such as image capture device 122) may capture a plurality of images and transmit them over a digital connection (e.g., USB, wireless, Bluetooth, etc.) to processing unit 110. In some embodiments, processing unit 110 may receive more than one plurality of images via a plurality of data interfaces. For example, processing unit 110 may receive a plurality of images from each of image capture devices 122, 124, 126, each of which may have an associated data interface for communicating data to processing unit 110. The disclosed embodiments are not limited to any particular data interface configurations or protocols.

[0207] At step 1520, processing unit 110 may execute curve recognition module 1502 to detect a curve located ahead of vehicle 200 based on, for example, map and/or position data (e.g., data stored in map database 160). Such data may indicate the location of a curve that is present on a given road. The data may indicate the absolute position of a particular curve (e.g., via GPS coordinates) or the relative position of the curve (e.g., by describing the curve relative to vehicle 200, road sign 1302, traffic light 1304, and/or other descriptive landmarks). In some embodiments, processing unit 110 may execute curve recognition module 1502 to detect the curve by analyzing the plurality of images. The analysis may be conducted using techniques described in connection with FIGS. 5A-5D and 6, above.

[0208] At step 1530, processing unit 110 may execute velocity module 1406 to determine an initial target velocity for vehicle 200 based on, for example, data derived from execution of curve recognition module 1402. The initial target velocity may reflect a speed and a direction for vehicle 200 to safely enter an upcoming curve and may be determined using techniques described in connection with FIG. 14, above. For example, velocity module 1406 may determine the initial target velocity based on known or estimated characteristics associated with the upcoming curve, such as the curve radius 1308 and the degree of banking. Velocity module 1406 may calculate the initial target velocity in accordance with mathematical models and/or formulae and based on various constraints. In some embodiments, for example, velocity module 1406 may determine the Initial target velocity based on the presence of traffic lights (such as traffic light 1304) before, during, or after a curve, weather conditions (e.g., light rain, heavy rain, windy, clear, etc.), road conditions (e.g., paved road, unpaved road, potholes, etc.), posted speed limits, the presence of vehicles or pedestrians nearby, etc. The initial target velocity may also be based on a lateral acceleration limit associated with vehicle 200. In some embodiments, the lateral acceleration limit may be in the range of 0.2 m/sec^2 and 3.0 m/sec^2 and may be adjusted depending on the curve characteristics, the road width, or lane width 1306. Additionally, the initial target velocity may be based on a focal range associated with one or more of cameras, such as image capture devices 122 and 124.

[0209] For example, velocity module 1406 may determine the initial target velocity based on the radius of curvature of the road ahead of vehicle 200. Velocity module 1406 may determine the radius of curvature at various distances from vehicle 200 and store the information in a vector $R(1{:}n)$. In one embodiment, velocity module 1406 may determine the radius of curvature at: (1) the current position of vehicle 200, (2) a distance D_{end} from vehicle 200, where D_{end} represents the distance ahead of vehicle 200 at which knowledge of the road characteristics allows system 100 to control navigational responses in vehicle 200 such that the driver may feel comfortable, and (3) at incremental distances from vehicle 200, such as every 1 meter, etc. The value of distance D_{end} may depend on the current speed of vehicle 200, V_{ego}. For example, the greater the value of V_{ego} (e.g., the faster vehicle 200 is traveling), the greater the value of D_{end} (e.g., the longer the distance may be taken into account to provide system 100 with sufficient time to provide a navigational response, such as comfortably reducing the speed of vehicle 200 based on an approaching sharp turn or curve). In one embodiment, D_{end} may be calculated according to the following equation: $D_{end} = (V_{ego}^2 / 2) / (0.7 / 40 * V_{ego} + 0.5)$. Thus, the vector $D(1{:}n) = [1{:}1{:}n]$, where $n = \text{floor}(D_{end})$.

[0210] In some embodiments, velocity module 1406 may determine the initial target velocity based on a lateral acceleration constraint, a_{max}, e.g., the maximum allowed lateral acceleration. a_{max} may fall in the range of 1.5 to 3.5 meters / sec^2. Based on a_{max} and the radius of curvature vector R (discussed above), velocity module 1406 may limit the speed of vehicle 200 (e.g., at different points or distances from the current position of vehicle 200) to a speed v_{hm}, calculated as: $v_{hm}(1{:}n) = \text{sqrt}(a_{max} * R(1{:}n))$. In addition, a deceleration constraint that follows from the determination of v_{hm} may be calculated as: $dec_{hm} = \min\{((v_{hm}(1{:}n)^2 - V_{ego}^2)/2), \max\{d_{min}, D(1{:}n) - 2 * V_{ego}\}\}$, where d_{min} is equal to 40 meters. The value of d_{min} may represent a point at which deceleration feels comfortable for the driver of vehicle 200.

[0211] In some embodiments, velocity module 1406 may determine the initial target velocity based on a curvature slew rate constraint, $slew_{max}$, which may be based on the curvature rate of change. $slew_{max}$ may fall in the range of 0.5 to 1.5 meters / sec^3. Velocity module 1406 may determine v_{hm} according the following equation: $v_{hm}(1{:}n) = (slew_{max} / \text{abs}\{\text{diff}\{1/R(1{:}n)\}\})^{1/3}$. Further, velocity module 1406 may determine dec_{hm} according to the equation: $dec_{lim} = \min\{((v_{lim}(1{:}n)^2 - V_{ego}^2)/2), \max\{d_{min}, D(1{:}n) - 2 * V_{ego}\}\}$, where d_{min} is equal to 40 meters.

[0212] In some embodiments, velocity module 1406 may determine a comfort constraint such that the driver

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of vehicle 200 is comfortable while vehicle 200 is undergoing various navigational responses, such as making a turn or navigating a curve. Velocity module 1406 may determine v_{lim} according to the following equation: $v_{lim}(1{:}n)$ - 4/500 * $R(1n)$ + 22.5. Further, velocity module 1406 may determine dec_{lim} according to the equation: dec_{lim} = min{$((v_{lim}(1{:}n)^2 - V_{ego}^2)/2)$, max{$d_{min}D(1{:}n)$ - 2 * V_{ego}}}, where d_{min} is equal to 40 meters.

[0213] Velocity module 1406 may merge the three constraints determined above-the lateral acceleration constraint, the curvature slew rate constraint, and comfort constraint-by using the smallest value of dec_{lim} calculated in association with each constraint. After merging the constraints, velocity module 1406 may arrive at the initial target velocity by determining how much to adjust the speed of vehicle 200, denoted v_{cam}, according to the following equation: $v_{cam} = v_{cam(prev)} + dec_{lim} * \Delta t$, where $v_{cam(prev)}$ represents the prior speed of vehicle 200 (e.g., a previously determined speed, the speed of vehicle 200 prior to any adjustment by velocity module 1406, etc.), and Δt represents the time between the determination of v_{cam} and $v_{cam(prev)}$.

[0214] At step 1540, processing unit 110 may execute velocity module 1406 to adjust a velocity of vehicle 200 to the initial target velocity determined at step 1530. Based on the current velocity of vehicle 200 and the initial target velocity determined at step 1530, processing unit 110 may transmit electronic signals to throttling system 220, braking system 230, and/or steering system 240 of vehicle 200 to change the velocity of vehicle 200 to the initial target velocity. Further, one or more actuators may control throttling system 220, braking system 230, and/or steering system 240. For example, processing unit 110 may transmit electronic signals that cause system 100 to physically depress the brake by a predetermined amount or ease partially off the accelerator of vehicle 200. Further, processing unit 110 may transmit electronic signals that cause system 100 to steer vehicle 200 in a particular direction. In some embodiments, the magnitude of acceleration (or de-acceleration) may be based on the difference between the current velocity of vehicle 200 and the initial target velocity. Where the difference is large (e.g., the current velocity is 10 km/hr greater than the initial target velocity), for example, system 100 may change the current velocity by braking in a manner that maximizes deceleration and results in vehicle 200 achieving the initial target velocity in the shortest amount of time safely possible. Alternatively, system 100 may apply the brakes in a manner that minimizes deceleration and results in vehicle 200 achieving the initial target velocity gradually. More generally, system 100 may change the current velocity to the initial target velocity according to any particular braking profile (e.g., a braking profile calling for a high level of braking for the first two seconds, and a low level of braking for the subsequent three seconds). The disclosed embodiments are not limited to any particular braking profile or manner of braking.

[0215] At step 1550, processing unit 110 may execute characteristic observation module 1404 to determine one or more characteristics of a curve located ahead of vehicle 200 based on, for example, analysis of the plurality of images conducted using techniques described in connection with FIGS. 5A-5D, above. The characteristics may include, for example, estimated and/or actual values associated with curve radius 1308, a road width or lane width 1306, a degree of curvature, a rate of change in curvature, a degree of banking, and the like. The characteristics may also include, for example, information conveyed by one or more road signs (such as road sign 1302). Furthermore, the characteristics may include the length or arc length of the detected curve, which may be a function of the speed of vehicle 200 as it approaches the curve. Processing unit 110 may execute characteristic observation module 1404 to calculate values associated with these characteristics (e.g., curve radius 1308, the degree of curvature, the rate of change in curvature, the arc length of the curve, etc.) based on mathematical models and/or formulae. In some embodiments, processing unit 110 may execute characteristic observation module 1404 to construct a mathematical model expressing the curvature of the curve as a function of distance (e.g., distance traveled). Such a model may be subject to constraints such as a maximum lateral acceleration constraint (e.g., in the range of 1.5 to 3.0 m/sec^2) and/or a maximum lateral acceleration derivative constraint (e.g., in the range of 0.8 to 1.2 m/sec^2). These constraints may yield a maximum speed for vehicle 200 as a function of distance traveled.

[0216] At step 1560, processing unit 110 may execute velocity module 1406 to calculate an updated target velocity based on the characteristics determined at step 1550. The updated target velocity may reflect an updated speed and/or direction for vehicle 200 to safely perform any combination of: (i) entering an upcoming curve, (ii) navigating through a curve, or (iii) exiting a curve. The updated target velocity may be determined using techniques described in connection with FIG. 14 and step 1530, above. For example, velocity module 1406 may determine the updated target velocity based on characteristics associated with a curve and mathematical models and/or formulae.

[0217] At step 1570, processing unit 110 may execute velocity module 1406 to adjust the velocity of vehicle 200 to the updated target velocity determined at step 1560. This adjustment may be accomplished using techniques described in connection with step 1540, above. For example, based on the current velocity of vehicle 200 and the updated target velocity determined at step 1560, processing unit 110 may transmit electronic signals (e.g., via a CAN bus) to throttling system 220, braking system 230, and/or steering system 240 of vehicle 200 to change the velocity of vehicle 200 to the updated target velocity. At this point, the current velocity of vehicle 200 is not necessarily the same as the initial target velocity determined at step 1530. For example, processing unit 110 may have determined the updated target velocity at step

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1560 while in the process of adjusting the velocity of vehicle 200 to the initial target velocity. This may be true in the case where the difference in the velocity of vehicle 200 and the initial target velocity is large (e.g., greater than 10 km/hr) and the associated acceleration is small.

[0218] In some embodiments, system 100 may make regular updates to the target velocity based on continued observations of characteristics of a curve (e.g., based on image data depicting portions of the curve that vehicle 200 is approaching). Additionally, after system 100 has navigated vehicle 200 through a curve, system 100 may cause vehicle 200 to accelerate to a new target velocity suitable for traveling a segment of the road that does not have curves, as determined by analyzing map data, positional data, and/or image data acquired by system 100.

Mimicking A Leading Vehicle

[0219] System 100 may provide driver assist functionality that causes vehicle 200 to mimic (or decline to mimic) a leading vehicle in different scenarios, such as when the leading vehicle switches lanes, accelerates, or makes a turn. For example, system 100 may be configured to detect the leading vehicle by analyzing a plurality of images and determine one or more actions taken by the leading vehicle. In some scenarios, such as when the leading vehicle is turning at an intersection, system 100 may be configured to cause vehicle 200 to decline to mimic the turn. In other scenarios, such as when the leading vehicle is turning at an intersection without changing lanes within the intersection, system 100 may be configured to cause vehicle 200 to mimic the turn. System 100 may also be configured to cause vehicle 200 to mimic one or more actions of the leading vehicle based on a navigation history of the leading vehicle.

[0220] FIGS. 16A and 16B are diagrammatic representations of a primary vehicle 200a mimicking one or more actions of a leading vehicle 200b on road 1600a, consistent with the disclosed embodiments. As illustrated in FIGS. 16A and 16B, primary vehicle 200a may be trailing leading vehicle 200b while traveling in the same lane of road 1600a. The lane may have a left edge 1620, a right edge 1630, and a midpoint 1610, with w_1 and w_2 indicating the left and right halves of the lane, respectively. Primary vehicle 200a and leading vehicle 200b may be positioned in the lane such that neither vehicle is centered on the midpoint 1610. As shown in FIG. 16A, for example, primary vehicle 200a may be centered to the right of midpoint 1610 such that the distance c_1 between primary vehicle 200a and left edge 1620 is greater than the distance c_2 between primary vehicle 200a and right edge 1630. In contrast, leading vehicle 200b may be centered to the left of midpoint 1610 such that the distance c_3 between leading vehicle 200b and left edge 1620 is less than the distance c_4 between leading vehicle 200b and right edge 1630. Different configurations of the positions of primary vehicle 200a and leading vehicle 200b are possible. For example, primary vehicle 200a and leading vehicle 200b may be positioned anywhere on road 1600a. Further, although FIG. 16A depicts leading vehicle 200b as having a camera system, the disclosed embodiments are not limited to a configuration in which leading vehicle 200b includes a camera system.

[0221] System 100 of primary vehicle 200a may cause primary vehicle 200a to mimic one or more actions of leading vehicle 200b. As shown in FIG. 16B, for example, primary vehicle 200a may mimic a lane shift performed by leading vehicle 200b. After mimicking the lane shift, distance c_1 may be equal to distance c_3, and distance c_2 may be equal to distance c_4. In some embodiments, primary vehicle 200a may mimic a lane shift performed by leading vehicle 200b in a way such that distances c_1 and c_3, and c_2 and c_4, are unequal. For example, in the case where primary vehicle 200a mimics a leftward lane shift of primary vehicle 200b and is positioned (after the lane shift) to the left of primary vehicle 200a, c_1 will be less than c_3 and c_2 will be greater than c_4. Alternatively, where primary vehicle 200a mimics a leftward lane shift of primary vehicle 200b and is positioned to the right of primary vehicle 200a, c_1 will be greater than c_3 and c_2 will be less than c_4.

[0222] FIGS. 16C and 16D are diagrammatic representations of a primary vehicle 200a mimicking one or more actions of a leading vehicle 200b on road 1600b, consistent with the disclosed embodiments. As illustrated in FIG. 16C, primary vehicle 200a may be traveling behind leading vehicle 200b, which may make a left turn at an intersection. System 100 of primary vehicle 200a may cause primary vehicle 200a to mimic the left turn of leading vehicle 200b, as shown in FIG. 16D. System 100 may cause primary vehicle 200a to mimic the left turn based on various factors, such as whether leading vehicle 200b changes lanes while turning within the intersection, the navigation history associated with leading vehicle 200b, the relative difference in speed between primary vehicle 200a and leading vehicle 200b, and the like. Additionally, primary vehicle 200a may mimic leading vehicle 200b under various conditions, such as based on whether leading vehicle 200b is traveling along the same route or the same portion of a route that primary vehicle 200a is traveling along. Further detail regarding scenarios in which system 100 may cause primary vehicle 200a to mimic one or more actions of leading vehicle 200b are described in connection with FIGS. 17-22, below.

[0223] In some embodiments, system 100 may be configured to determine whether to mimic a particular movement of a leading vehicle. For example, system 100 may determine that certain movements of the leading vehicle do not need to be mimicked because the movements do not affect the course of the leading vehicle. For example, system 100 may determine that small changes in movements, such as moving within a particular lane, do not need to be mimicked. In other embodiments, system 100 may implement a smoothing operation to filter out small movements of a leading vehicle. The smoothing operation may cause the primary vehicle to implement more

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significant and/or important movements (e.g., changing lanes) of a leading vehicle while filtering out smaller movements not affecting the overall course of the leading vehicle.

[0224] FIG. 17 is an exemplary block diagram of a memory configured to store instructions for performing one or more operations consistent with the disclosed embodiments. As shown in FIG. 17, memory 140 may store a lane constraint module 1702, an action detection module 1704, and an action response module 1706. The disclosed embodiments are not limited to any particular configuration of memory 140. Further, processing unit 110 may execute the instructions stored in any of modules 1702-1706 included in memory 140.

[0225] In one embodiment, lane constraint module 1702 may store software instructions (such as computer vision software) which, when executed by processing unit 110, determine one or more constraints associated with a lane that primary vehicle 200a is traveling in. The lane constraints may include a midpoint 1610, a left edge 1620, and a right edge 1630 of the lane. The lane constraints may also include one or more lines or other symbols marked on the surface of road 1600a or 1600b. Processing unit 110 may execute lane constraint module 1702 to determine the constraints by, for example, analyzing one or more sets of images and/or using map and/or position data (e.g., data stored in map database 160). The image sets may be acquired by one or more of image capture devices 122, 124, and 126. Based on the analysis, system 100 (e.g., via processing unit 110) may cause primary vehicle 200a to travel within a lane defined by left edge 1620 and right edge 1630. In some embodiments, system 100 may cause primary vehicle 200a to move away from left edge 1620 or right edge 1630 if one of distance c_1 or c_2 is less than a predetermined threshold.

[0226] In one embodiment, action detection module 1704 may store software instructions (such as computer vision software) which, when executed by processing unit 110, detects one or more actions taken by leading vehicle 200b traveling in front of primary vehicle 200a. Leading vehicle 200b may be traveling in the same or different lane as primary vehicle 200a. Processing unit 110 may execute action detection module 1704 to detect one or more actions taken by leading vehicle 200b by, for example, analyzing one or more sets of images acquired by one or more of image capture devices 122, 124, and 126. Based on the analysis, processing unit 110 may determine, for example, that leading vehicle 200b has shifted lanes, made a turn, accelerated, decelerated, applied its brakes, and/or the like. As another example, leading vehicle 200b may perform a maneuver such that a first offset distance on a side of leading vehicle 200b adjacent to a first lane constraint is different from a second offset distance on a side of leading vehicle 200b adjacent to a second lane constraint. For example, processing unit 110 may perform the analysis based on the techniques described in connection with FIGS. 5A-5D, above.

[0227] In one embodiment, action response module 1706 may store software instructions (such as computer vision software) which, when executed by processing unit 110, determines one or more actions for primary vehicle 200a to take based on one or more actions taken by leading vehicle 200b detected by system 100 (e.g., via execution of action detection module 1704). For example, processing unit 110 may execute action response module 1706 to determine whether to mimic one or more actions of leading vehicle 200b. This determination may be based on the nature of leading vehicle 200b's actions (e.g., turn, lane shift, etc.), information associated with primary vehicle 200a (e.g., speed, distance c_1 and c_2 from the lane edges, etc.), road and environmental conditions (e.g., potholes, heavy rain or wind, etc.), and the like. In the case where processing unit 110 determines to mimic one or more actions of leading vehicle 200b, processing unit 110 may accomplish this by, for example, transmitting electronic signals (e.g., via a CAN bus) to throttling system 220, braking system 230, and/or steering system 240 of primary vehicle 200a to trigger a turn, lane shift, change in speed, and/or change in direction of primary vehicle 200a. Processing unit 110 may use the techniques described in connection with FIGS. 4-7, above, to cause primary vehicle 200a to mimic the one or more actions. To mimic the one or more actions, system 100 may provide control signals to one or more of throttling system 220, braking system 230, and steering system 240 to navigate vehicle 200 (e.g., by causing an acceleration, a turn, a lane shift, etc.). Further, one or more actuators may control throttling system 220, braking system 230, and/or steering system 240.

[0228] FIG. 18 is a flow chart showing an exemplary process for causing primary vehicle 200a to mimic one or more actions of leading vehicle 200b consistent with disclosed embodiments. At step 1810, processing unit 110 may receive a plurality of images via data interface 128 between processing unit 110 and image acquisition unit 120. For instance, a camera included in image acquisition unit 120 (such as image capture device 122) may capture a plurality of images and transmit them over a digital connection (e.g., USB, wireless, Bluetooth, etc.) to processing unit 110. In some embodiments, processing unit 110 may receive more than one plurality of images via a plurality of data interfaces. For example, processing unit 110 may receive a plurality of images from each of image capture devices 122, 124, 126, each of which may have an associated data interface for communicating data to processing unit 110. The disclosed embodiments are not limited to any particular data interface configurations or protocols.

[0229] At steps 1820 and 1830, processing unit 110 may execute lane constraint module 1702 to determine constraints for each side of primary vehicle 200a associated with a lane that primary vehicle 200a is traveling in. Processing unit 110 may determine the constraints by analyzing the images received at step 1810. Thus, at

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step 1820, processing unit 110 may determine a first lane constraint on a first side of primary vehicle 200a (e.g., the distance between the left side of primary vehicle 200a and left edge 1620 of the lane, c_1) and, at step 1830, a second lane constraint on a second side opposite the first side (e.g., the distance between the right side of primary vehicle 200a and right edge 1620 of the lane, c_2). In some embodiments, processing unit 110 may determine the constraints by using map and/or position data (e.g., data stored in map database 160) indicating the position of primary vehicle 200a relative to midpoint 1610, left edge 1620, and right edge 1630 of the lane. Processing unit 110 may determine the constraints based on both an analysis of the images received at step 1810 and map and/or position data; doing so may increase the confidence level associated with the constraints.

[0230] At step 1840, processing unit 110 may execute lane constraint module 1702 to cause primary vehicle 200a to travel within the lane constraints determined at steps 1820 and 1830. For example, the left side of primary vehicle 200a may be positioned to the left of left edge 1620, or the right side of primary vehicle 200a may be positioned to the right of right edge 1630. In such a scenario, processing unit 110 may transmit electronic signals (e.g., via a CAN bus) to throttling system 220, braking system 230, and/or steering system 240 of primary vehicle 200a to cause primary vehicle 200a to adjust its position and travel within the lane constraints.

[0231] At step 1850, processing unit 110 may execute action detection module 1704 to locate a leading vehicle 200b within the images received at step 1810 by analyzing the images. Processing unit 110 may detect the presence of vehicles in the images using the techniques described in connection with FIGS. 5A and 5B, above. For each detected vehicle, processing unit 110 may construct a multi-frame model of the detected vehicle's position, velocity (e.g., speed and direction), and acceleration relative to primary vehicle 200a. Processing unit 110 may use the techniques described in connection with FIGS. 5A and 5B, above, to construct such a model. In addition, processing unit 110 may determine a lane of travel associated with each detected vehicle, based on, for example, lane or other road markings and lane constraints determined at steps 1820 and 1830. Processing unit 110 may determine leading vehicle 200b to be the detected vehicle that is closest to, and is traveling in the same lane as, primary vehicle 200a. At step 1860, processing unit 110 may execute action detection module 1704 to determine one or more actions taken by the leading vehicle 200b detected within the images at step 1850. For example, processing unit 110 may determine that leading vehicle 200b has shifted lanes, made a turn, accelerated, decelerated, and/or the like. In addition, processing unit 110 may analyze the images to determine characteristics associated with leading vehicle 200b, such as its speed and position (e.g., relative to primary vehicle 200a). These determinations may be based on the techniques described in connection with FIGS. 5A and 5B, above. In some embodiments, processing unit 110 may analyze the images to determine characteristics associated with an action performed by leading vehicle 200b. For example, where leading vehicle 200b makes a turn, processing unit 110 may determine position information for leading vehicle 200b right before it begins the turn, position information for leading vehicle 200b as it completes the turn, a turning radius, and a speed profile describing changes in speed (e.g., over time) for leading vehicle 200b as it makes the turn.

[0232] At step 1870, processing unit 110 may execute action response module 1706 to cause primary vehicle 200a to mimic the one or more actions of leading vehicle 200b determined at step 1850. For example, processing unit 110 may transmit electronic signals (e.g., via a CAN bus) to throttling system 220, braking system 230, and/or steering system 240 of primary vehicle 200a to trigger a turn, lane shift, change in speed, and/or change in direction of primary vehicle 200a. In addition, processing unit 110 may construct a set of path points to guide changes in position and speed for primary vehicle 200a. The path points may be based on lane marks (e.g., midpoint 1610, left edge 1620, right edge 1630, etc.) represented by a polynomial (e.g., of the third-degree) and target coordinates associated with a target vehicle, such as leading vehicle 200b. Processing unit 110 may adjust the coefficients of the polynomial so that the path points pass through the target coordinates. Processing unit 110 may also offset the path points (e.g., relative to left edge 1620 and right edge 1630) based on a predetermined offset amount. As processing unit 110 adjusts the polynomial coefficients and offsets the path points, processing unit 110 may also calculate local curvature information for each of the resulting segments formed between the path points.

[0233] In some embodiments, processing unit 110 (e.g., via execution of action response module 1706) may cause primary vehicle 200a to mimic leading vehicle 200b within certain position, speed, and/or acceleration constraints associated with the two vehicles. For example, the constraints may require a predetermined minimum distance (e.g., a safety distance) between primary vehicle 200a and leading vehicle 200b or a predetermined maximum difference in speed and/or acceleration between the vehicles. Thus, if mimicking an action performed by leading vehicle 200b would violate one or more constraints (e.g., mimicking an acceleration would result in primary vehicle 200a being too close to leading vehicle 200b), processing unit 110 may cause primary vehicle 200a to decline to mimic the one or more actions of leading vehicle 200b. In addition, even while mimicking an action performed by leading vehicle 200b (e.g., a lane shift), processing unit 110 may cause primary vehicle 200a to follow leading vehicle 200b's speed profile and maintain a predetermined distance or a safety distance from leading vehicle 200b. Processing unit 110 may accomplish this by causing primary vehicle 200a to: (i) continuously close the distance gap from leading vehicle

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200b when the gap is greater than the predetermined minimum distance, (ii) continuously close the gap between the speeds of primary vehicle 200a and leading vehicle 200b, and (iii) match the acceleration of leading vehicle 200b to the extent it is consistent with predetermined constraints. To control the extent to which of these actions should be performed, processing unit 110 may associate each action with weights in real-time based on the current and predicted distance to leading vehicle 200b. Thus, for example, as the distance to leading vehicle 200b decreases more weight may be put on decelerating rather than matching the acceleration of leading vehicle 200b.

[0234] As another example, in the case where primary vehicle 200a is approaching leading vehicle 200b at a speed greater than the speed of leading vehicle 200b, processing unit 110 may cause primary vehicle 200a to gradually slow down such that, when the distance between the two vehicles equals a predetermined safety distance such as a minimum following distance, the speed of the two vehicles is the same. In another example, where a leading vehicle 200b abruptly appears in front of primary vehicle 200a, causing the distance between the two vehicles to be less than the minimum following distance, processing unit 110 may cause primary vehicle 200a to gradually slow down to avoid approaching leading vehicle 200b any closer while at the same increasing the distance between the vehicles until it reaches the minimum following distance.

[0235] FIG. 19 is a flow chart showing an exemplary process 1900 for causing primary vehicle 200a to decline to mimic a turn of leading vehicle 200b, consistent with disclosed embodiments. At step 1910, processing unit 110 may receive a plurality of images via data interface 128 between processing unit 110 and image acquisition unit 120, as described in connection with step 1810 of FIG. 18, above. At step 1920, processing unit 110 may execute action detection module 1704 to locate a leading vehicle 200b within the images received at step 1910 by analyzing the images, as described in connection with step 1850 of FIG. 18, above. At step 1925, processing unit 110 may execute action detection module 1704 to determine whether leading vehicle 200b is turning at an intersection, using the techniques described in connection with step 1860 of FIG. 18, above. If leading vehicle 200b is determined to be turning at the intersection (step 1925, yes), processing unit 110 may cause primary vehicle 200a to decline to mimic the turn of leading vehicle 200b at step 1930. Otherwise (step 1925, no), process 1900 concludes.

[0236] FIG. 20 is a flow chart showing an exemplary process 2000 for causing primary vehicle 200a to mimic or decline a turn of leading vehicle 200b, consistent with disclosed embodiments. At step 2010, processing unit 110 may receive a plurality of images via data interface 128 between processing unit 110 and image acquisition unit 120, as described in connection with step 1810 of FIG. 18, above. At step 2020, processing unit 110 may execute action detection module 1704 to locate a leading vehicle 200b within the images received at step 2010 by analyzing the images, as described in connection with step 1850 of FIG. 18, above, At step 2025, processing unit 110 may execute action detection module 1704 to determine whether leading vehicle 200b is turning at an intersection, using the techniques described in connection with step 1860 of FIG. 18, above. If leading vehicle 200b is determined to be turning at the intersection (step 2025, yes), at step 2035, processing unit 110 may execute action detection module 1704 to determine whether leading vehicle 200b is changing lanes within the intersection, using the techniques described in connection with step 1860 of FIG. 18, above. Otherwise (step 2025, no), process 2000 concludes. If leading vehicle 200b is determined to be changing lanes within the intersection (step 2035, yes), processing unit 110 may cause primary vehicle 200a to decline to mimic the turn of leading vehicle 200b at step 2050. Otherwise (step 2035, no), processing unit 110 may cause primary vehicle 200a to mimic the turn of leading vehicle 200b at step 2040.

[0237] FIG. 21 is a flow chart showing another exemplary process 2100 for causing primary vehicle 200a to mimic one or more actions of a first leading vehicle, consistent with disclosed embodiments. At step 2110, processing unit 110 may receive a plurality of images via data interface 128 between processing unit 110 and image acquisition unit 120, as described in connection with step 1810 of FIG. 18, above. At steps 2120 and 2130, processing unit 110 may execute action detection module 1704 to locate a first and second leading vehicle within the images received at step 2110 by analyzing the images, as described in connection with step 1850 of FIG. 18, above. At step 2135, processing unit 110 may execute action detection module 1704 to determine whether the first leading vehicle path has a lower turning radius than the second leading vehicle path, using the techniques described in connection with step 1860 of FIG. 18, above. If the first leading vehicle path is determined to have a lower turning radius than the second leading vehicle path (step 2135, yes), processing unit 110 may cause primary vehicle 200a to mimic the turn of the first leading vehicle at step 2140. Otherwise (step 2135, no), process 2100 concludes.

[0238] FIG. 22 is a flow chart showing an exemplary process 2200 for causing primary vehicle 200a to mimic one or more actions of leading vehicle 200b based on a navigation history, consistent with disclosed embodiments. At step 2210, processing unit 110 may receive a plurality of images via data interface 128 between processing unit 110 and image acquisition unit 120, as described in connection with step 1810 of FIG. 18, above. At step 2220, processing unit 110 may execute action detection module 1704 to locate a leading vehicle 200b within the images received at step 2210 by analyzing the images, as described in connection with step 1850 of FIG. 18, above.

[0239] At step 2230, processing unit 110 may deter-

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mine position information for leading vehicle 200b by analyzing the images received at step 2210. Position information for leading vehicle 200b may indicate the position of leading vehicle 200b relative to primary vehicle 200a. Processing unit 110 may analyze the images to derive position information for leading vehicle 200b and one or more actions taken by leading vehicle 200b by using the techniques described in connection with FIGS. 5A-5D, above.

[0240] At step 2240, processing unit 110 may compare the position information for leading vehicle 200b determined at step 2230 to predetermined map data (e.g., data stored in map database 160). For example, by comparing the position information to predetermined map data, processing unit 110 may derive position coordinates for leading vehicle 200b. In addition, processing unit 110 may use the predetermined map data as an indicator of a confidence level associated with the position information determined at step 2230.

[0241] At step 2250, processing unit 110 may create a navigation history associated with leading vehicle 200b by, for example, tracking the actions taken by leading vehicle 200b. Processing unit 110 may associate the actions taken by leading vehicle 200b (e.g., determined from analysis of the images at step 2230) with predetermined map data from step 2240. Thus, the navigation history may indicate that leading vehicle 200b performed certain actions (e.g., a turn, a lane shift, etc.) at certain position coordinates.

[0242] At step 2260, processing unit 110 may execute action response module 1706 to determine whether to cause primary vehicle 200a to mimic one or more actions of leading vehicle 200b based on the navigation history created at step 2250 and using the techniques described in connection with step 1870 of FIG. 18, above. For example, processing unit 110 (e.g., via action response module 1706) may cause primary vehicle 200a to mimic a turn of leading vehicle 200b, even where no turn is detected from analysis of the images (e.g., at step 2230), when the navigation history indicates that leading vehicle 200b has successfully navigated at least one prior turn. More generally, processing unit 110 may cause primary vehicle 200a to mimic an action taken by leading vehicle 200b in cases where the navigation history indicates the leading vehicle 200b had successfully performed such an action.

Navigating a Vehicle to Pass Another Vehicle

[0243] System 100 may provide driver assist functionality that monitors the vicinity around vehicle 200 and aborts lane changes in the event that the lane change is deemed to be at risk of causing a collision, such as with another vehicle (e.g., a target vehicle). For example, system 100 may enable vehicle 200 to complete a pass of a target vehicle if the target vehicle is determined to be in a different lane than vehicle 200. If, before completion of a pass, system 100 determines that the target vehicle is entering the lane in which vehicle 200 is traveling, system 100 may cause vehicle 200 to abort the pass. For example, aborting the pass may include causing vehicle 200 to brake or causing vehicle 200 to stop accelerating.

[0244] As illustrated in FIG. 23, vehicle 200 may travel on roadway 2300. Vehicle 200 may be equipped with system 100 and may implement any of the disclosed embodiments for identifying lane constraints and operating vehicle 200 within the lane constraints. System 100 may also facilitate lane changes made by vehicle 200. For example, system 100 may determine whether circumstances allow vehicle 200 to safety change lanes and, if the circumstances change during the lane change, cause vehicle 200 to abort lane change.

[0245] As shown in FIG. 23 and as previously discussed with respect to FIG. 8, vehicle 200 may include first vehicle side 802, which may be first distance 805 from a first lane constraint 2302. Similarly, vehicle 200 may include second vehicle side 812 opposite from first vehicle side 802, and second vehicle side 812 may be second distance 815 from a second lane constraint 2304. In this manner, first lane constraint 810 and second lane constraint 2304 may define a lane 2330 within which vehicle 200 may travel.

[0246] System 100 may determine first lane constraint 2302 and second lane constraint 2304 based on a plurality of images acquired by one or more of image capture devices 122-126. According to some embodiments, first lane constraint 2302 and/or second lane constraint 2304 may be identified by visible lane boundaries, including lines marked on a road surface. Additionally or alternatively, first lane constraint 2302 and/or second lane constraint 2304 may include an edge of a road surface. According to some embodiments, system 100 may determine first lane constraint 2302 and/or second lane constraint 2304 by identifying a midpoint of a road surface width 2320 (or any other suitable road feature that vehicle 200 may use as a navigation reference). System 100 may identify lane constraints in this manner when, for example, lines designating road lanes are not painted or otherwise labeled.

[0247] When passing a target vehicle 2310, the lane change of vehicle 200 may be complicated by a change in the trajectory of target vehicle 2330. Thus, system 100 may identify target vehicle 2310 based on an analysis of a plurality of images acquired by one or more of image capture devices 122-126. System 100 may also identify second lane 2340 in which target vehicle 2310 is traveling. Further, system 100 may determine whether second lane 2340 is different than lane 2330 in which vehicle 200 is traveling. If second lane 2340 is different than lane 2330, system 100 may be configured to enable vehicle 200 to pass target vehicle 2310.

[0248] System 100 may also monitor target vehicle 2310 based on the plurality of images. For example, system 100 may monitor a position of target vehicle 2310, such as monitoring its position relative to vehicle 200, relative to first lane constraint 2302 and/or second lane

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constraint 2304, an absolute position, or relative to another reference point. Additionally or alternatively, monitoring a position of target vehicle 2310 may include estimating a speed of target vehicle 2310.

[0249] If system 100 determines that target vehicle 2310 is entering lane 2330 in which vehicle 200 is traveling, system 100 may cause vehicle 200 to abort the pass of target vehicle 2310. For example, system 100 may cause vehicle 200 to stop accelerating or brake. Additionally or alternatively, system 100 may issue an audible announcement, such as to notify driver of vehicle 200 that the lane change is being aborted.

[0250] FIG. 24A is an exemplary block diagram of memory 140, which may store instructions for performing one or more operations consistent with disclosed embodiments. As illustrated in FIG. 24A, memory 140 may store one or more modules for identification of the target vehicle and responses described herein. For example, memory 140 may store a lane constraint module 2400, a target vehicle acquisition module 2410, and an action module 2415.

[0251] In one embodiment, lane constraint module 2400 may store instructions which, when executed by processing unit 110, may detect and define first lane constraint 2302 and second lane constraint 2304. For example, processing unit 110 may execute lane offset module 2400 to process the plurality of images received from at least one image capture device 122-124 and detect first lane constraint 2302 and second lane constraint 2304. As discussed above, this may include identifying painted lane lines or markers and/or measuring a midpoint of a road surface. Processing unit 110 may perform the analysis based on the techniques described in connection with FIGS. 5A-5D, above.

[0252] In some embodiments, target acquisition module 2410 may store instructions which, when executed by processing unit 110, may detect the presence of target vehicle 2310 and monitor the position of target vehicle 2310. For example, target acquisition module 2410 may process the plurality of images to detect and monitor target vehicle 2310. Additionally or alternatively, when executing target acquisition module 2410, processing unit 110 may receive information from another module or other system indicative of the presence and/or location of target vehicle 2310. Processing unit 110 may perform the analysis based on the techniques described in connection with FIGS. 5A-5D, above.

[0253] Processing unit 110 may be configured to determine the presence of one or more objects such as target vehicle 2310 in the vicinity of vehicle 200. For example target vehicle 2310 may comprise another vehicle, such as a car, truck or motorcycle traveling near vehicle 200. Processing unit 110 may determine, for each target vehicle 2310, an offset profile. The offset profile may include a determination of whether in its current and predicted position, target vehicle 2310 will be within a predefined range of vehicle 200. If processing unit 110 determines that target vehicle 2310 is or will be within a predefined range of vehicle 200, processing unit may determine whether there is enough space within first lane constraint 810 and second lane constraint 820, for vehicle 200 to bypass target vehicle 2310. If there is not enough space, processing unit 110 may execute a lane change. If there is enough space, processing unit 110 may determine whether there is enough time to bypass target vehicle 2310 before the distance between vehicle 200 and target vehicle 2310 closes. If there is enough time, processing unit 110 may initiate and or activate the offset maneuver to bypass target vehicle 2310. The offset maneuver may be executed by processing unit 110 so that the movement of vehicle 200 is smooth and comfortable for the driver. For example, the offset slew rate may be approximately 0.15 to 0.75 m/sec. The offset maneuver may be executed so that the maximum amplitude of the offset maneuver will occur when the gap between vehicle 200 and object 825 closes. If there is not enough time, processing unit 110 may initiate braking and then initiate an offset maneuver.

[0254] Further, processing unit 110 may execute action module 2415 to abort the plan of vehicle 200 to pass target vehicle 2310. If target vehicle 2310 is not in lane 2330 of vehicle 200, instructions included in action module 1230 may enable vehicle 200 to pass target vehicle 2330. However, if execution of target vehicle acquisition module 2410 indicates that target vehicle 2310 is changing lanes into lane 2330 of vehicle 200, processing unit 110 may execute instructions included in action module 2415 to abort the lane change of vehicle 200. For example, processing unit 110 may transmit electronic signals to throttling system 220, braking system 230, and/or steering system 240 of vehicle 200 to abort the lane change. Additionally or alternatively, processing unit may cause an audible notification to sound.

[0255] FIG. 24B illustrates a flowchart of an exemplary process 2420 for navigating a vehicle among encroaching vehicles, consistent with disclosed embodiments. Process 2420 may identify lane constraints that define a lane of travel for a vehicle (e.g., vehicle 200) to travel, identify and monitor a target vehicle (e.g., vehicle 2310), and enable the vehicle to pass the target vehicle or abort the pass if it is determined that the target vehicle is entering a lane in which the vehicle is traveling.

[0256] At step 2430, at least one of image capture device 122, 124, and/or 126 may acquire a plurality of images of an area in the vicinity of vehicle 200. For example, a camera included in image acquisition unit 120 (such as image capture device 122) may capture a plurality of images and transmit them over a digital connection (e.g., USB, wireless, Bluetooth, etc.) to processing unit 110. In some embodiments, processing unit 110 may receive more than one plurality of images via a plurality of data interfaces. For example, processing unit 110 may receive a plurality of images from each of image capture devices 122, 124, 126, each of which may have an associated data interface for communicating data to processing unit 110. The disclosed embodiments are not limited to any

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particular data interface configurations or protocols.

[0257] Next, at step 2440, processing unit 110 may determine a first lane constraint on first vehicle side 802 and a second lane constraint on second vehicle side 812 using the plurality of images received via data interface 128. For example, as part of implementing step 2440, processing unit 110 may execute instructions of lane constraint module 910. Further, as part of determining the first and second lane constraints, processing unit 110 may use one or more of the processes discussed above in connection with FIGS. 5A-5D.

[0258] At step 2450, processing unit 110 may acquire target vehicle 2310. To acquire target vehicle 2310, processing unit 110 may execute target vehicle acquisition module 2410. For example, processing unit 110 may execute instructions to analyze acquired images to identify second lane 2340 in which target vehicle 2310 is traveling and determine whether target vehicle 2310 is traveling in lane 2330 in which vehicle 200 is traveling. This determination may be based on the techniques described in connection with FIGS. 5A-5D, above.

[0259] At step 2455, processing unit 110 may determine whether second lane 2340 in which target vehicle 2310 is traveling is different than lane 2330 in which vehicle 200 is traveling.

[0260] At step 2460, processing unit 110 may enable vehicle 200 to pass target vehicle 2310 if second lane 2340 is different than lane 2330 in which vehicle 200 is traveling. To enable vehicle 200 to pass target vehicle 2310, processing unit may execute action module 2415.

[0261] Next, at step 2465, processing unit 110 may execute target acquisition module 2410 to monitor target vehicle 2310. This may include estimating a velocity of target vehicle 2310 and determining the location of target vehicle 2310, such as with respect to vehicle 200.

[0262] Step 2470 may include determining whether target vehicle 2310 has entered lane 2330. If processing unit 110 determines that target vehicle 2310 has not entered lane 2330, at step 2480, processing unit 110 may allow vehicle 200 to complete the pass.

[0263] At step 2490, if processing unit 110 determines that target vehicle 2310 has entered lane 2330 (or is entering lane 2330 or is otherwise on a trajectory to bring vehicle 2310 into lane 2330), processing unit 110 may execute action module 2415 to abort the pass. This may include, for example, issuing an audible notification to driver of vehicle 200 via speakers 360. Additionally or alternatively, step 2490 may include executing instructions included in action module 2415 to cause processing unit 110 to transmit electronic signals to throttling system 220, braking system 230, and/or steering system 240 of vehicle 200 to abort lane change.

Navigating a Vehicle to Avoid Encroaching Traffic

[0264] System 100 may provide driver assist functionality that monitors the vicinity around vehicle 200 and responds to the presence of another vehicle encroaching upon vehicle 200. Monitoring the vicinity around vehicle 200 may include monitoring a collision threshold. For example a collision threshold may include a time to collision or a minimum predetermined distance between vehicle 200 and other traffic. System 100 may further cause vehicle 200 to take evasive action to avoid encroaching traffic. For example, evasive action may include braking, changing lanes, or otherwise altering the course of vehicle 200.

[0265] As illustrated in FIG. 25, vehicle 200 may travel on roadway 2500. Vehicle 200 may include system 100 to detect and respond to encroaching traffic. For example, vehicle 200 may determine that another vehicle is entering into the lane in which vehicle 200 is traveling or otherwise determine that another vehicle is crossing a collision threshold. Vehicle 200 may react to an encroaching vehicle, such as by altering course, braking, or accelerating.

[0266] As discussed with respect to FIG. 8 and as shown in FIG. 25, vehicle 200 may include first vehicle side 802, which may be first distance 805 from a first lane constraint 2502. Similarly, vehicle 200 may include second vehicle side 812 opposite from first vehicle side 802, and second vehicle side 812 may be second distance 815 from a second lane constraint 2504. In this manner, first lane constraint 2502 and second lane constraint 2504 may define a lane 2505 within which vehicle 200 may travel.

[0267] System 100 may determine first lane constraint 2502 and second lane constraint 2504 based on a plurality of images acquired by one or more of image capture devices 122-126. According to some embodiments, first lane constraint 2502 and/or second lane constraint 2504 may be identified by visible lane boundaries, such a line marked on a road surface. Additionally or alternatively, first lane constraint 2502 and/or second lane constraint 2504 may include an edge of a road surface. According to some embodiments, system 100 may determine first lane constraint 2502 and/or second lane constraint 2502 by identifying a midpoint 2520 of a road surface width (or any other suitable road feature vehicle 200 may use as a navigation reference). System 100 may identify lane constraints in this manner when, for example, lines designating road lanes are not painted or otherwise labeled.

[0268] Detection of first lane constraint 2502 and/or second lane constraint 2504 may include processing unit 110 determining their 3D models in a camera coordinate system. For example, the 3D models of first lane constraint 2502 and/or second lane constraint 2504 may be described by a third-degree polynomial. In addition to 3D modeling of first lane constraint 2502 and/or second lane constraint 2504, processing unit 110 may estimate motion parameters, such as the speed, yaw and pitch rates, and acceleration of vehicle 200. Optionally, processing unit may detect static and moving vehicles and their position, heading, speed, and acceleration, all relative to vehicle 200. Processing unit 110 may determine a road elevation model to transform the information acquired

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from the plurality of images into 3D space.

[0269] The driver of vehicle 200 cannot assume that other traffic traveling in adjacent or near-adjacent lanes will only change lanes if it is safe for that traffic to shift into lane 2505 in which vehicle 200 is driving. Thus, it may be desirable to consider and monitor traffic traveling in nearby lanes to detect lateral encroachment into lane 2505 of vehicle 200, so that vehicle 200 may react to lateral encroachment to avoid a collision. System 100 may identify an encroaching vehicle 2510 based on the plurality of images and determine that encroaching vehicle 2510 is approaching vehicle 200. System 100 may then cause an action to account for the encroaching vehicle. For example, system 100 may cause vehicle 200 to maintain a current velocity and travel within first lane constraint 2502 and second lane constraint 2504 such that a first distance 2530, which is on first vehicle side 802 on which encroaching vehicle 2510 is approaching, is greater than a second distance 2540.

[0270] Processing unit 110 may be configured to determine the presence of one or more encroaching vehicles 2510 in the vicinity of vehicle 200. Processing unit 110 may determine, for each encroaching vehicle 2510 an offset profile. The offset profile may include a determination of whether in its current and predicted position, encroaching vehicle 2510 will be within a predefined range of vehicle 200. If processing unit 110 determines that encroaching vehicle 2510 is or will be within a predefined range of vehicle 200, processing unit may determine whether there is enough space within first lane constraint 2502 and second lane constraint 2504, for vehicle 200 to bypass encroaching vehicle 2510. If there is not enough space, processing unit 110 may execute a lane change. If there is enough space, processing unit 110 may determine whether there is enough time to bypass encroaching vehicle 2510 before the distance between vehicle 200 and encroaching vehicle 2510 closes.

[0271] For example, if there is enough time, processing unit 110 may initiate and or activate the offset maneuver to bypass encroaching vehicle 2510. The offset maneuver may be executed by processing unit 110 so that the movement of vehicle 200 is smooth and comfortable for the driver. For example, the offset slew rate may be approximately 0.15 to 0.75 m/sec. The offset maneuver may be executed so that the maximum amplitude of the offset maneuver will occur when the gap between vehicle 200 and encroaching vehicle 2510 closes. If there is not enough time, processing unit 110 may initiate braking (e.g., via transmitting electronic signals to braking system 230) and then initiate offset maneuver (e.g., by transmitting electronic signals to throttling system 220 and/or steering system 240).

[0272] System 100 may determine, based on a plurality of images acquired by one or more of image capture devices 122-126, that encroaching vehicle 2510 has crossed at least one collision threshold. For example, the at least one collision threshold may include a minimum predetermined distance 2550 between vehicle 200 and encroaching vehicle 2510. For example, encroaching vehicle 2510, as illustrated in FIG. 25, is shown exceeding minimum predetermined distance 2550. Additionally or alternatively, the at least one collision threshold may include a time to collision of vehicle 200 and encroaching vehicle 2510. The time-to-collision threshold may be determined based on the distance between vehicle 200 and encroaching vehicle 2510, the velocity of vehicle 200 and/or encroaching vehicle 2510, the lateral velocity of vehicle 200 and/or encroaching vehicle 2510, and/or the acceleration of vehicle 200 and/or encroaching vehicle 2510. A collision threshold based on a time to collision may be set to allow enough time for system 100 to effectively conduct evasive action to avoid collision.

[0273] If system 100 determines that at least one collision threshold has been crossed, system 100 may cause vehicle 200 to take evasive action. For example, this may include causing other subsystems of vehicle 200 to operate. Thus, system 100 may operate to cause vehicle 200 to increase speed by communicating with throttling system 220, braking system 230, and/or steering system 240 to change the speed and/or direction of vehicle 200.

[0274] The evasive action may include causing vehicle 200 to change lanes. This may be a desirable response if, for example, vehicle 200 is traveling on a multilane highway and system 100 determines that changing lanes to move away from encroaching vehicle 2510 will avoid a collision. Evasive action may include vehicle 200 altering its course. Additionally or alternatively, evasive action may include altering course of vehicle 200. For example, to take evasive action, processing unit 110 may transmit electronic signals to throttling system 220, braking system 230, and/or steering system 240.

[0275] System 100 may also be configured to cause vehicle 200 to take an action after the evasive action has been completed. For example, system 100 may cause vehicle 200 to return to midpoint 2520 of lane 2505 in which vehicle 200 is traveling. Additionally or alternatively, system 100 may cause vehicle 200 to resume a preset speed after braking in response to encroaching vehicle 2510.

[0276] FIG. 26 is an exemplary block diagram of memory 140, which may store instructions for detecting and responding to traffic laterally encroaching on a vehicle consistent with disclosed embodiments. As illustrated in FIG. 26, memory 140 may store a lane constraint module 2610, an encroaching vehicle acquisition module 2620, and an action module 2630.

[0277] In one embodiment, lane constraint module 2610 may store instructions which, when executed by processing unit 110, may detect and define first lane constraint 2502 and second lane constraint 2504. For example, processing unit 110 may execute lane offset constraint module 2610 to process the plurality of images received from at least one image capture device 122-126 and detect first lane constraint 2502 and second lane constraint 2504. As discussed above, this may include

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identifying painted lane lines and/or measuring a midpoint of a road surface. Processing unit 110 may perform the analysis based on the techniques described in connection with FIGS. 5A-5D, above.

[0278] In one embodiment, encroaching vehicle acquisition module 2620 may store instructions which, when executed by processing unit 110, may detect the presence of encroaching vehicle 2510 and monitor encroaching vehicle 2510. For example, encroaching vehicle acquisition module 2620 may include instructions for determining a relative location of encroaching vehicle 2510 to vehicle 200. In some embodiments, this may include monitoring the velocity of encroaching vehicle 200. According to some embodiments, encroaching vehicle acquisition module 2620 may determine whether encroaching vehicle 2510 has exceeded a collision threshold. A collision threshold may be, for example, a minimum predetermined distance between vehicle 200 and encroaching vehicle 2510. If encroaching vehicle 2510 comes closer to vehicle 200 than the minimum predetermined distance, processing unit 110 may determine that encroaching vehicle 2510 is indeed encroaching and execute instructions to avoid collision with encroaching vehicle 2510.

[0279] Additionally or alternatively, a collision threshold may include a time to collision. The time-to-collision threshold may be determined based on the distance between vehicle 200 and encroaching vehicle 2510, the velocity of vehicle 200 and/or encroaching vehicle 2510, the lateral velocity of vehicle 200 and/or encroaching vehicle 2510, and/or the acceleration of vehicle 200 and/or encroaching vehicle 2510. A collision threshold based on a time to collision may be set to allow enough time for processing unit 110 and system 100 to effectively conduct evasive action to avoid collision.

[0280] Further, processing unit 110 may execute action module 2630 to respond to the detection of encroaching vehicle 2510 and/or the crossing of a collision threshold. For example, action module 2630 may include instructions to cause vehicle 200 to maintain a current velocity and to travel within first lane constraint 2502 and second lane constraint 2504 such that first distance 2530 is greater than second distance 2540. The first distance 2530 may be on the same side of vehicle 200 as encroaching vehicle 2510, so that vehicle 200 is farther away from encroaching vehicle 2510 while still within first lane constraint 2502 and second lane constraint 2504. If processing unit 110 determines that a collision threshold has been crossed, processing unit 110 may execute action module 2630 to cause vehicle 200 to take evasive action, such as altering course, braking, and/or changing lanes. Action module 2630 may also include instructions that cause vehicle 200 to resume course after completing evasive action. For example, processing unit 110 may cause vehicle 200 to resume a preset speed after braking or return to the center of lane 2505.

[0281] FIG. 27 illustrates a flowchart of an exemplary process 2720 detecting and responding to traffic laterally encroaching on a vehicle, consistent with disclosed embodiments. Process 2720 may identify lane constraints that define a lane of travel for vehicle travel, determine whether an encroaching vehicle 2510 is approaching, and cause vehicle 200 to maintain current velocity and to travel within first lane constraint 2501 and second lane constraint 2504 such that first distance 2530, on the side of vehicle 200 that encroaching vehicle 2510 is approaching, is greater than second distance 2540.

[0282] At step 2730, at least one image capture device 122, 124, and/or 126 may acquire a plurality of images of an area in the vicinity of vehicle 200. For example, a camera included in image acquisition unit 120 (such as image capture device 122) may capture a plurality of images and transmit them over a digital connection (e.g., USB, wireless, Bluetooth, etc.) to processing unit 110. In some embodiments, processing unit 110 may receive more than one plurality of images via a plurality of data interfaces. For example, processing unit 110 may receive a plurality of images from each of image capture devices 122, 124, 126, each of which may have an associated data interface for communicating data to processing unit 110. The disclosed embodiments are not limited to any particular data interface configurations or protocols.

[0283] Next, at step 2740, processing unit 110 may determine a first lane constraint on first vehicle side 802 and a second lane constraint on second vehicle side 812 using the plurality of images received via data interface 128. For example, as part of implementing step 2740, processing unit 110 may execute instructions of lane constraint module 2610. Further, as part of determining the first and second lane constraints, processing unit 110 may use one or more of the processes discussed above in connection with FIGS. 5A-5D.

[0284] At step 2750, processing unit 110 may determine whether encroaching vehicle 2510 is approaching. To make this determination, processing unit 110 may execute encroaching vehicle acquisition module 2620. Encroaching vehicle acquisition module 2620 may include instructions to process images to detect other traffic. This may include identifying vehicles within a certain range of vehicle 200, such as those vehicles that are adjacent to vehicle 200. These adjacent vehicles may be encroaching vehicles 2510.

[0285] Once encroaching vehicle 2510 is identified, processing unit may determine more information regarding vehicle 2510. For example, at step 2555, processing unit 110 may determine whether target vehicle 2330 has exceeded a collision threshold. A collision threshold may be, for example, a minimum predetermined distance between vehicle 200 and encroaching vehicle 2510. If encroaching vehicle 2510 comes closer to vehicle 200 than the minimum predetermined distance, processing unit 110 may determine that encroaching vehicle 2510 is indeed encroaching and execute instructions to avoid collision with encroaching vehicle 2510.

[0286] Additionally or alternatively, a collision threshold may be a time to collision. The time-to-collision

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threshold may be determined based on the distance between vehicle 200 and encroaching vehicle 2510, the velocity of vehicle 200 and/or encroaching vehicle 2510, the lateral velocity of vehicle 200 and/or encroaching vehicle 2510, and/or the acceleration of vehicle 200 and/or encroaching vehicle 2510. A collision threshold based on a time to collision may be set to allow enough time for processing unit 110 and system 100 to effectively conduct evasive action to avoid collision.

[0287] At step 2760, processing unit 110 may cause vehicle 200 to maintain current velocity and to travel within first lane constraint 2502 and second lane constraint 2504. To cause vehicle 200 to operate in this manner, processing unit 110 may execute action module 2630. Additionally or alternatively, step 2760 may include executing instructions on action module 1230 to cause processing unit 110 to transmit electronic signals to the accelerator 2610, brakes 2620, and/or steering system of vehicle 200 to cause vehicle 200 to maintain current velocity and to travel within first and second lane constraints 810 and 820.

[0288] If, at step 2755, processing unit 110 determined that a collision threshold has been exceeded, the processing unit 110 may take evasive action. The evasive action may include causing vehicle 200 to change lanes. This may be a desirable response if, for example, vehicle 200 is traveling on a multilane highway and system 100 determines that changing lanes to move away from encroaching vehicle 2510 will avoid a collision. Evasive action may include vehicle 200 altering its course. Additionally or alternatively, evasive action may include altering course of vehicle 200. For example, processing unit 110 may undertake evasive action by transmitting electronic signals to throttling system 220, braking system 230, and/or steering system 240 of vehicle 200. After the evasive action is completed, at step 2780, processing unit 110 may control vehicle 200 to resume its prior navigation (e.g., to resume navigation to a desired location).

Multi-Threshold Reaction Zone for Vehicle Navigation

[0289] System 100 may provide driver assist functionality that causes a response in vehicle 200, such as braking, accelerating, switching lanes, turning, and/or other navigational responses. For example, if system 100 detects the presence of another vehicle ahead of vehicle 200 that is traveling at a rate of speed slower than vehicle 200, system 100 may cause vehicle 200 to reduce its speed by braking. System 100 may apply a braking profile that accounts for the immediacy of the risk (e.g., the risk of collision) to provide the driver with a natural driving sensation.

[0290] System 100 may cause various different responses depending on the situation and a determined risk of collision with another vehicle, for example. System 100 may take no action in response to changes in speed or direction of a target vehicle ahead if the target vehicle is sufficiently far ahead and the determined risk of collision is low. Where the target vehicle may be closer or when the risk of collision rises above a predetermined level, system 100 may cause a response, such as braking, etc. When the risk of collision is even higher (e.g., where system 100 determines that a collision would be imminent without evasive action), system 100 may cause vehicle 100 to take an evasive action, such as maximum or near maximum braking, change of direction, etc.

[0291] FIGS. 28A and 28B are diagrammatic representations of a primary vehicle 200a on a road 2800, consistent with disclosed embodiments. In some instances, road 2800 may be divided into two lanes, lane 2810 and lane 2820. A target object, such as target vehicle 200b, may be traveling ahead of primary vehicle 200a in the same lane (e.g., lane 2820 as shown in FIGS. 28A and 28B) or in a different lane. As shown in the example depicted in FIG. 28A, primary vehicle 200a and target vehicle 200b may be separated by a distance d_1. At a given time after the scene depicted in FIG. 28A, primary vehicle 200a and target vehicle 200b may be separated by a distance d_2 as shown in FIG. 28B, where d_2 is less than d_1. For example, primary vehicle 200a may be traveling at a rate of speed greater than target vehicle 200b, causing the distance between the vehicles to decrease from d_1 to d_2.

[0292] As another example, primary vehicle 200a and target vehicle 200b may be traveling at the same rate of speed until target vehicle 200b reduces its speed by braking, or primary vehicle 200a increases its speed by accelerating, causing the distance between the vehicles to decrease from d_1 to d_2. As another example, target vehicle 200b may encroach from a side of primary vehicle 200a. In some circumstances, if target vehicle 200b is ahead or a sufficient distance away from primary vehicle 200a (e.g., five meters or more, 10 meters or more, etc.) and moves toward primary vehicle 200a, system 100 may not take any action. However, if target vehicle 200b continues to move closer to primary vehicle 200a, then system 100 may cause primary vehicle 200a to brake, change speed, and/or change lanes. For example, if target vehicle 200b is within a predetermined threshold (e.g., within five meters), primary vehicle 200a may then take action. Different scenarios involving the relative speeds and positions of primary vehicle 200a and target vehicle 200b are possible, and the disclosed embodiments are not limited to any particular scenario.

[0293] In some embodiments, the multi-threshold reaction zone may provide a natural feeling driving experience to the user. For example, as discussed above, if the risk of collision is low, then system 100 may disregard movements by target vehicle 200b. As a result, primary vehicle 200a may not respond to movements or actions of target vehicle 200b when there is not a risk of a collision (e.g., primary vehicle 200a would not need to mimic every motion of target vehicle 200b when it's 100 meters ahead). However, if target vehicle 200b is close to primary vehicle 200a and/or if system 100 determines that the risk of collision is high, then a responsive maneuver

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may be taken such that the user feels safer by increasing space between primary vehicle 200a and target vehicle 200b. If system 100 determines that a crash may be imminent, then system 100 may take a more dramatic action without causing the user to be surprised, because the action may be necessary to avoid a collision.

[0294] Accordingly, in some embodiments, system 100 may associate the different reaction zones with different degrees of responsive actions. For example, in some embodiments, system 100 may take no action when target vehicle 200b is within a first threshold (e.g., when target vehicle 200b is far away from primary vehicle 200a), system 100 may take a medium action with target vehicle 200b is within a second threshold (e.g., when target vehicle 200b is becoming closer to primary vehicle 200a), and system 100 may take a more dramatic action when target vehicle 200 is within a third threshold (e.g., when target vehicle 200b is sufficiently close to primary vehicle 200a that there is a risk of a collision). In a first reaction zone associated with the first threshold, system 100 may take no action when the estimated distance-to-target associated with target vehicle 200b is greater than twice a predetermined safety distance. In some embodiments, the first reaction zone may apply where the estimated distance-to-target associated with target vehicle 200b falls in the range of 1.5 to 2.5 times the predetermined safety distance.

[0295] The estimated distance-to-target may be the current distance between primary vehicle 200a and target vehicle 200b plus the expected change of this distance over a prediction time (e.g., in the range of 0.1 to 1.0 seconds, depending on factors associated with system 100 such as velocity tracking control loops, actuators, and vehicle dynamics). The expected change of distance may be calculated as: $(v_{target} - v_{primary}) * t_{prediction} + ((a_{target} - a_{primary}) * t_{prediction}^{1/2})$, where v_{target} and $v_{primary}$ correspond to the speed of target vehicle 200b and primary vehicle 200a, respectively, a_{target} and $a_{primary}$ correspond to the acceleration of target vehicle 200b and primary vehicle 200a, respectively, and $t_{prediction}$ corresponds to the prediction time. Choosing a prediction time approximating the overall reaction time of system 100 may account for the fact that desired navigational responses for primary vehicle 200a may not be implemented immediately, and thereby may provide the driver and/or passengers of primary vehicle 200a with a smooth, natural driving experience.

[0296] The predetermined safety distance may be defined as: max $\{d_{static}, d_{dynamic}\}$, d_{static}, which may fall in the range of 2 to 10 meters, may represent a desired safety distance between primary vehicle 200a and another vehicle (such as target vehicle 200b) while the vehicles are stopping and/or moving at a low rate of speed. $d_{dynamic}$ may represent a desired safety distance when the vehicles are moving at a speed greater than a low rate of speed, and may be calculated as: $t_{safety} * \min(v_{target}, v_{primary})$, where v_{target} and $v_{primary}$ correspond to the speed of target vehicle 200b and primary vehicle 200a, respectively. t_{safety} may fall in the range of 0.5 to 2.5 seconds and may be adjusted by the driver of primary vehicle 200a via user interface 170 according to the driver's preferences. Thus, the driver may be able to control the distance that system 100 maintains between primary vehicle 200a and other vehicles.

[0297] In a second reaction zone associated with the second threshold, system 100 may place target vehicle 200b in a safety zone and apply different weights to different maneuvers performed by target vehicle 200b. For example, as target vehicle 200b may approach a lower boundary of the safety zone, e.g., the estimated distance-to-target associated with target vehicle 200b may approach the predetermined safety distance (discussed above in connection with the first reaction zone), system 100 may assign more weight to deceleration maneuvers (e.g., mimicked more) and less weight to acceleration maneuvers (e.g., mimicked less). In some embodiments, the lower boundary may fall in the range of 0.5 to 1.5 times the predetermined safety distance, depending on driver preferences. Conversely, as target vehicle 200b approaches an upper boundary of the safety zone, e.g., the estimated distance-to-target associated with target vehicle 200b may approach twice the predetermined safety distance, system 100 may assign less weight to deceleration maneuvers (e.g., mimicked less) and more weight to acceleration maneuvers (e.g., mimicked more). In some embodiments, the lower boundary may fall in the range of 1.5 to 2.5 times the predetermined safety distance, depending on driver preferences.

[0298] In a third reaction zone associated with the third threshold, system 100 may place target vehicle 200b in a danger zone when the estimated distance-to-target associated with target vehicle 200b is less than the predetermined safety distance. In this scenario, system 100 may cause primary vehicle 200a to mimic (e.g., immediately) any deceleration maneuvers (while disregarding any acceleration maneuvers) performed by target vehicle 200b. In some embodiments, the first reaction zone may apply where the estimated distance-to-target associated with target vehicle 200b falls in the range of 0.5 to 1.5 times the predetermined safety distance, depending on driver preferences.

[0299] In some embodiments, system 100 may cause a response in primary vehicle 200a, such as braking. As indicated in FIG. 28B, for example, the distance between the primary vehicle 200a and target vehicle 200b may decrease from d_1 to d_2. Depending on the distance d_2 and, by extension, the time before collision, system 100 may cause primary vehicle 200a to reduce its speed so as to avoid a collision with target vehicle 200b. In addition, system 100 may apply one or more braking profiles when causing primary vehicle 200a to reduce its speed, also based on, for example, the time before collision. Thus, if the time before collision (and/or the distance d_2) exceeds a first predetermined threshold, system 100 may cause primary vehicle 200a to brake in a gradual manner, change lanes, and/or change speed, whereas if the time

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before collision (and/or the distance d_2) is below a second predetermined threshold, system 100 may cause primary vehicle 200a to brake, change lanes, and/or change speed in a more rapid manner.

[0300] FIG. 29 is an exemplary block diagram of a memory configured to store instructions for performing one or more operations, consistent with the disclosed embodiments. As shown in FIG. 29, memory 140 may store a target monitoring module 2902, an intercept time module 2904, and an action response module 2906. The disclosed embodiments are not limited to any particular configuration of memory 140. Further, processing unit 110 may execute the instructions stored in any of modules 2902-2906 included in memory 140.

[0301] In one embodiment, target monitoring module 2902 may store software instructions (such as computer vision software) which, when executed by processing unit 110, identifies and monitors a target object (such as target vehicle 200b) appearing in a plurality of images representing an environment in the vicinity of primary vehicle 200. For purposes of this disclosure, the target object may also be referred to as target vehicle 200b, although the target object may be a pedestrian, road hazard (e.g., large debris), and the like. The plurality of images may be acquired by one or more of image capture devices 122, 124, and 126. Processing unit 110 may execute target monitoring module 2902 to identify and monitor target vehicle 200b by, for example, analyzing the plurality of images using the techniques described in connection with FIGS. 5A-5D, above. Thus, target monitoring module 2902 may track different variables, such as the motion (e.g., direction of travel and trajectory), speed, and acceleration associated with target vehicle 200b, as well as the distance between primary vehicle 200a and the target vehicle 200b. Such information may be tracked continuously or at predetermined intervals.

[0302] In one embodiment, intercept time module 2904 may store software instructions which, when executed by processing unit 110, determines an indicator of an intercept time between primary vehicle 200a and target vehicle 200b. The intercept time may refer to an amount of time before primary vehicle 200a makes contact (e.g., collides) with target vehicle 200b. Processing unit 110 may execute intercept time module 2904 to determine an indicator of the intercept time based on an analysis of images acquired by one or more of image capture devices 122, 124, and 126. For example, intercept time module 2904 may make the determination using a series of time-based observations, e.g., of the position, speed, and/or acceleration of target vehicle 200b (relative to primary vehicle 200a), such as Kalman filters or linear quadratic estimation (LQE). The Kalman filters may be based on a measurement of the scale of target vehicle 200b, where the scale measurement is proportional to the intercept time.

[0303] In one embodiment, action response module 2906 may store software instructions (such as computer vision software) which, when executed by processing unit 110, causes one or more responses in primary vehicle 200a. The responses may be based on the identification and monitoring of target vehicle 200b (e.g., performed via execution of target monitoring module 2902) and/or the indicator of an intercept time between primary vehicle 200a and target vehicle 200b (e.g., determined via execution of intercept time module 2904). Processing unit 110 may cause one or more responses in primary vehicle 200a by, for example, transmitting electronic signals (e.g., via a CAN bus) to throttling system 220, braking system 230, and/or steering system 240 of primary vehicle 200a to brake, accelerate, or trigger a turn, lane shift, and/or change in direction of primary vehicle 200a. Processing unit 110 may use extended Kalman Filters to estimate data associated with target vehicle 200b and primary vehicle 200a, such as: speed, acceleration, turn rate, pitch angle, pitch rate, position and heading of target vehicle 200b relative to primary vehicle 200a, the size of target vehicle 200b, road geometry, and the like. For example, processing unit 110 may receive measurements from components on primary vehicle 200a, such as an odometer, an inertial measurement unit (IMU), image processor 190, and the like. Thus, processing unit 110 may calculate data associated with target vehicle 200b and/or primary vehicle 200a using state equations derived from kinematic equations of motion, rigidity constraints, and motion assumptions, where inputs to the equations may include measurements from components on primary vehicle 200a. Processing unit 110 may also use the techniques described in connection with FIGS. 4-7, above, to cause one or more responses in primary vehicle 200a.

[0304] FIG. 30 is a flow chart showing an exemplary process 3000 for causing a response in a primary vehicle, consistent with disclosed embodiments. At step 3010, processing unit 110 may receive a plurality of images via data interface 128 between processing unit 110 and image acquisition unit 120. For instance, one or more cameras included in image acquisition unit 120 may capture a plurality of images of an area forward of primary vehicle 200a (or to the sides or rear of a vehicle, for example) and transmit them over a data connection (e.g., digital, wired, USB, wireless, Bluetooth, etc.) to processing unit 110.

[0305] At step 3020, processing unit 110 may execute target monitoring module 2902 to identify a target object (such as target vehicle 200b) within the plurality of images. For example, target monitoring module 2902 may detect the presence of vehicles in the images using the techniques described in connection with FIGS. 5A and 5B, above. Multiple vehicles (and/or objects) may be detected in the same lane or in a different lane as primary vehicle 200a, and at varying distances from primary vehicle 200a, based on image data, position data (e.g., GPS location information), map data, the yaw rate of primary vehicle 200a, lane or other road markings, speed data, and/or data from sensors included in primary vehicle 200a. In a scenario where multiple vehicles are detected,

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target monitoring module 2902 may determine target vehicle 200b to be the vehicle traveling in the same lane as primary vehicle 200a and/or located closest to primary vehicle 200a.

[0306] At step 3030, processing unit 110 may execute target monitoring module 2902 to monitor target vehicle 200b identified at step 3020. For example, target monitoring module 2902 may track information associated with target vehicle 200b, such as the motion (e.g., direction of travel and trajectory), speed, and acceleration, as well as the distance between primary vehicle 200a and the target vehicle 200b. Target monitoring module 2902 may track such information continuously, or at predetermined intervals, by analyzing the plurality of images using the techniques described in connection with FIGS. 5A-5D, above. At step 3040, processing unit 110 may execute intercept time module 2904 to determine an indicator of an intercept time between primary vehicle 200a and target vehicle 200b. Intercept time module 2904 may make the determination by tracking the position, speed, and/or acceleration of target vehicle 200b (relative to primary vehicle 200a) over one or more periods of time. Intercept time module 2904 may use the techniques described in connection with FIGS. 5A and 5B, above to track such information.

[0307] At step 3050, processing unit 110 may execute action response module 2906 to cause one or more responses in primary vehicle 200a. For example, processing unit 110 may transmit electronic signals (e.g., via a CAN bus) to throttling system 220, braking system 230, and/or steering system 240 of primary vehicle 200a to brake, accelerate, or trigger a turn, lane shift, and/or change in direction of primary vehicle 200a. Further, one or more actuators may control throttling system 220, braking system 230, and/or steering system 240. For example, processing unit 110 may transmit electronic signals that cause system 100 to physically depress the brake by a predetermined amount or ease partially off the accelerator of vehicle 200. Further, processing unit 110 may transmit electronic signals that cause system 100 to steer vehicle 200 in a particular direction. Such responses may be based on the monitoring of target vehicle 200b (performed at step 3030) and/or the indicator of an intercept time between primary vehicle 200a and target vehicle 200b (determined at step 3040). In some embodiments, the intercept time may be compared with one or more predetermined thresholds, e.g., a first and second intercept threshold. For example, the response may include an emergency avoidance action if the indicator of intercept time indicates that a target object is within a particular intercept threshold (e.g., within the second intercept threshold). The emergency avoidance action may include changing lanes and/or emergency braking.

[0308] The thresholds may be expressed as units of time. Thus, for example, if the indicator of intercept time indicates that target vehicle 200b is outside of the first threshold (e.g., the time before collision between primary vehicle 200a and target vehicle 200b exceeds the first threshold), then action response module 2906 may cause a response in primary vehicle 200a based on an averaged motion profile associated with target vehicle 200b. The averaged motion profile associated with target vehicle 200b may represent an averaged position and/or averaged speed of target vehicle 200b for a particular threshold. In some embodiments, if target vehicle 200b is a certain distance and/or traveling a certain speed, system 100 may elect to take no action. For example, if target vehicle 200b is ahead or a sufficient distance away from primary vehicle 200a (e.g., five meters, 10 meters, etc.), system 100 may not take any action unless target vehicle 200b becomes closer to primary vehicle 200.

[0309] If the indicator of intercept time indicates that target vehicle 200b is between the first and second thresholds (e.g., the time before collision between primary vehicle 200a and target vehicle 200b falls in between the first and second thresholds), then action response module 2906 may cause a response in primary vehicle 200a based on the actual motion associated with target vehicle 200b. The actual motion may represent a position and/or speed of target vehicle 200b (e.g., not averaged or delayed) If the indicator of intercept time indicates that target vehicle 200b is within the second threshold (e.g., the time before collision between primary vehicle 200a and target vehicle 200b is below the second threshold), then action response module 2906 may cause an emergency action in primary vehicle 200a (such as a lane change or emergency braking).

[0310] FIG. 31 is a flow chart showing an exemplary process 3100 for declining to cause a response in a primary vehicle, consistent with disclosed embodiments. At step 3110, processing unit 110 may receive a plurality of images via data interface 128 between processing unit 110 and image acquisition unit 120, as described in connection with step 3010 of FIG. 30, above.

[0311] At step 3120, processing unit 110 may execute target monitoring module 2902 to locate a target object (e.g., target vehicle 200b) within the images received at step 3010 by analyzing the images, as described in connection with step 3020 of FIG. 30. above. At step 3125, processing unit 110 may execute target monitoring module 2902 to determine whether the target object (e.g., target vehicle 200b) is traveling in a lane different from primary vehicle 200a, using the techniques described in connection with step 3030 of FIG. 30, above. If target vehicle 200b is determined to be traveling in a lane different from primary vehicle 200a (step 3125, yes), processing unit 110 may decline to cause a response in primary vehicle 200a at step 3130. Alternatively, if system 100 determines that target vehicle 200b does not constitute an imminent risk of collision (e.g., target vehicle 200b a nonintersecting trajectory with primary vehicle 200a or a potential time to collision beyond a threshold such that the target object does not pose an imminent risk at the present time), processing unit 110 may decline to cause a response in primary vehicle 200a at step 3130. Other-

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wise (step 3125, no), process 3100 may conclude and no response occurs.

Stopping an Autonomously Driven Vehicle Using a Multi-Segment Braking Profile

[0312] System 100 may provide driver assist functionality that monitors and responds to environmental conditions to control the braking of vehicle 200. For instance, system 100 may detect, based on a plurality of images, an object that triggers the stopping of vehicle 200. For example, this object may include another vehicle in the vicinity of vehicle 200, a traffic light, and/or a traffic sign. System 100 may use a braking profile to slow and/or stop vehicle 200. According to some embodiments, the braking profile may include multiple segments, where deceleration is executed at different stages. For example, the braking profile may cause system 100 to stop vehicle 200 at a decreasing rate of deceleration.

[0313] By providing a braking profile that includes multiple segments, system 100 may cause vehicle 200 to operate in a manner that feels natural to a driver and/or passengers. For example, when a driver stops a vehicle at a traffic light, the brakes are typically not applied at a constant rate from the moment they are applied until the moment when the vehicle stops. Operating brakes in such a manner result in an abrupt stop at the end. Instead, the driver may apply the brakes gently at first, then with increasing pressure, and then as the vehicle reaches its target stopping location, the driver may decrease the level of braking until it reaches zero (or near zero) at the moment the car stops. Operating the vehicle in this manner may provide a natural stopping progression, i.e., the driver may cause-a progressive deceleration at first so the vehicle does not experience an abrupt initial deceleration and then at the end, so that vehicle does not come to an abrupt stop.

[0314] System 100 may provide autonomous vehicle navigation that may implement braking according to an approach that feels natural to the driver and/or passengers of vehicle 200. For example, in some embodiments, system 100 may cause one or more of image capture devices 122-126 to acquire a plurality of images of an area in a vicinity of vehicle 200. Processing device 110 may receive the receive the plurality of images via data interface 128 and identify, based on analysis of the plurality of images, a trigger (e.g., an object, a traffic light, and/or a traffic sign) for stopping vehicle 200. Based on the identified trigger, system 100 may cause vehicle 200 to stop according to a braking profile. In some embodiments, the braking profile may include a plurality of segments (e.g., including a first segment associated with a first deceleration rate, a second segment which includes a second deceleration rate less than the first deceleration rate, and a third segment in which a level of braking is decreased as a target stopping location is approached, as determined based on the analysis of the plurality of images.

[0315] FIG. 32A illustrates vehicle 200 traveling on a roadway 3210 that includes an object 3220. System 100 may identify a trigger (e.g., object 3220) for stopping vehicle 200 in respect to detection of the trigger. For example, system 100 may first slow vehicle 200 after the trigger is detected and bring vehicle 200 to a stop before reaching object 3220.

[0316] Processing unit 110 may be configured to determine a trigger for stopping vehicle 200 based on a plurality of images acquired by one or more of image capture devices 122-126. Processing unit 110 may receive the images from image capture devices 122-126 via data interface 128. According to some embodiments, the trigger may include object 3220. For example, object 3220 may be another vehicle on roadway 2810. According to some embodiments, processing unit 110 may identify a trigger if object 3220 is within a certain vicinity of vehicle 200. For example, identification of the trigger may depend on a relative distance between object 3220 and vehicle 200. Further, this identification may optionally consider the relative velocity and/or relative acceleration between object 3220 and vehicle 200.

[0317] Additionally or alternatively, the trigger may include a traffic sign, such as traffic sign 3240 shown in FIG. 32A. For example, traffic sign 3240 may be a stop sign and/or a speed limit sign. According to some embodiments, processing unit 110 may process the plurality of images to determine the content of traffic sign 3240 as part of determining whether a trigger exists. For example, processing unit 110 may determine that a trigger is present based on a speed limit specified by traffic sign 3240 if vehicle 200 is exceeding the speed limit. As another example, processing unit 110 may determine a trigger exists based on a traffic light 2830 if the yellow and/or red light is on.

[0318] Based on the plurality of images, processing unit 110 may determine a target stopping location 3250 at which vehicle 200 will stop once a braking profile is executed. Reaching target stopping location 3250 may be accompanied by a release in braking pressure of vehicle 200. Target stopping location 3250 may be based on the location of traffic light 3230 and/or traffic sign 3240 such that vehicle 200 complies with traffic light 3230 and/or traffic sign 3240. Alternatively, target stopping location 3250 may be based on object 3220 such that vehicle 200 stops before reaching object 3220. Accordingly, target stopping location 3250 may be based on the location of object 3220 to avoid a collision between vehicle 200 and object 3220. In some embodiments, target stopping location 3250 may be updated based on new information obtained from the plurality of images, such as newly identified targets, newly visible obstacles, newly visible signs, etc.

[0319] FIG. 32B illustrates an exemplary braking profile, consistent with disclosed embodiments. In the example shown in FIG. 32B, the braking profile includes four segments. However, the number of segments is exemplary and a braking profile consistent with the dis-

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closed embodiments may include any appropriate number of segments (e.g., 2, 3, 4. 5, 6, etc., segments).

[0320] In segment 1, system 100 may prepare for a possible braking scenario. For example, in this zone, system 100 may receive information (e.g., map data and/or image data) about an upcoming intersection (e.g., an intersection with traffic lights). System 100 may gradually reduce the speed of vehicle 200 (e.g., the speed of vehicle 200 may be gradually reduced to about 70-50 km/hr, depending on the characteristics of the intersection). System 100 may cause the speed adjustment, for example, approximately 100-200 meters before the junction at average deceleration around 0.2-0.4 m/sec^2 (with a maximum of about 0.5 m/sec^2). By decreasing the speed of vehicle 200 in segment 1, system 100 may provide the driver and/or passengers of vehicle 200 with confidence that system 100 is aware of the approaching intersection.

[0321] In segment 2, system 100 may apply strong braking. In this segment, system 100 may receive information based on the analysis of image data that, for example, a traffic light is red and/or there is a stopped vehicle at the intersection in the line in which vehicle 200 is traveling. System 100 may cause vehicle 200 to experience significant speed reduction in this zone, while the distance to the stop line or stopped vehicle is still large. Doing so may provide the driver and/or passengers of vehicle 200 with a comfortable feeling that system 100 will have more than enough space to complete the braking maneuver. This zone may be approximately 30-100 meters away from the stop line, and the average deceleration may be about 1.5-2.5 m/sec^2 (with a maximum of about 3.5 m/sec^2).

[0322] In segment 3, system 100 may make a moderate braking adjustment. For example, in this segment, system 100 may adjust the speed of vehicle 200 according to the remaining distance to the stop line or stopped vehicle and based on the current speed and deceleration of vehicle 200. By making this adjustment, system 100 may provide the driver and/or passengers of vehicle 200 with an indication that system 100 is releasing most of the braking power while the speed is still being reduced but slower than before. This zone may be approximately 5-30 meters away from the stop line or stopped vehicle, and the average deceleration may be about 0.5-1.5 m/sec^2 (with a maximum of about 2 m/sec^2).

[0323] In segment 4, system 100 may make a small braking adjustment. In this segment, system 100 may close the remaining distance to the stop line or stopped vehicle at a very low speed gradually bringing it to zero. In this zone, the driver and/or passengers may feel that vehicle 200 is slowly sliding into its position (e.g., at the stop line or behind another vehicle). This zone may constitute approximately the last 5-7 meters to the stop line or stopped vehicle, and the average deceleration may be about 03-0.5 m/sec^2 (with a maximum of about 1 m/sec^2).

[0324] FIG. 33 is an exemplary block diagram of memory 140 and/or 150, which may store instructions for performing one or more operations consistent with disclosed embodiments. As illustrated in FIG. 33, memory 140 may store one or more modules for performing the trigger detection and responses described herein. For example, memory 140 may store a trigger identification module 3300 and an action response module 3310.

[0325] Trigger identification module 3300 may store instructions which, when executed by processing unit 110, may detect the presence and/or existence of a trigger for stopping vehicle 200. For example, trigger identification module 3300 may process the plurality of images received from at least one image capture device 122-124 to detect the presence of a trigger. As discussed above, this may include identifying object 3220, traffic light 3230, and/or traffic sign 3240.

[0326] Action response module 3310 may store instructions which, when executed by processing unit 110, may respond to the presence of a trigger. For example, action response module 3310 may execute control to decelerate and/or stop vehicle 200. For example, action response module 3310 may execute a braking profile to decelerate and/or stop vehicle 200. The action response module 3310 may determining to execute one of a plurality of braking profiles based on a number of braking profiles based on, for example, environmental factors, the type of trigger detected, and the velocity of vehicle 200. To navigate vehicle 200 to a stop based on the detected trigger, processing unit 110 may transmit electronic signals to one or more of throttling system 220, braking system 230, and/or steering system 240 of vehicle 200. Further, one or more actuators may control throttling system 220, braking system 230, and/or steering system 240. For example, processing unit 110 may transmit electronic signals that cause system 100 to physically depress the brake by a predetermined amount.

[0327] Fig. 34 illustrates a process 3400 for navigating vehicle 200, consistent with disclosed embodiments. Process 3000 may identify a trigger (e.g., an object, vehicle, traffic light, traffic sign, etc.) for stopping vehicle 200 and execute a braking profile in response to the detection of the trigger. Process 3400 may detect various types of triggers determine which of a plurality of braking profiles to execute.

[0328] The braking profile may be based on the type of a detected trigger and/or other environmental conditions related to the detected trigger (e.g., a distance to an object). For example, in some embodiments, the braking profile may include a plurality of segments (e.g., three segments). In a three segment braking profile, a first segment of the braking profile may be associated with a first deceleration rate, a second segment of the braking profile may include a second deceleration rate less than the first deceleration rate, and a third segment of the braking profile may include causing a level of braking to be decreased as a target stopping location is approached, as determined based on an analysis of a plurality of images acquired by one or more of image capture devices 122-126. For example, in some embodiments, the first

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segment may cause vehicle 200 to progressively increase deceleration, the second segment may cause vehicle 200 to decelerate at a constant rate, and the third segment may cause vehicle 200 to progressively decrease its deceleration rate to zero (or near zero).

[0329] At step 3410, process 3400 may acquire, using at least one of image capture devices 122-126, a plurality of images of an area in the vicinity of vehicle 200. For example, processing unit 110 may receive the plurality of images may through data interface 128. Processing unit 110 may be configured to determine the presence of one or more objects and/or signs located on or near roadway 3210 based on the acquired images. For example, processing unit 110 may be configured to determine the presence of object 3220, traffic light 3230, and/or traffic sign 3240. Processing unit 110 may be further configured to read the content of traffic sign 3240. For example, processing unit 110 may be configured to differentiate between a speed limit sign and a stop sign. Further, processing unit 110 may be configured to process images to determine the speed limit based on traffic sign 3240.

[0330] At step 3420, process 300 may include a trigger for stopping vehicle 200. For example, processing unit 110 may identify a trigger based on the presence of object 3220 within the vicinity of vehicle 200. Additionally or alternatively, processing unit 110 may identify a trigger based on a current signal status of traffic light 3230. According to some embodiments, processing unit 110 may determine that traffic light 3230 constitutes a trigger if it is not green. According to some embodiments, processing unit 110 may determine that traffic sign 3240 constitutes a trigger if it is a stop sign, for example. In some embodiments, traffic sign 3240 may constitute a trigger if it is a speed limit sign and vehicle 200 is exceeding the posted speed limit. Further in some embodiments, processing unit 110 may cause system 100 to provide an audible announcement identifying the trigger and/or indicating that vehicle 200 is braking or about to begin braking.

[0331] After processing unit 110 identifies the trigger, at step 3430, processing unit 110 may cause vehicle 200 to slow down and/or stop according to a braking profile. In some embodiments, the braking profile may comprise a number of profile segments. The different profile segments of a braking profile may be defined by a time period and/or a vehicle speed. For example, processing unit 110 may execute controls of vehicle 200 in accordance with a first profile segment for a predetermined period of time or until the speed of vehicle 200 reaches a target value. The target value may be a predetermined speed or it may be a percentage of the speed that vehicle 200 was traveling prior to execution of the braking profile. To implement the braking profile, processing unit 110 may transmit electronic signals to one or more of throttling system 220, braking system 230, and/or steering system 240 of vehicle 200. Further, one or more actuators may control throttling system 220, braking system 230, and/or steering system 240.

[0332] As discussed above, according to some embodiments, a profile segment of the braking profile may correspond to a deceleration rate. For example, a braking profile may include multiple segments, and the first segment may be associated with a first deceleration rate. The braking profile may further include a second segment associated with a second deceleration rate. The second deceleration rate may be less than first deceleration rate.

[0333] Further, as discussed above, according to some embodiments, braking profile may include a third profile segment in which a level of braking is decreased as a function of the distance between vehicle 200 and underlying factors that give rise to the trigger (e.g., object 3220, traffic light 3230, traffic sign 3240). For example, the braking profile may include decreasing the level of braking as vehicle 200 approaches target stopping location 3250. Further, reaching target stopping location 3250 may be accompanied by a release in braking pressure of vehicle 200.

[0334] The foregoing description has been presented for purposes of illustration. It is not exhaustive and is not limited to the precise forms or embodiments disclosed. Modifications and adaptations will be apparent to those skilled in the art from consideration of the specification and practice of the disclosed embodiments. Additionally, although aspects of the disclosed embodiments are described as being stored in memory, one skilled in the art will appreciate that these aspects can also be stored on other types of computer readable media, such as secondary storage devices, for example, hard disks or CD ROM, or other forms of RAM or ROM, USB media, DVD, Blu-ray, or other optical drive media.

[0335] Computer programs based on the written description and disclosed methods are within the skill of an experienced developer. The various programs or program modules can be created using any of the techniques known to one skilled in the art or can be designed in connection with existing software. For example, program sections or program modules can be designed in or by means of Net Framework, .Net Compact Framework (and related languages, such as Visual Basic, C, etc.), Java, C++, Objective-C, HTML, HTML/AJAX combinations, XML, or HTML with included Java applets.

[0336] Moreover, while illustrative embodiments have been described herein, the scope of any and all embodiments having equivalent elements, modifications, omissions, combinations (e.g., of aspects across various embodiments), adaptations and/or alterations as would be appreciated by those skilled in the art based on the present disclosure. The limitations in the claims are to be interpreted broadly based on the language employed in the claims and not limited to examples described in the present specification or during the prosecution of the application. The examples are to be construed as non-exclusive. Furthermore, the steps of the disclosed methods may be modified in any manner, including by reordering steps and/or inserting or deleting steps. It is in-

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tended, therefore, that the specification and examples be considered as illustrative only, with a true scope and spirit being indicated by the following claims and their full scope of equivalents.

[0337] Also described herein are the following aspects:

1. A driver assist navigation system for a primary vehicle, the system comprising:

at least one image capture device configured to acquire a plurality of images of an area in a vicinity of the primary vehicle;
a data interface; and
at least one processing device configured to:

receive the plurality of images via the data interface;
determine, from at least some of the plurality of images, a first lane constraint on a first side of the primary vehicle;
determine, from at least some of the plurality of images, a second lane constraint on a second side of the primary vehicle opposite to the first side of the primary vehicle, wherein the first and second lane constraints define a lane within which the primary vehicle travels;
cause the primary vehicle to travel within the first and second lane constraints;
locate in the plurality of images a leading vehicle;
determine, based on the plurality of images, at least one action taken by the leading vehicle; and
cause the primary vehicle to mimic the at least one action of the leading vehicle.

2. The system of aspect 1, wherein at least one of the first and second lane constraints includes a line marked on a road surface.

3. The system of aspect 1, wherein at least one of the first and second lane constraints includes an edge of a road surface.

4. The system of aspect 1, wherein at least one of the first and second lane constraints includes a determined midpoint of a road surface width.

5. The system of aspect 1, wherein the at least one action taken by the leading vehicle includes a turn, and the at least one processing device causes the primary vehicle to execute a similar turn beginning at a location at which the leading vehicle initiated its turn.

6. The system of aspect 1, wherein the at least one action taken by the leading vehicle includes an acceleration.

7. The system of aspect 1, wherein the at least one action taken by the leading vehicle includes braking.

8. The system of aspect 1, wherein the at least one action taken by the leading vehicle includes providing a first offset distance on a side of the leading vehicle adjacent to the first lane constraint that is different from a second offset distance on a side of the leading vehicle adjacent to the second lane constraint.

9. The system of aspect 1, wherein the at least one processing device is further configured to:

determine, based on the plurality of images or based on map data and position information, whether the leading vehicle is turning at an intersection; and
if the leading vehicle is determined to be turning at an intersection, decline to mimic the turn of the leading vehicle.

10. The system of aspect 1, wherein the at least one processing device is further configured to:

determine, based on the plurality of images or based on map data and position information, whether the leading vehicle is turning at an intersection;
determine whether the leading vehicle is changing lanes within the intersection;
mimic the turn of the leading vehicle if the leading vehicle is determined to be turning at an intersection and not changing lanes within the intersection; and
decline to mimic the turn of the leading vehicle if the leading vehicle is determined to be turning at an intersection, but changing lanes within the intersection.

11. The system of aspect 1, wherein the at least one processing device is further configured to:

acquire a first leading vehicle based on the plurality of images;
acquire a second leading vehicle based on the plurality of images; and
cause the primary vehicle to mimic the first leading vehicle if, based on the plurality of images, the first leading vehicle is determined to be continuing on a path having less of a turning radius than a path followed by the second leading vehicle.

12. The system of aspect 1, wherein the at least one processing device is further configured to:

determine position information for the leading vehicle and compare the position information to predetermined map data;
create a navigation history for the leading vehicle by tracking movements of the leading vehicle relative to the predetermined map data; and

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determine whether to cause the primary vehicle to mimic the at least one action of the leading vehicle based on the navigation history of the leading vehicle.

13. The system of aspect 12, wherein the at least one processing device is configured to:
cause the primary vehicle to mimic a turn of the leading vehicle, even where no turn is detected based on the plurality of images, when the navigation history indicates that the leading vehicle has successfully navigated at least one prior turn.

14. A primary vehicle, comprising:

a body;
at least one image capture device configured to acquire a plurality of images of an area in a vicinity of the primary vehicle;
a data interface; and
at least one processing device configured to:

receive the plurality of images via the data interface;
determine, from at least some of the plurality of images, a first lane constraint on a first side of the primary vehicle;
determine, from at least some of the plurality of images, a second lane constraint on a second side of the primary vehicle opposite to the first side of the primary vehicle, wherein the first and second lane constraints define a lane within which the primary vehicle travels;
cause the primary vehicle to travel within the first and second lane constraints;
locate in the plurality of images a leading vehicle;
determine, based on the plurality of images, at least one action taken by the leading vehicle; and
cause the primary vehicle to mimic the at least one action of the leading vehicle.

15. The primary vehicle of aspect 14, wherein at least one of the first and second lane constraints includes a line marked on a road surface.

16. The primary vehicle of aspect 14, wherein at least one of the first and second lane constraints includes an edge of a road surface.

17. The primary vehicle of aspect 14, wherein at least one of the first and second lane constraints includes a determined midpoint of a road surface width.

18. The primary vehicle of aspect 14, wherein the at least one action taken by the leading vehicle includes a turn, and the at least one processing device causes the primary vehicle to execute a similar turn beginning at a location at which the leading vehicle initiated its turn.

19. The primary vehicle of aspect 14, wherein the at least one action taken by the leading vehicle includes an acceleration.

20. The primary vehicle of aspect 14, wherein the at least one action taken by the leading vehicle includes braking.

21. The primary vehicle of aspect 14, wherein the at least one action taken by the leading vehicle includes providing a first offset distance on a side of the leading vehicle adjacent to the first lane constraint that is different from a second offset distance on a side of the leading vehicle adjacent to the second lane constraint.

22. The primary vehicle of aspect 14, wherein the at least one processing device is further configured to:

determine, based on the plurality of images or based on map data and position information, whether the leading vehicle is turning at an intersection; and
if the leading vehicle is determined to be turning at an intersection, decline to mimic the turn of the leading vehicle.

23. The primary vehicle of aspect 14, wherein the at least one processing device is further configured to:

determine, based on the plurality of images or based on map data and position information, whether the leading vehicle is turning at an intersection;
determine whether the leading vehicle is changing lanes within the intersection;
mimic the turn of the leading vehicle if the leading vehicle is determined to be turning at an intersection and not changing lanes within the intersection; and
decline to mimic the turn of the leading vehicle if the leading vehicle is determined to be turning at an intersection, but changing lanes within the intersection.

24. The primary vehicle of aspect 14, wherein the at least one processing device is further configured to:

acquire a first leading vehicle based on the plurality of images;
acquire a second leading vehicle based on the plurality of images; and
cause the primary vehicle to mimic the first leading vehicle if, based on the plurality of images, the first leading vehicle is determined to be continuing on a path having less of a turning radius than a path followed by the second leading vehicle.

25. The primary vehicle of aspect 14, wherein the at least one processing device is further configured to:

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determine position information for the leading vehicle and compare the position information to predetermined map data;
create a navigation history for the leading vehicle by tracking movements of the leading vehicle relative to the predetermined map data; and
determine whether to cause the primary vehicle to mimic the at least one action of the leading vehicle based on the navigation history of the leading vehicle.

26. The primary vehicle of aspect 25, wherein the at least one processing device is configured to:
cause the primary vehicle to mimic a turn of the leading vehicle, even where no turn is detected based on the plurality of images, when the navigation history indicates that the leading vehicle has successfully navigated at least one prior turn.
27. A method for navigating a primary vehicle, the method comprising:

acquiring, using at least one image capture device, a plurality of images of an area in a vicinity of the primary vehicle;
determining, from at least some of the plurality of images, a first lane constraint on a first side of the primary vehicle;
determining, from at least some of the plurality of images, a second lane constraint on a second side of the primary vehicle opposite to the first side of the primary vehicle, wherein the first and second lane constraints define a lane within which the primary vehicle travels;
causing the primary vehicle to travel within the first and second lane constraints;
locating in the plurality of images a leading vehicle;
determining, based on the plurality of images, at least one action taken by the leading vehicle; and
causing the primary vehicle to mimic the at least one action of the leading vehicle.

Claims

1. An autonomous vehicle control system to control a vehicle, comprising:
at least one processing device configured to:

determine an initial target velocity for the vehicle based on global positioning data;
adjust a velocity of the vehicle toward the initial target velocity for a first portion of a navigation event;
determine an updated target velocity based on sensor data, the updated target velocity to be used in a second portion of the navigation event; and
adjust the velocity of the vehicle toward the updated target velocity during the second portion of the navigation event.

2. The autonomous vehicle control system of claim 1, wherein the navigation event is navigating a curve in a road, wherein the first portion of the navigation event includes navigating the vehicle on the road preceding the curve, and wherein the second portion of the navigation event includes navigating the vehicle on the road through the curve.

3. The autonomous vehicle control system of claim 1 or 2, wherein to determine the initial target velocity for the vehicle based on global positioning data, the at least one processing device is to recognize an upcoming road segment based on map data and the global positioning data.

4. The autonomous vehicle control system of any of claims 1 to 3, wherein the sensor data includes image data.

5. The autonomous vehicle control system of any of claims 1 to 4, comprising a plurality of cameras to acquire a plurality of images of an area in a direction of travel of the vehicle.

6. The autonomous vehicle control system of claim 5, wherein the at least one processing device is to determine road characteristics based on the plurality of images and use the road characteristics to determine the updated target velocity.

7. An autonomous vehicle control system, comprising:

a plurality of cameras to acquire a plurality of images of an area in a vicinity of a vehicle; and
at least one processing device configured to:

recognize a curve to be navigated based on map data and vehicle position information;
determine an initial target velocity for the vehicle based on at least one characteristic of the curve as reflected in the map data;
adjust a velocity of the vehicle to the initial target velocity;
determine, based on the plurality of images, observed characteristics of the curve;
determine an updated target velocity based on the observed characteristics of the curve; and
adjust the velocity of the vehicle to the updated target velocity.

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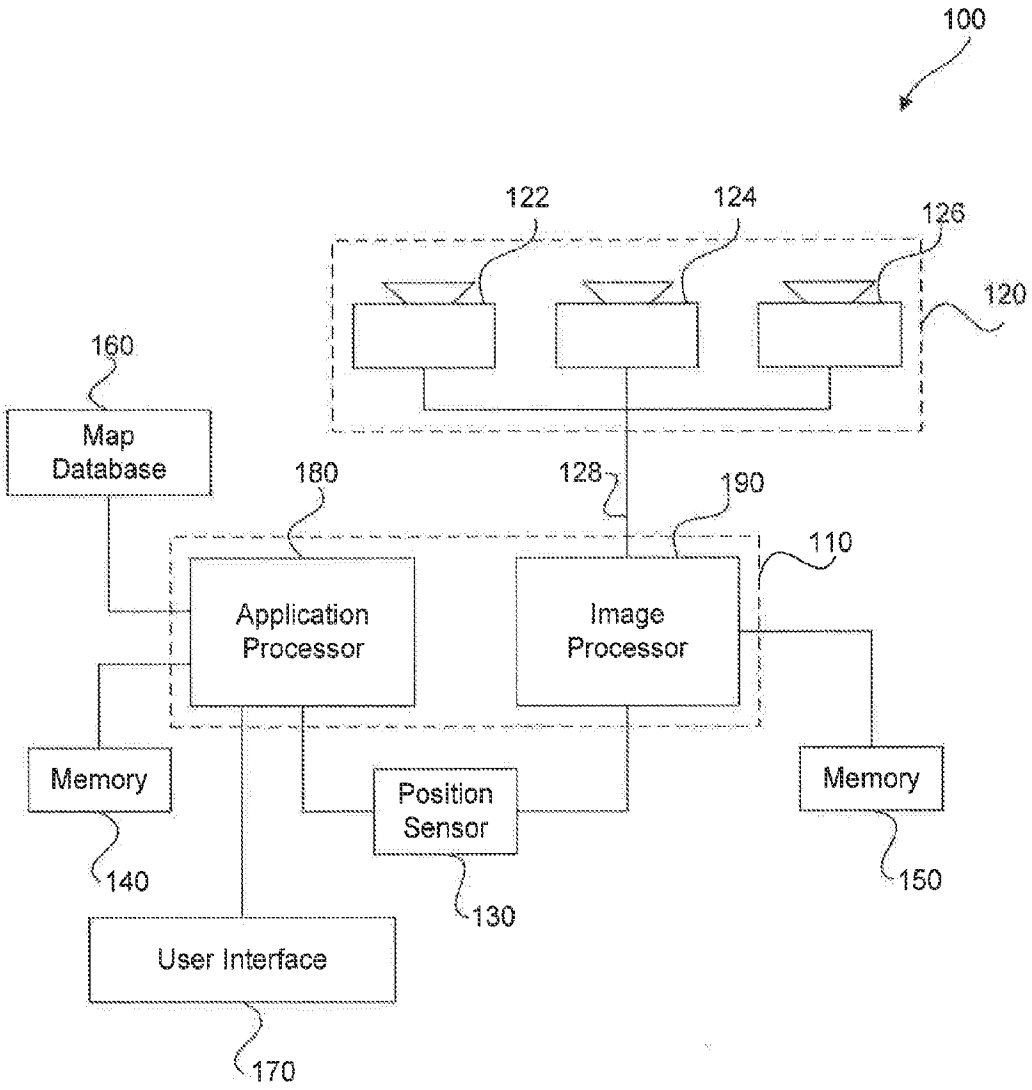


FIG. 1

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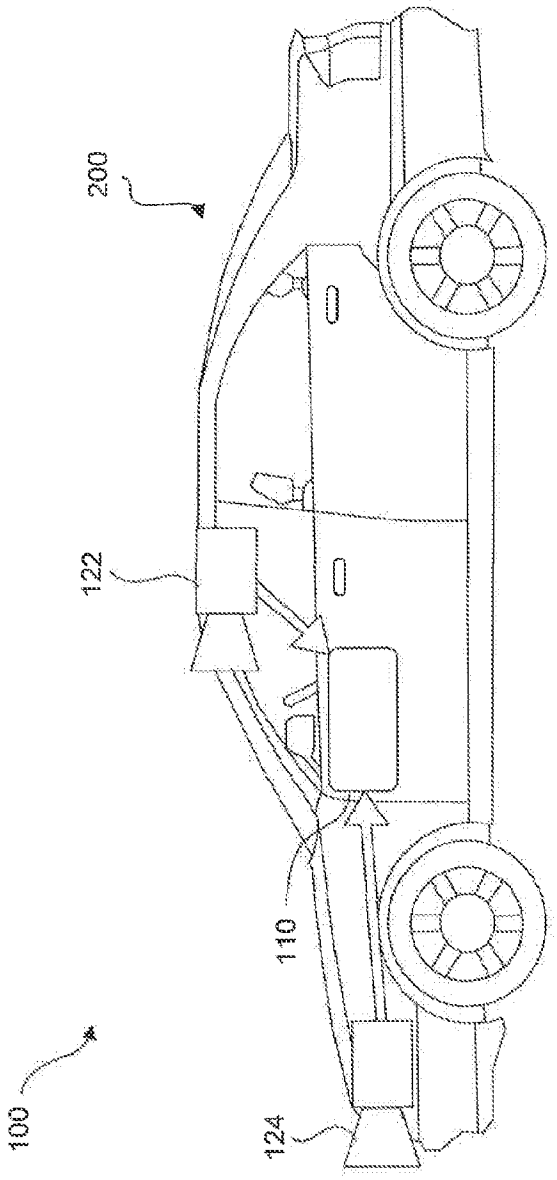


FIG. 2A

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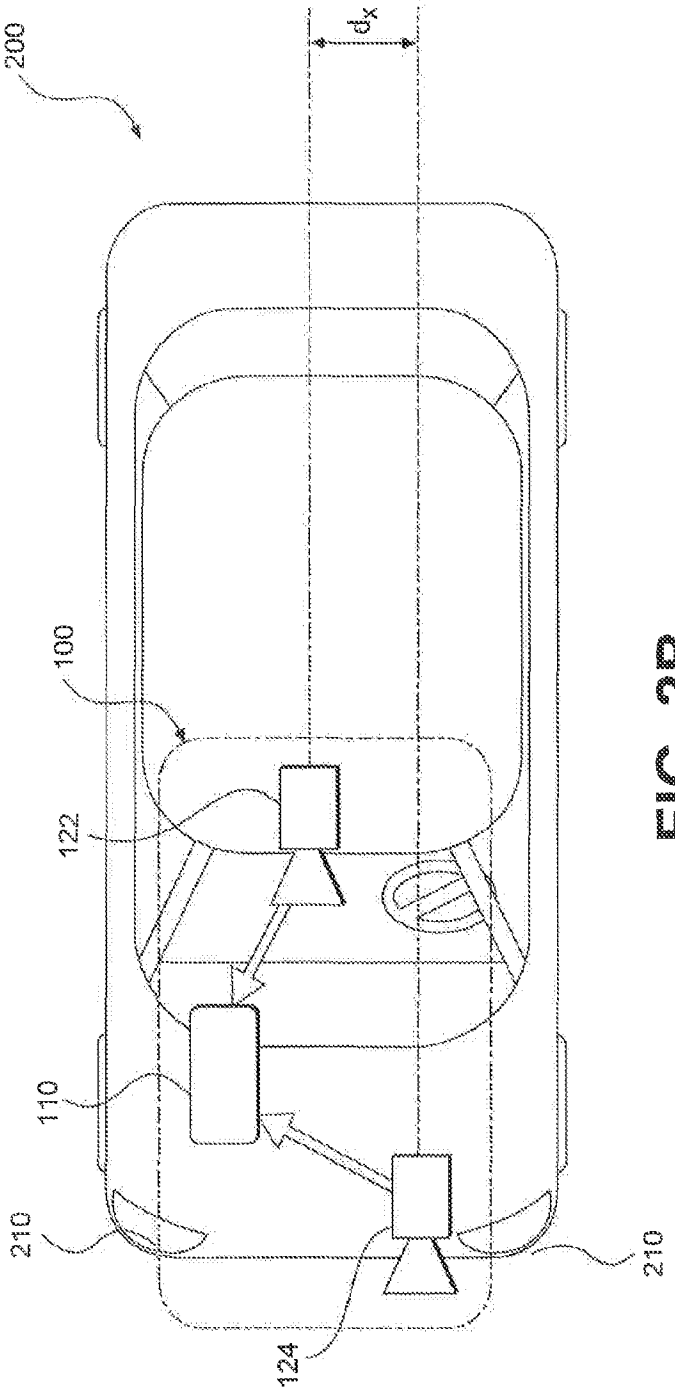


FIG. 2B

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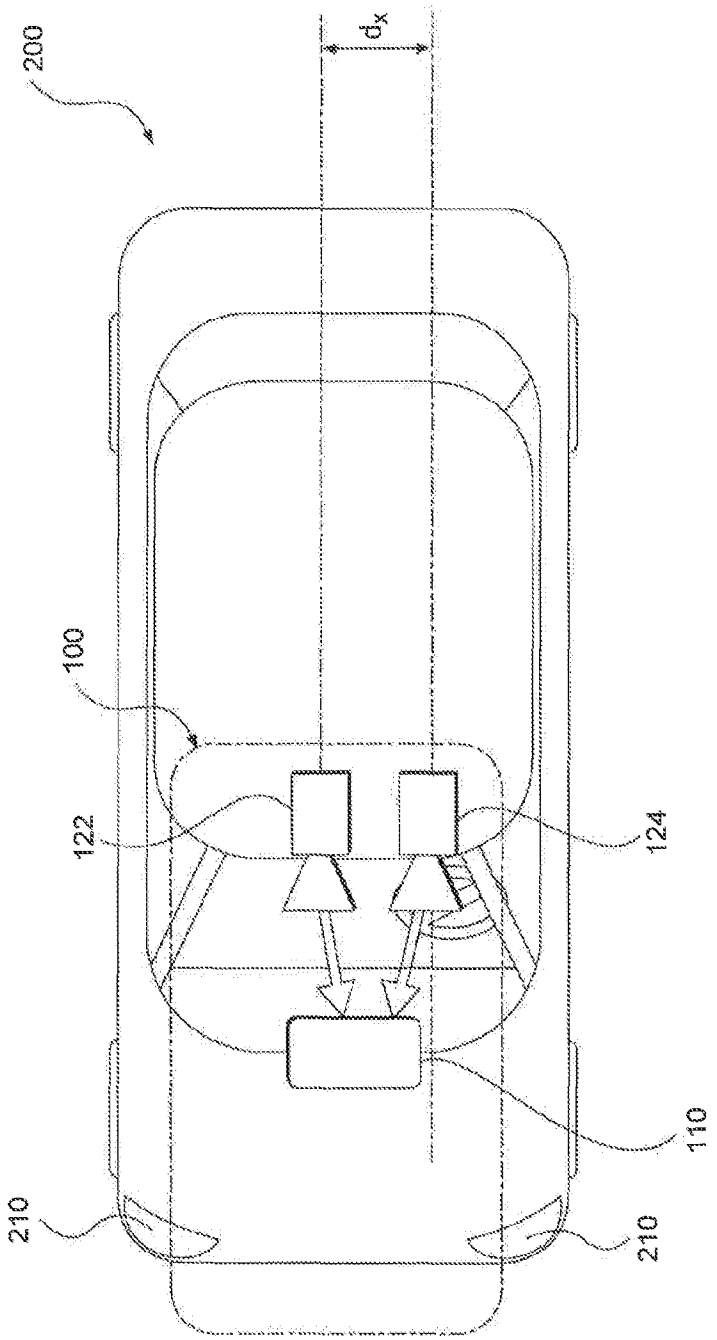


FIG. 2C

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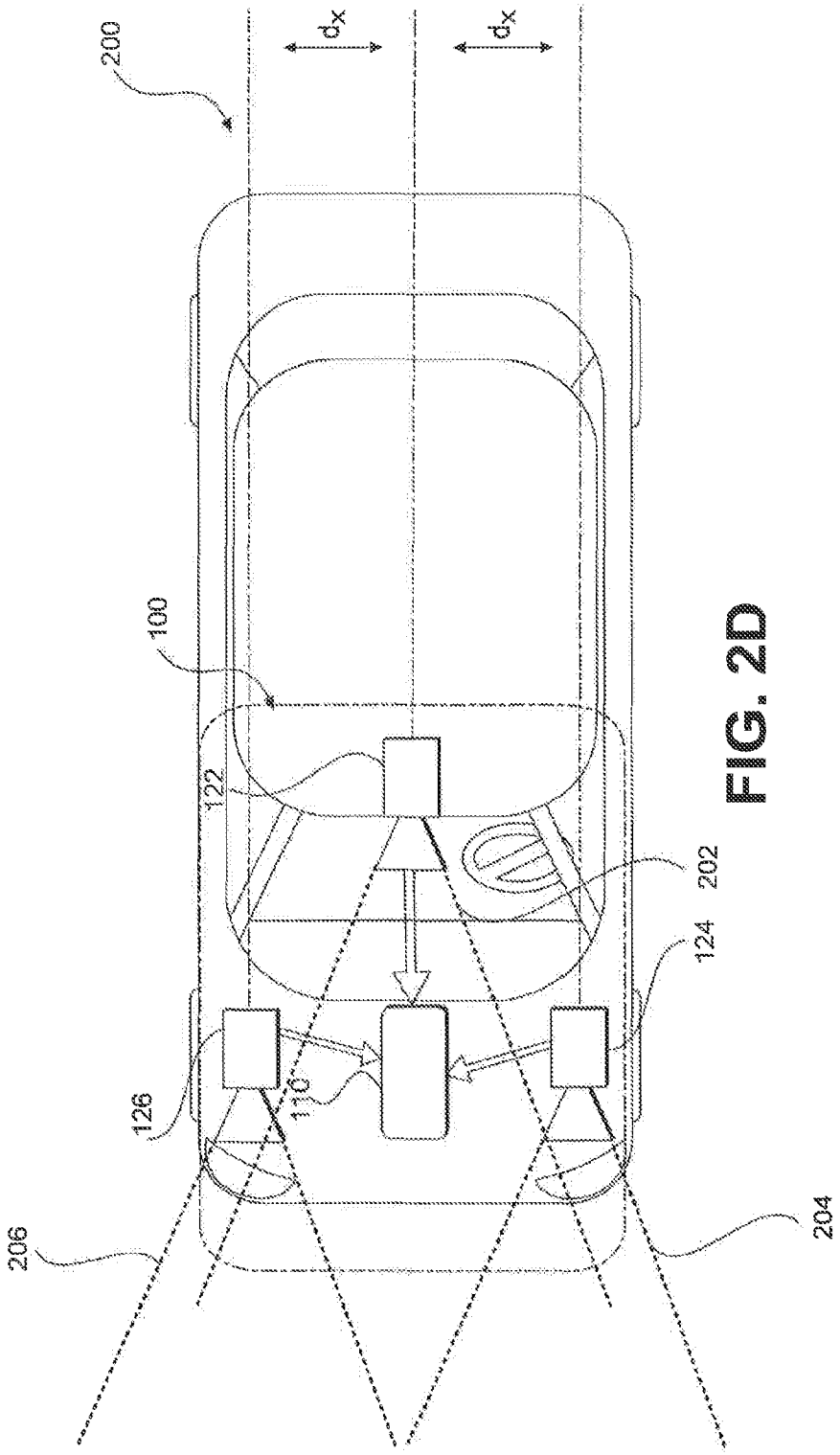


FIG. 2D

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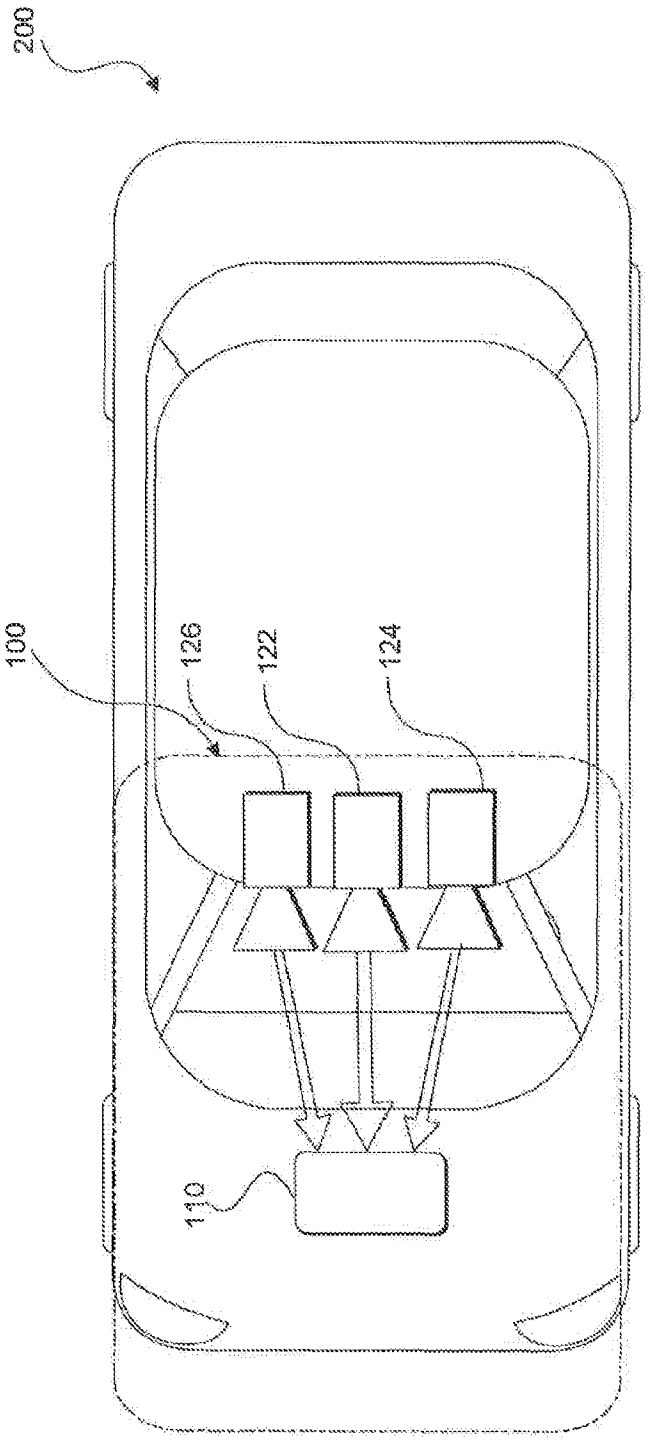


FIG. 2E

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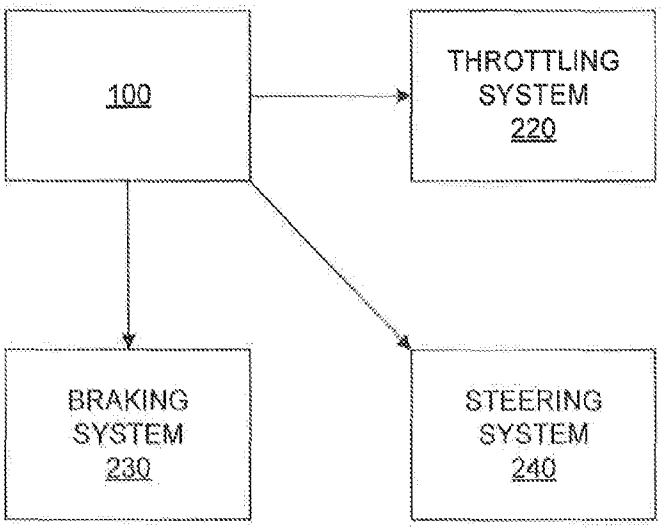


FIG. 2F

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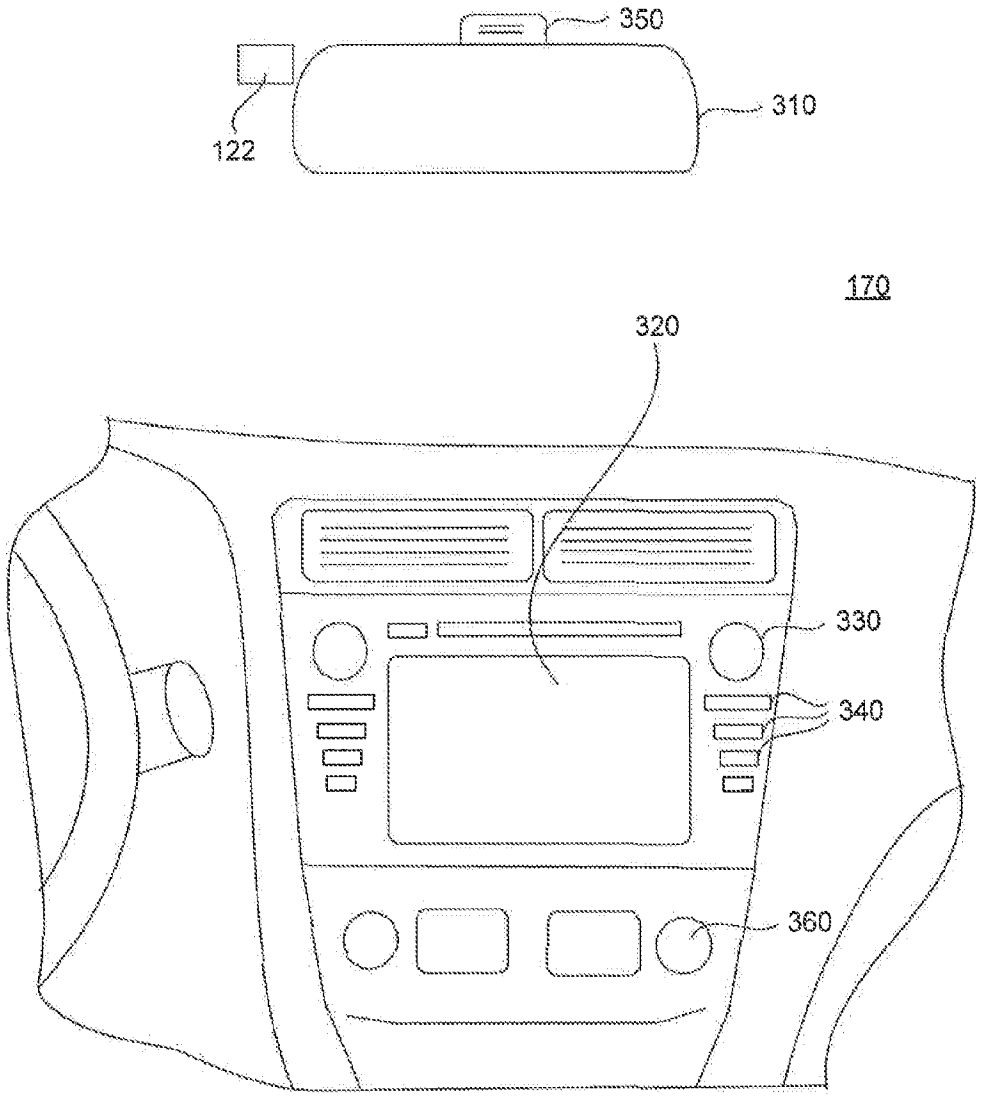


FIG. 3A

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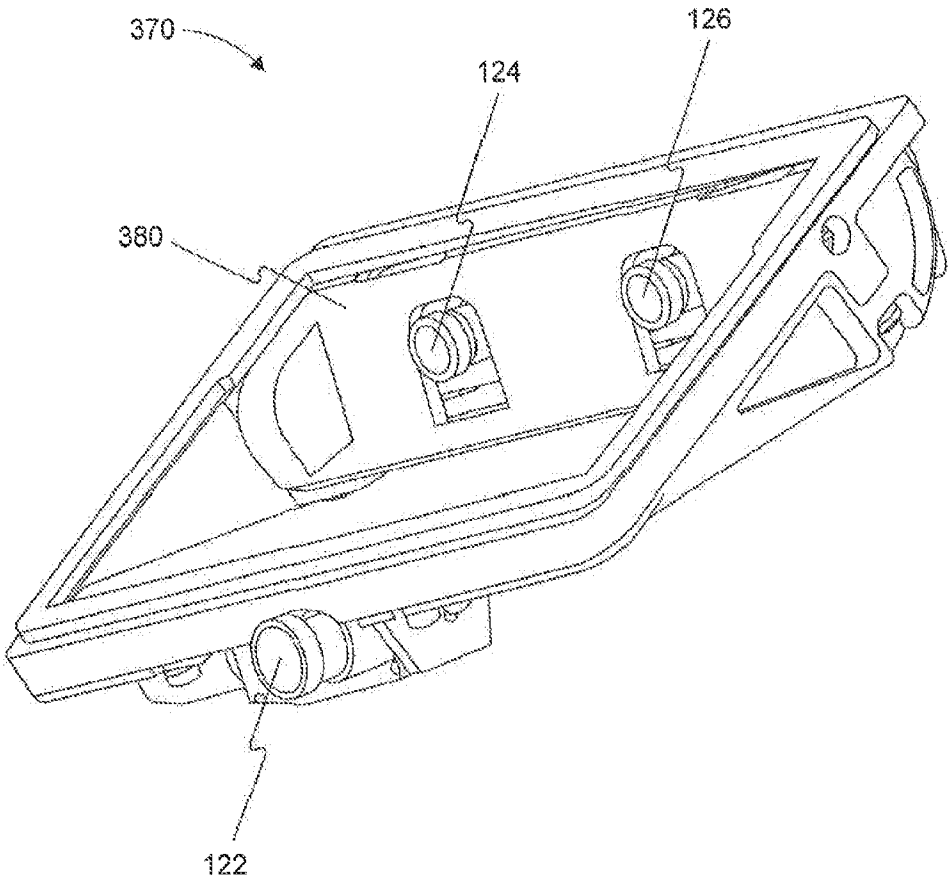


FIG. 3B

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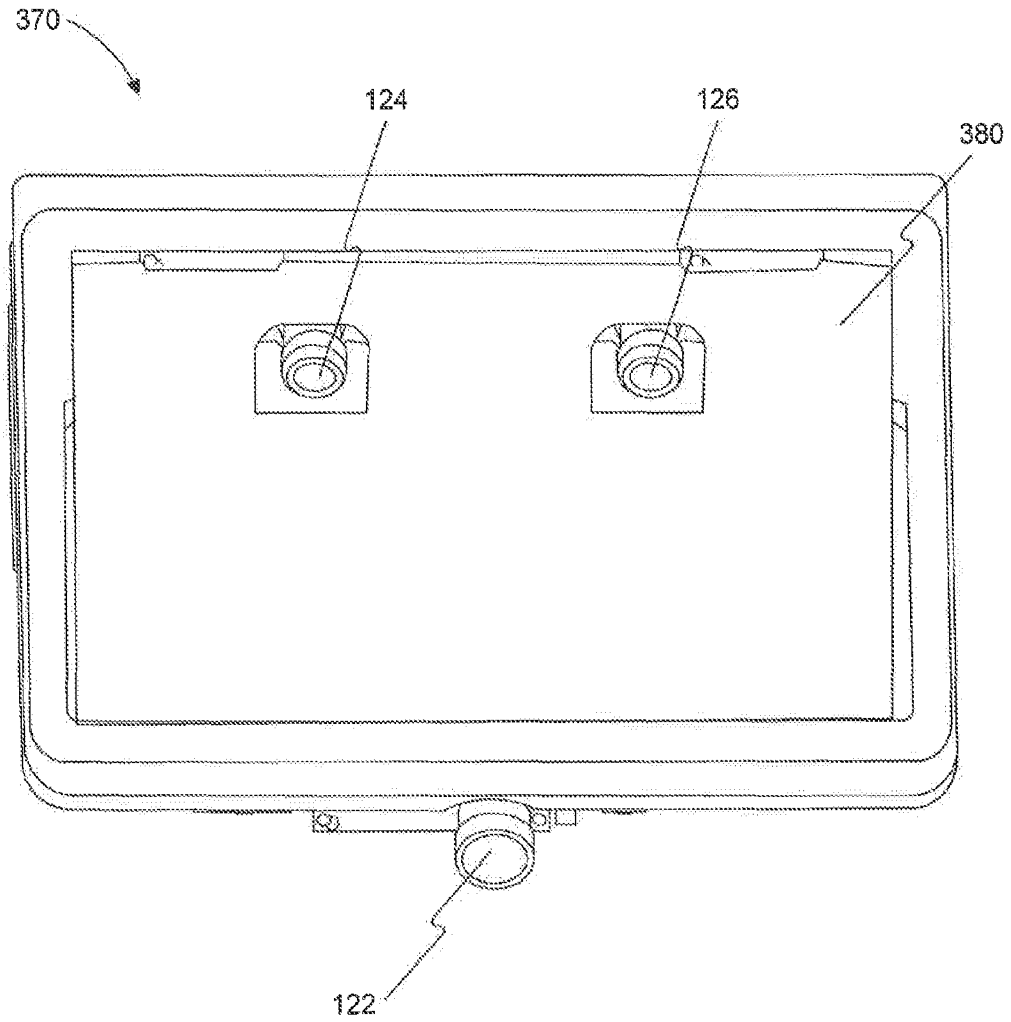


FIG. 3C

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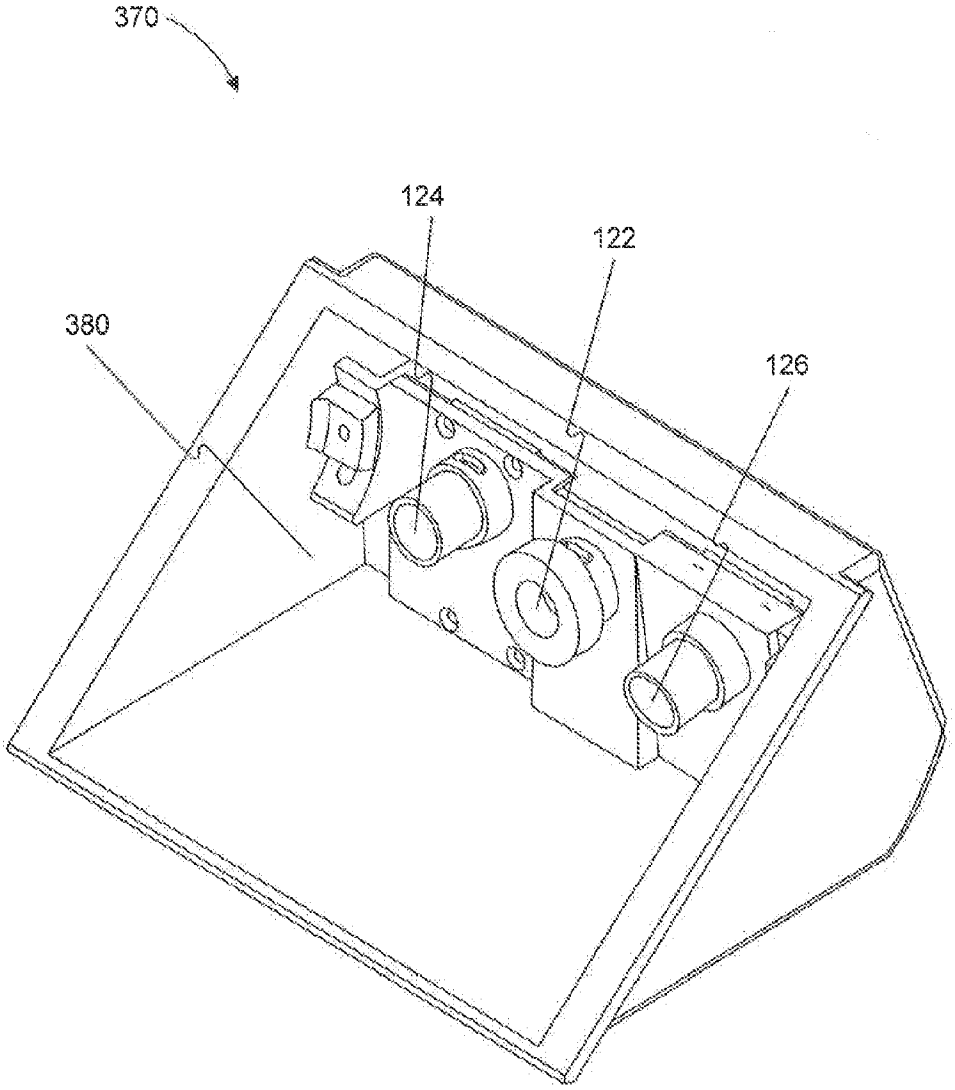


FIG. 3D

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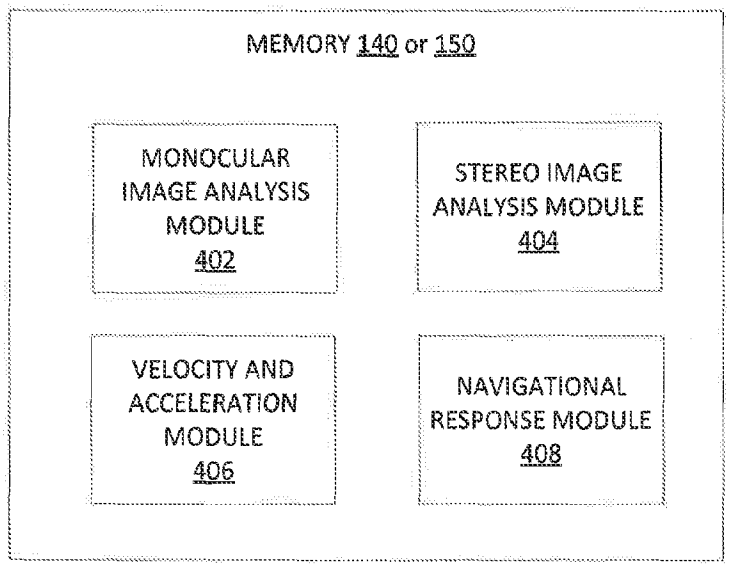


FIG. 4

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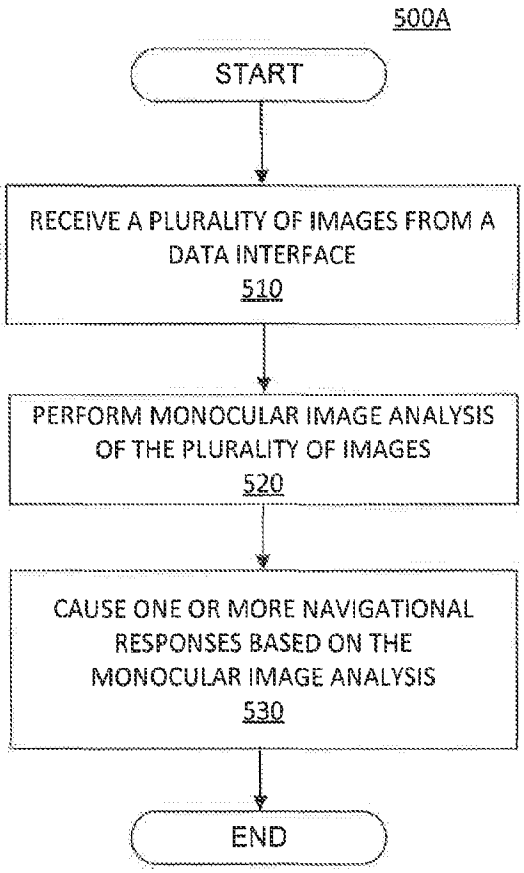


FIG. 5A

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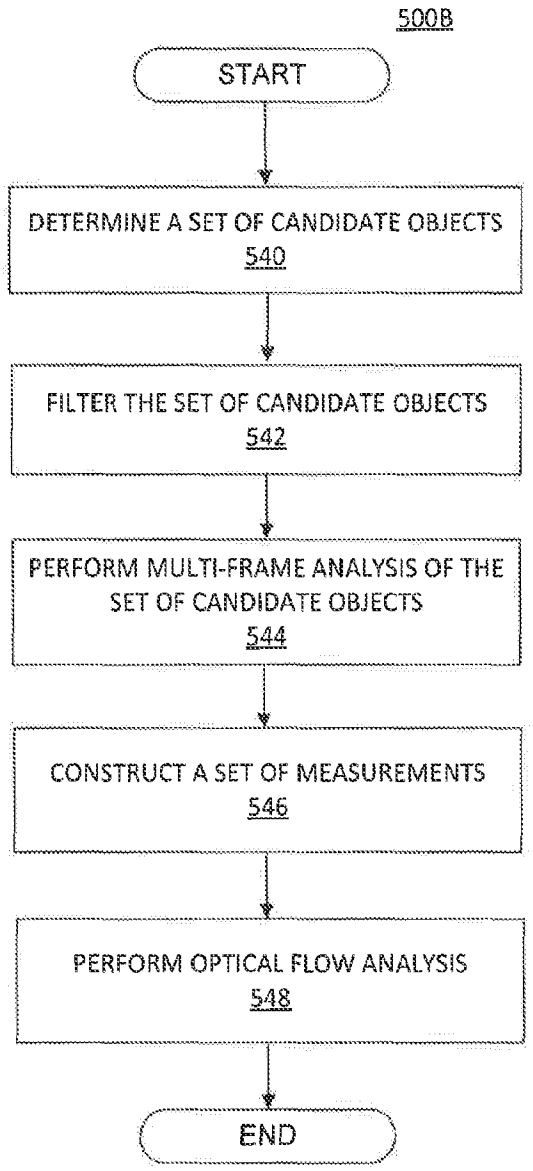


FIG. 5B

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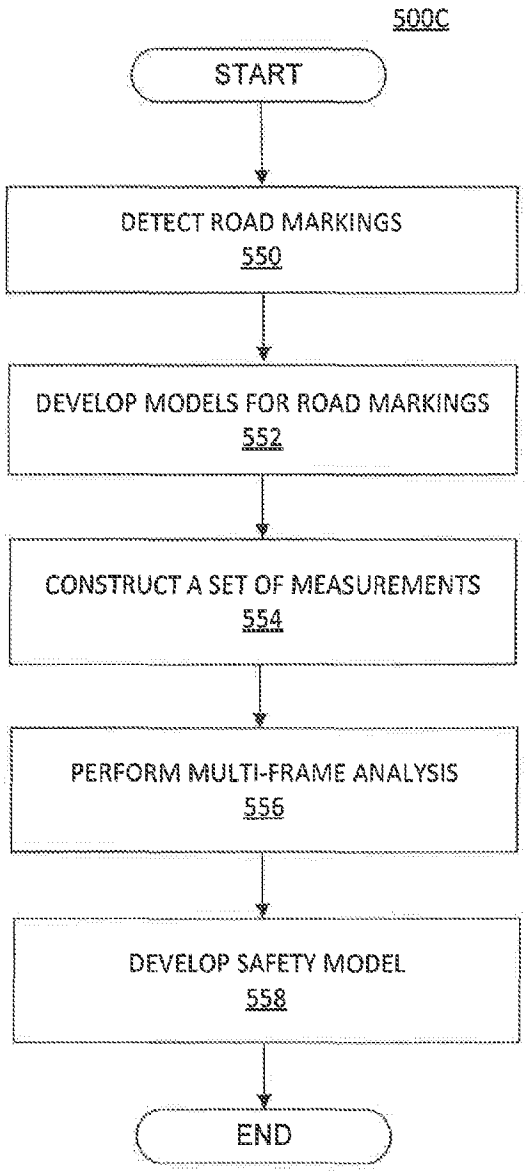


FIG. 5C

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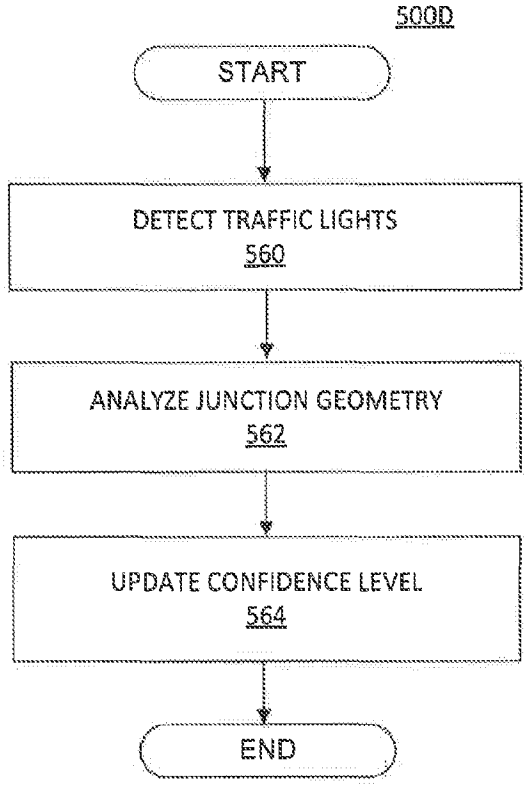


FIG. 5D

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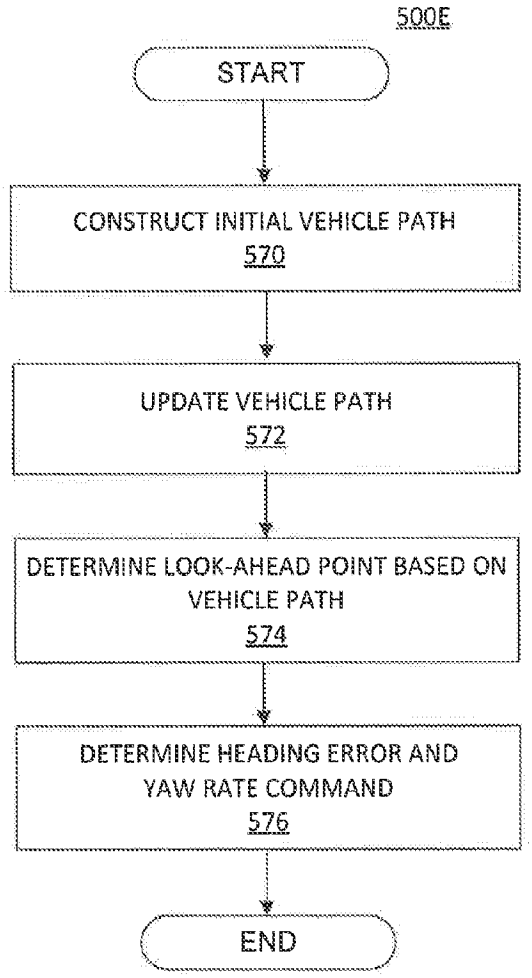


FIG. 5E

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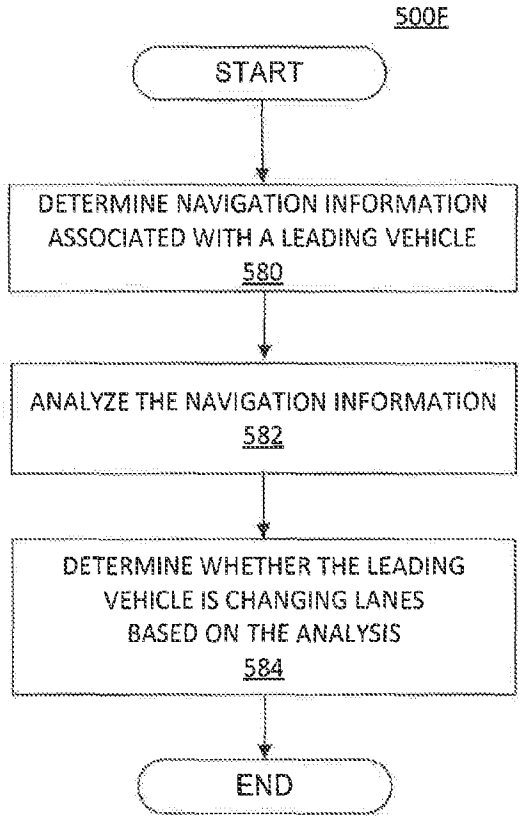


FIG. 5F

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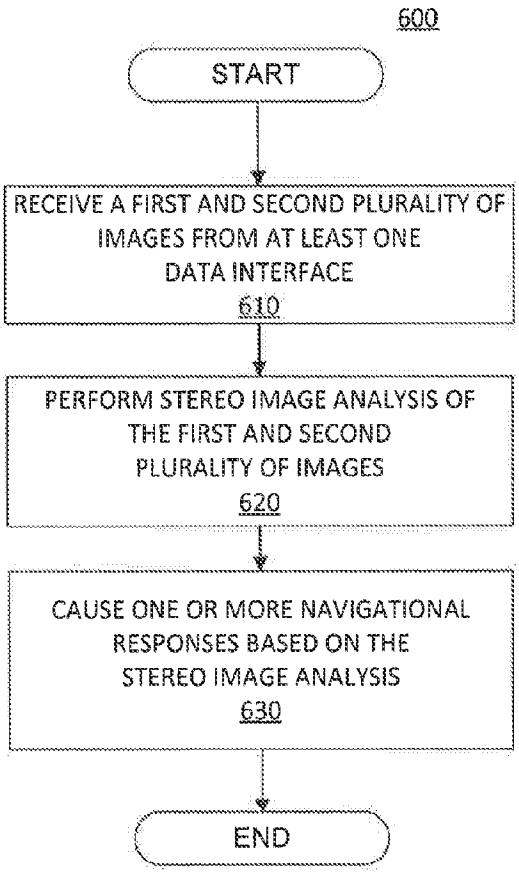


FIG. 6

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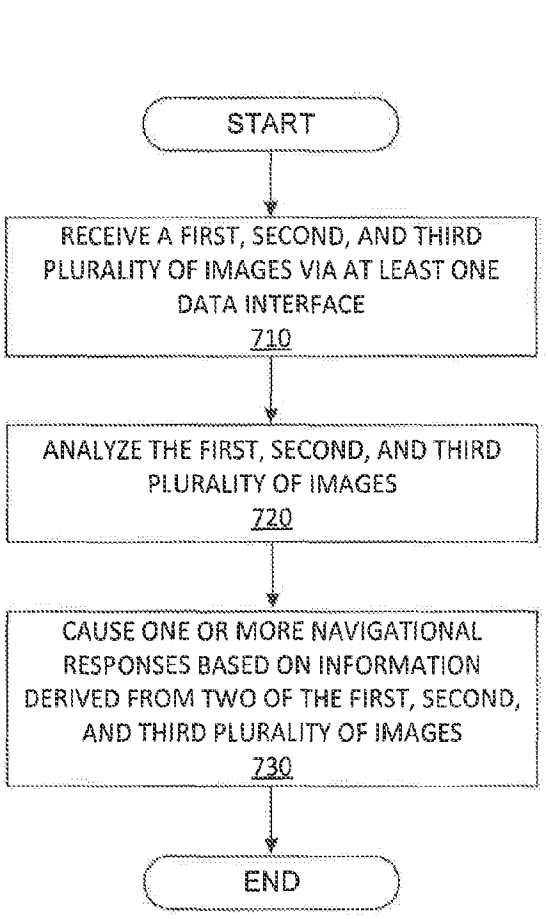


FIG. 7

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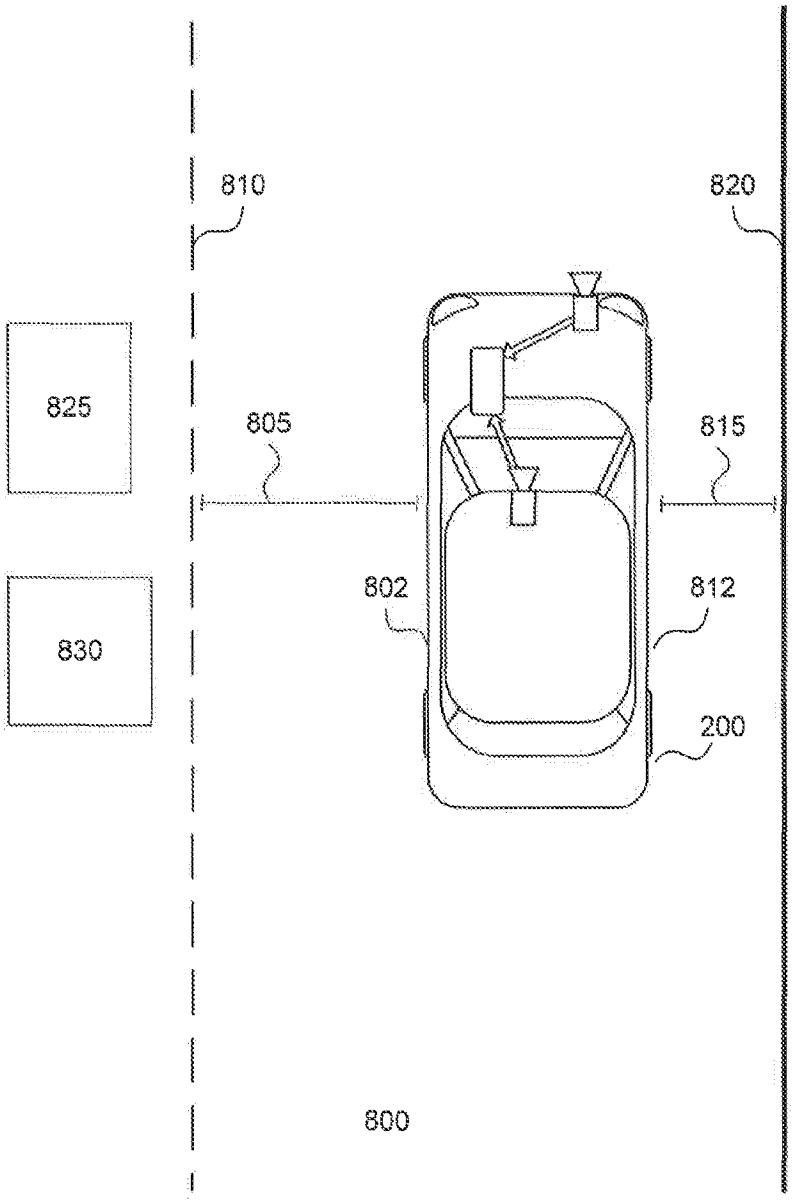


FIG. 8A

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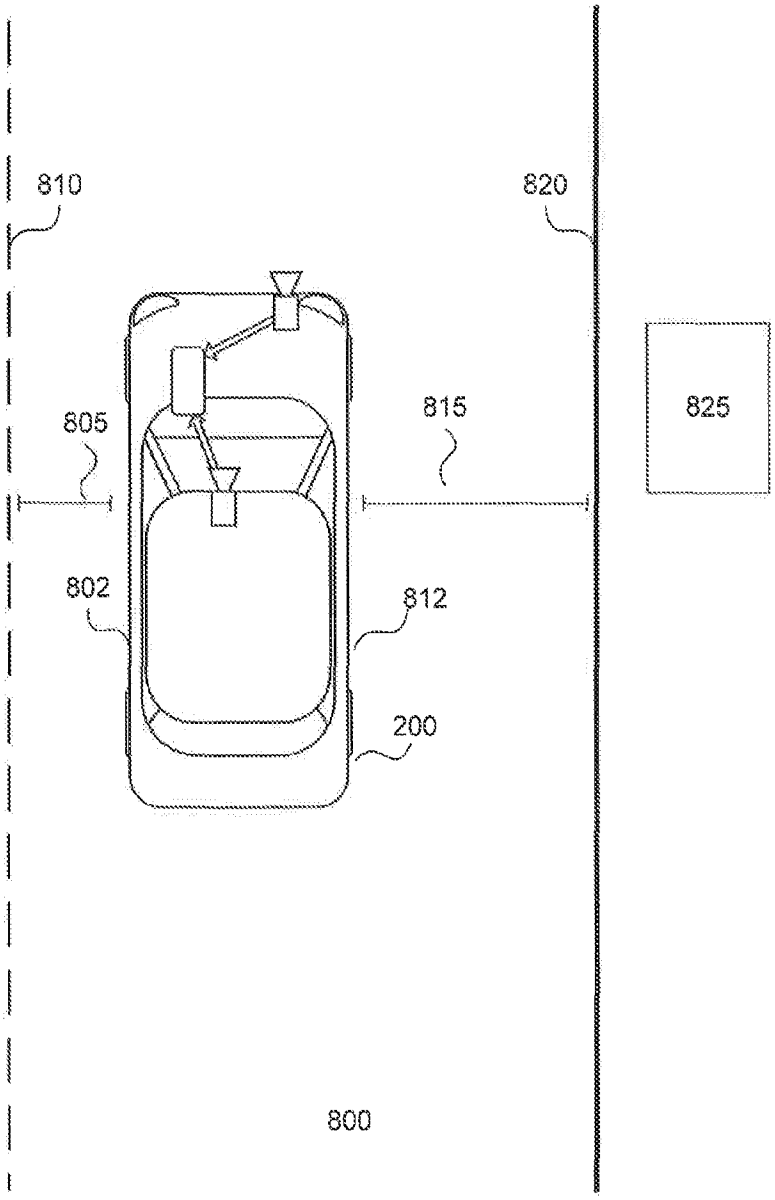


FIG. 8B

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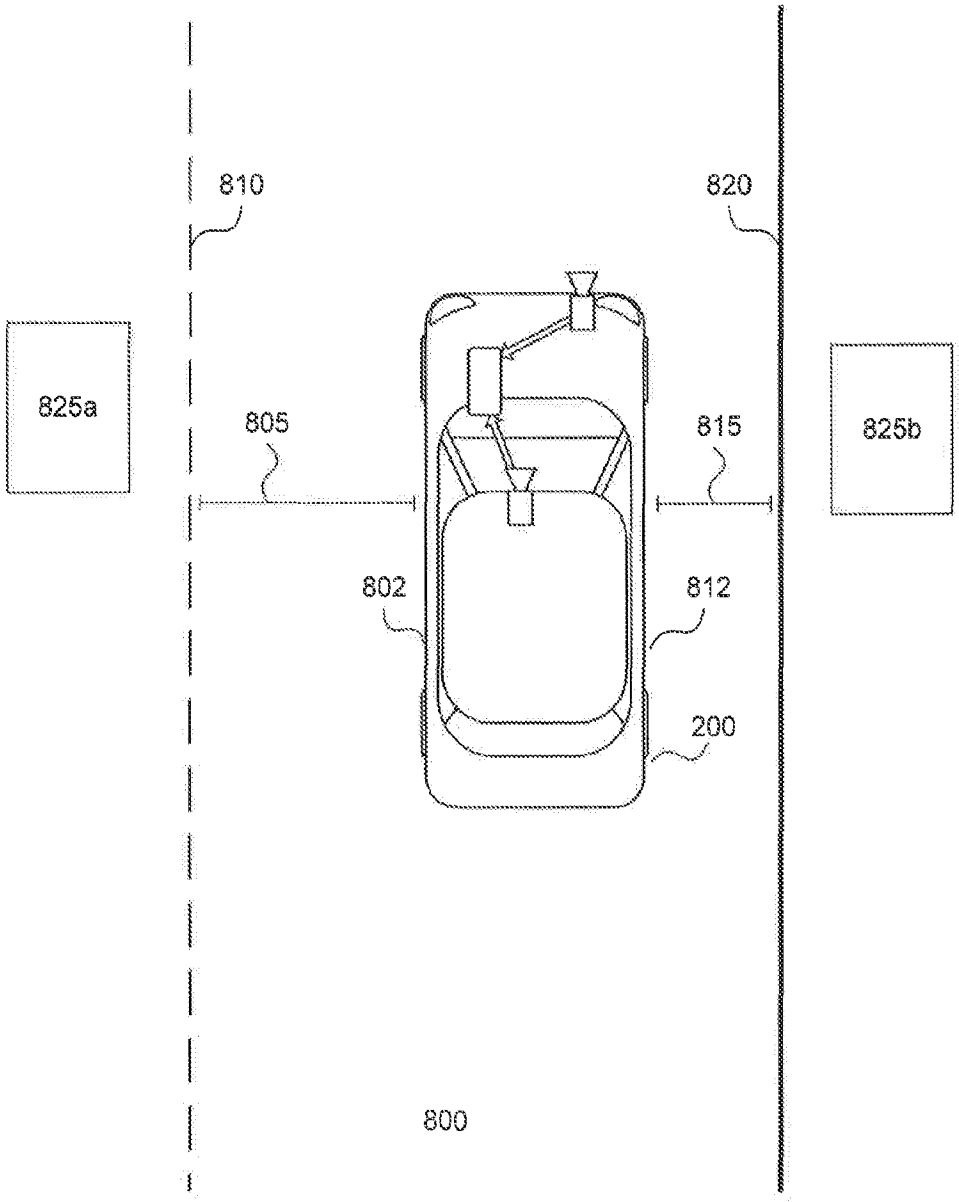


FIG. 8C

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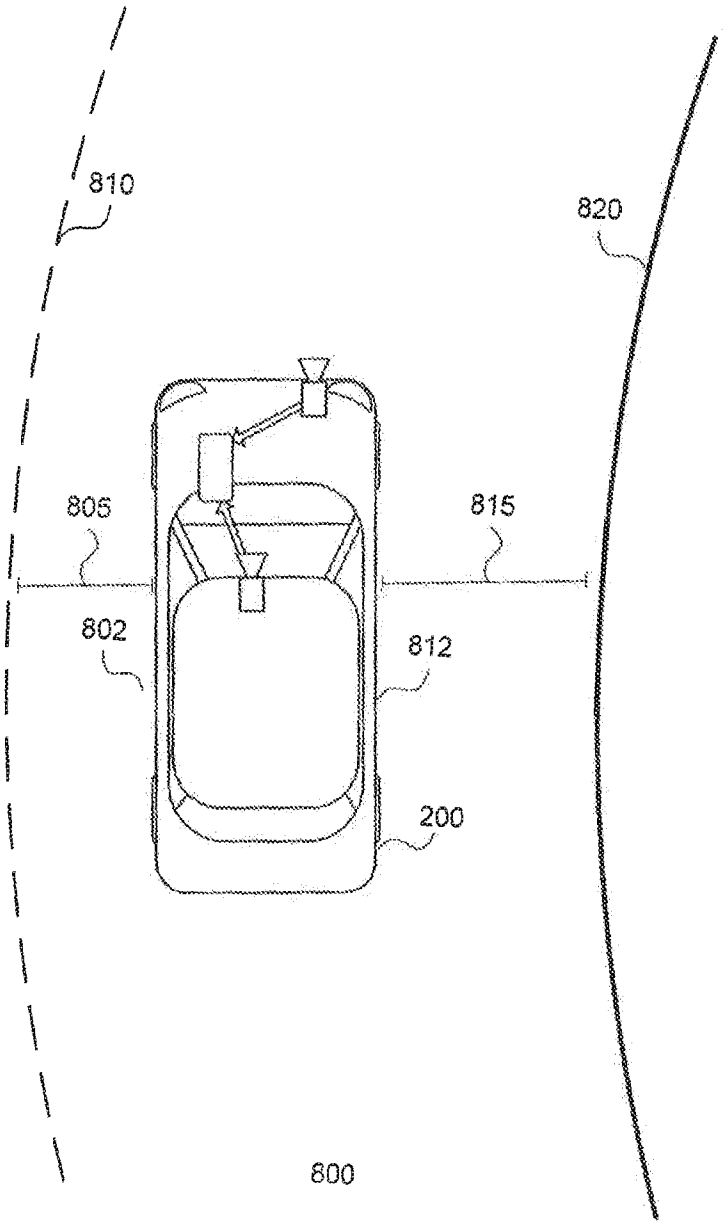


FIG. 8D

IPR2025-01034
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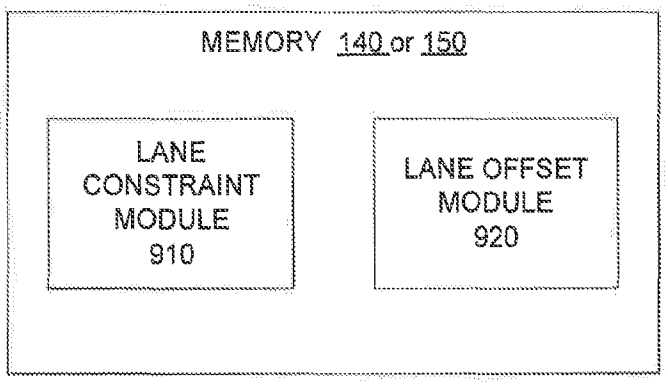


FIG. 9

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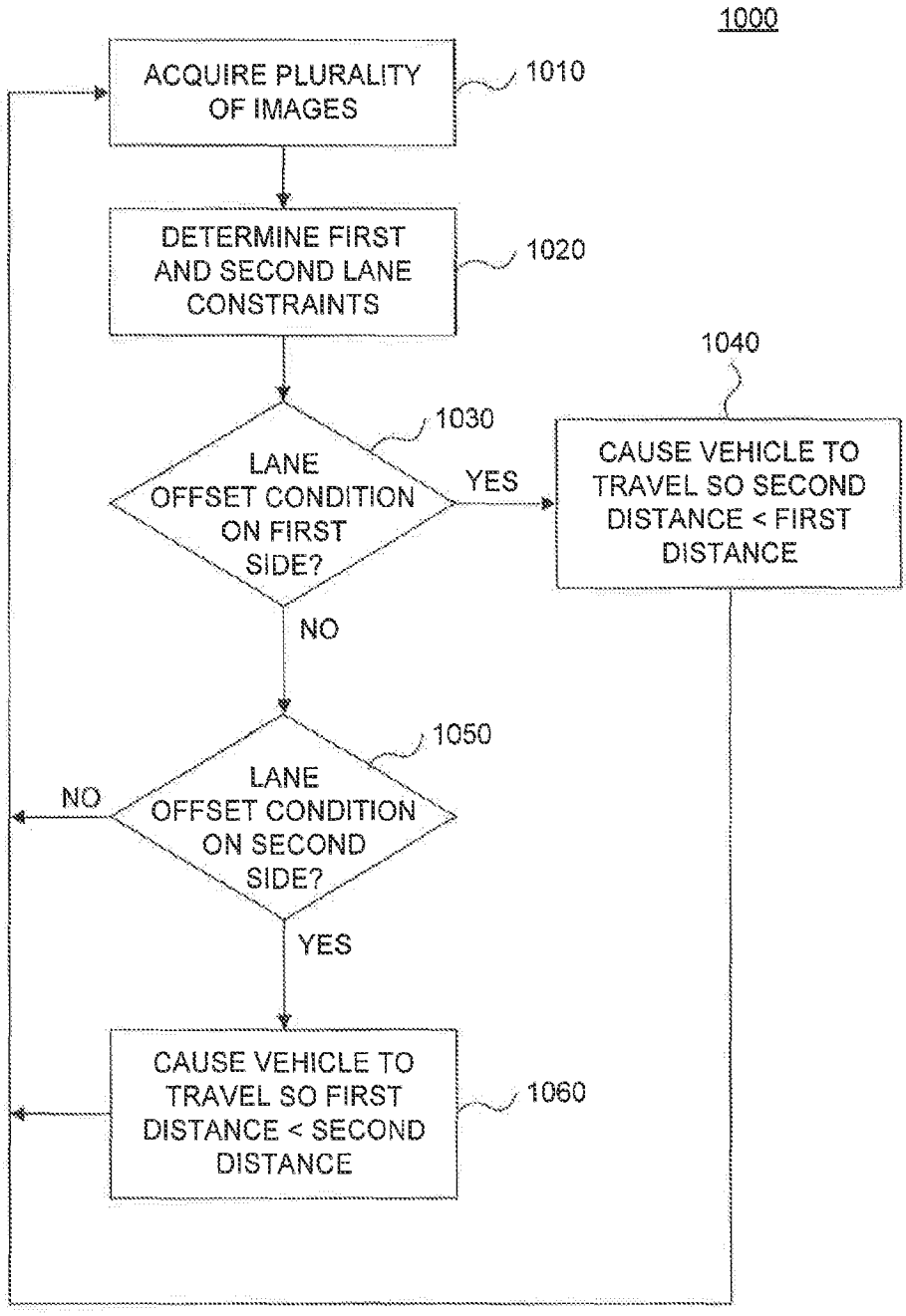


FIG. 10

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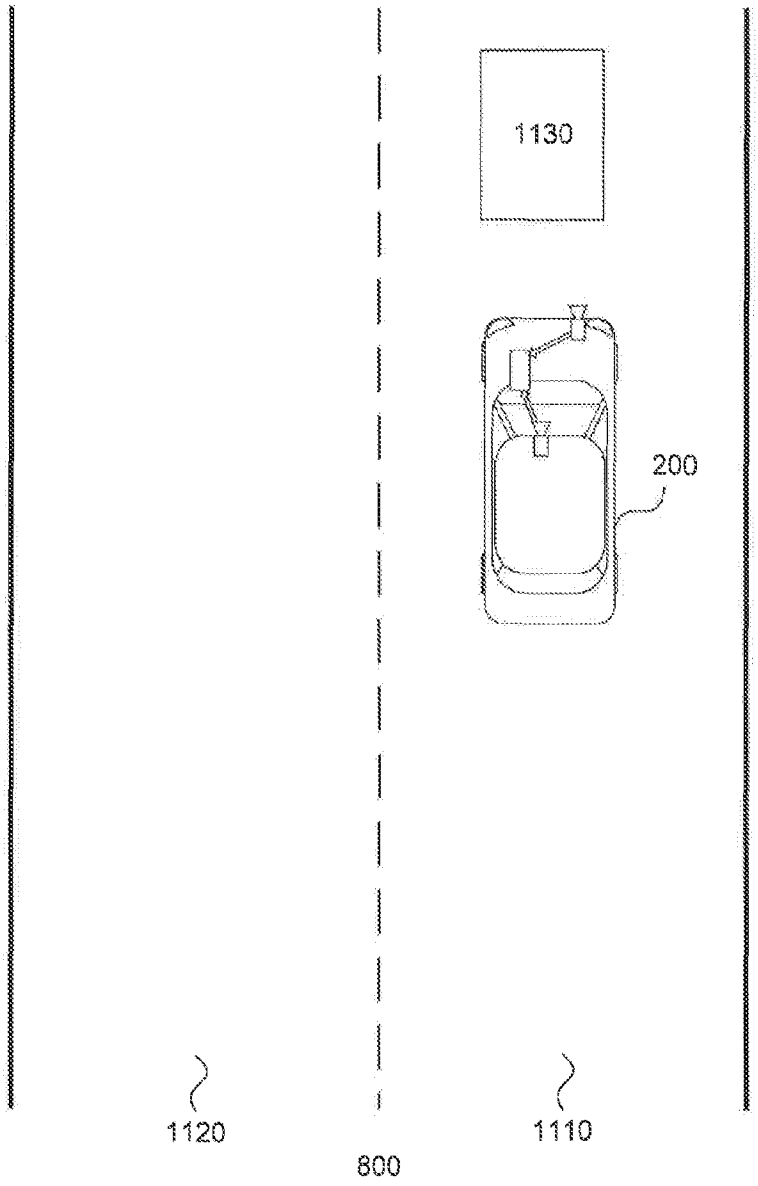


FIG. 11

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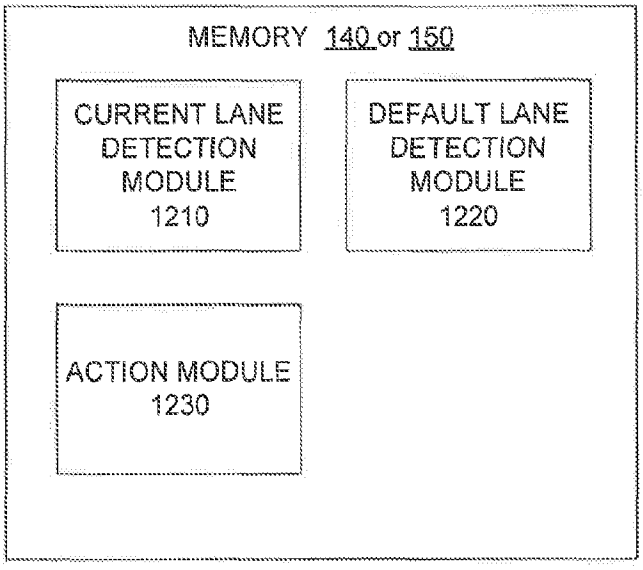


FIG. 12A

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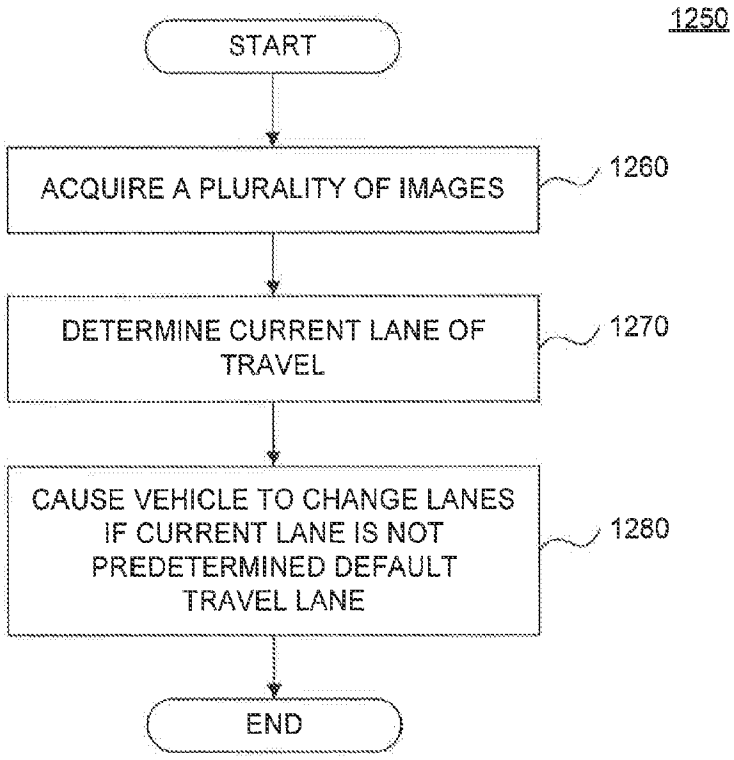


FIG. 12B

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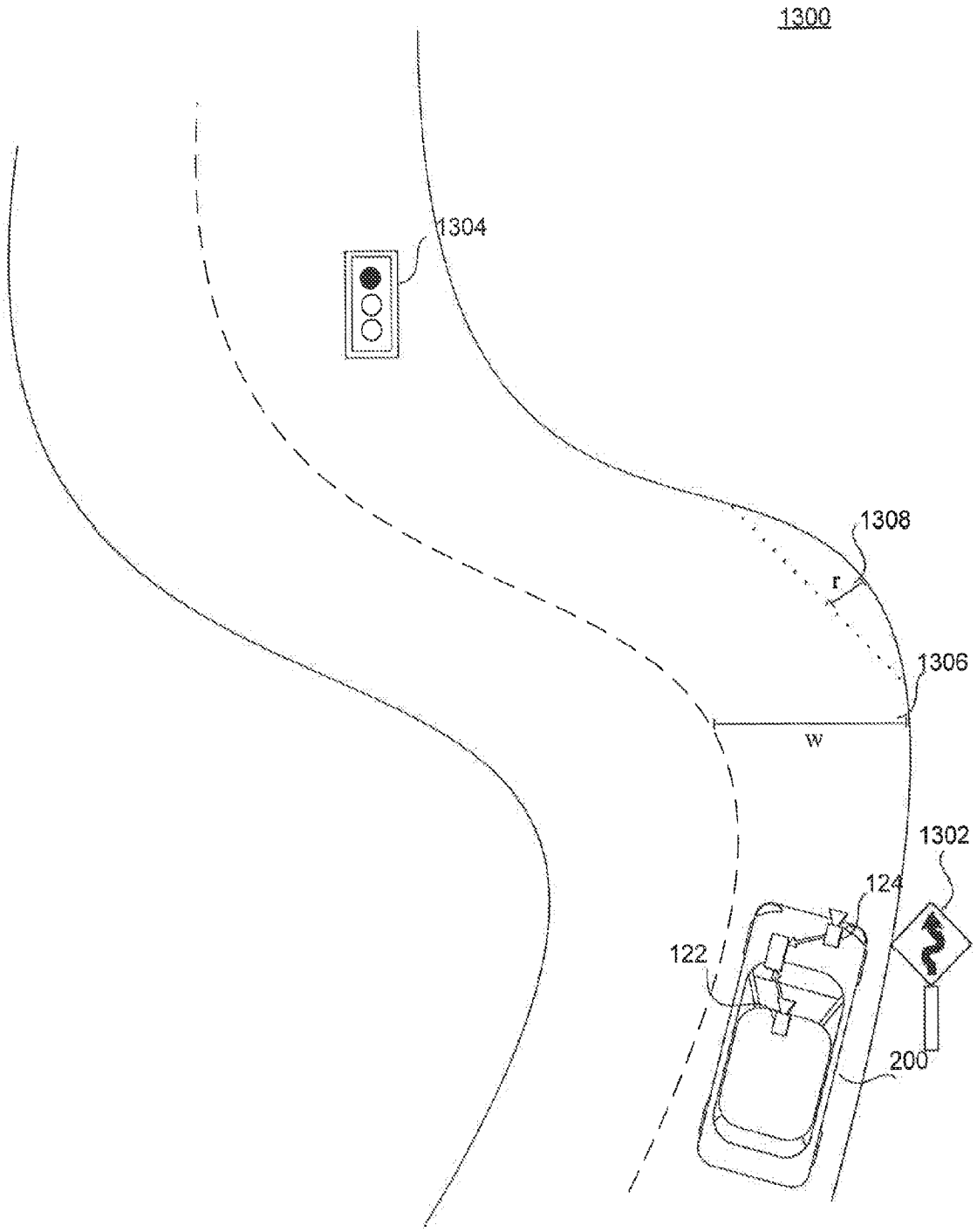


FIG. 13A

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