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(54) **DETECTION OF DRIVER BEHAVIORS USING IN-VEHICLE SYSTEMS AND METHODS**

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(73) Assignee: **TRIMBLE NAVIGATION LIMITED**, Sunnyvale, CA (US)

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(21) Appl. No.: **14/829,272**

(22) Filed: **Aug. 18, 2015**

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Related U.S. Application Data

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(51) **Int. Cl.**

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B60W 40/09	(2012.01)
G06K 9/00	(2006.01)
B60W 40/08	(2012.01)

(52) **U.S. Cl.**

CPC ***B60W 40/09*** (2013.01); ***G06K 9/00845*** (2013.01); *B60W 2040/0827* (2013.01); *B60W 2540/22* (2013.01); *B60W 2540/30* (2013.01); *B60W 2710/30* (2013.01)

(58) **Field of Classification Search**

CPC B60W 40/09; B60W 2710/30; B60W 2540/22; B60W 2040/0827; B60W 2540/30; G06K 9/00845

USPC 340/576, 435, 425.5, 439; 701/36, 206, 701/409, 32.9, 123, 33.3, 51, 29.5, 435, 701/425.5, 22

See application file for complete search history.

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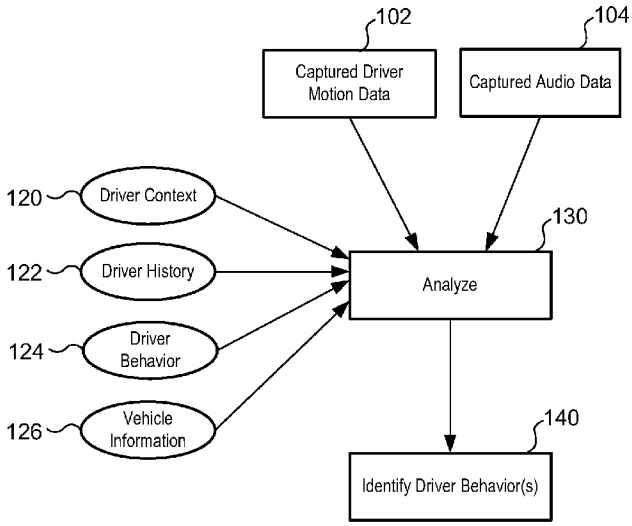
(57) **ABSTRACT**

A system includes a motion sensor system configured for deployment in a cab of a vehicle and to generate substantially in real-time a digital mapping of driver movement during operation of the vehicle. A computer is configured for deployment in the cab and coupled to the motion sensor system. A driver behavior detector is coupled to the computer and configured to detect a driver distraction event using the driver movement mapping. A communication device at the vehicle is configured to communicate an alert message to one or both of a user interface device in the cab and a remote system in response to the detected driver distraction event.

21 Claims, 25 Drawing Sheets



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2014/0058616	A1	2/2014	de Oliveira	
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2014/0210625	A1*	7/2014	Nemat-Nasser	B60K 28/066 340/575
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Figure 1

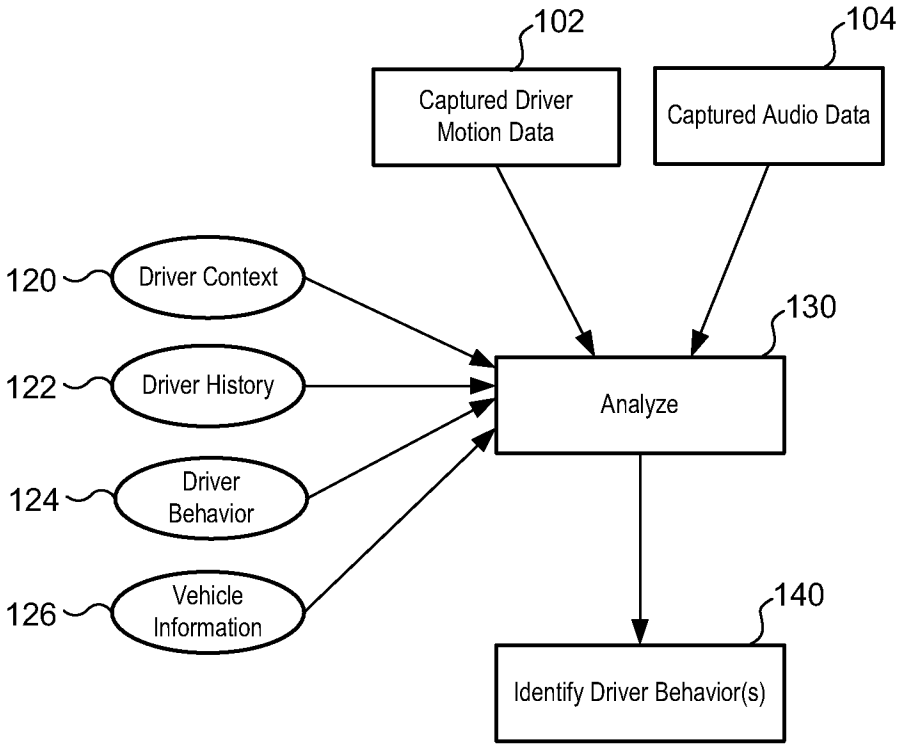

102
Captured Driver Motion Data
104
Captured Audio Data
120
Driver Context
122
Driver History
124
Driver Behavior
126
Vehicle Information
130
Analyze
140
Identify Driver Behavior(s)

Figure 2

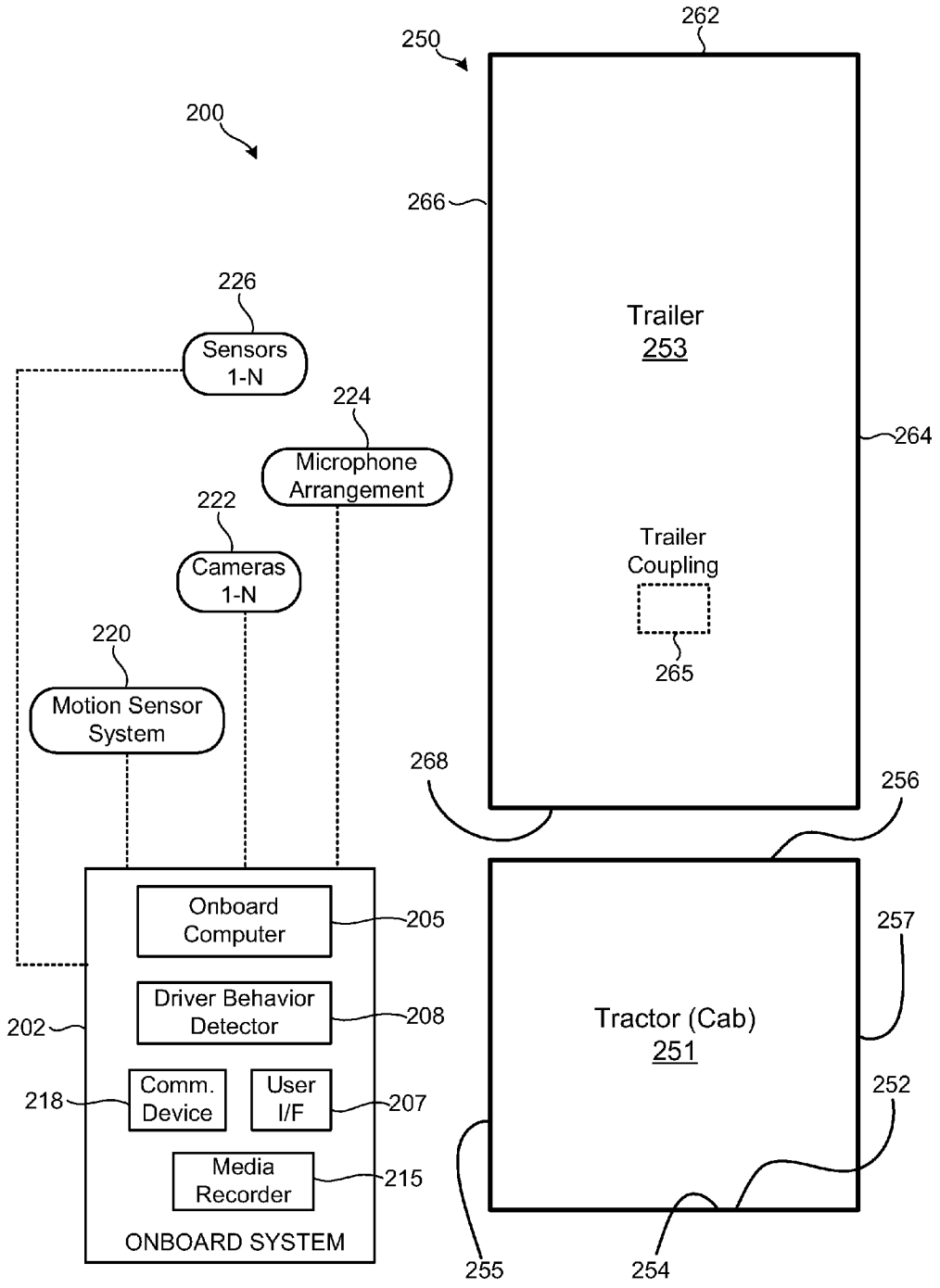

250
262
200
266
226
Sensors 1-N
224
Microphone Arrangement
222
Cameras 1-N
220
Motion Sensor System
Trailer 253
264
Trailer Coupling
265
268
256
Onboard Computer
205
Driver Behavior Detector
208
202
Comm. Device
User I/F
218
207
Media Recorder
215
ONBOARD SYSTEM
Tractor (Cab) 251
257
252
255
254

FIGURE 3

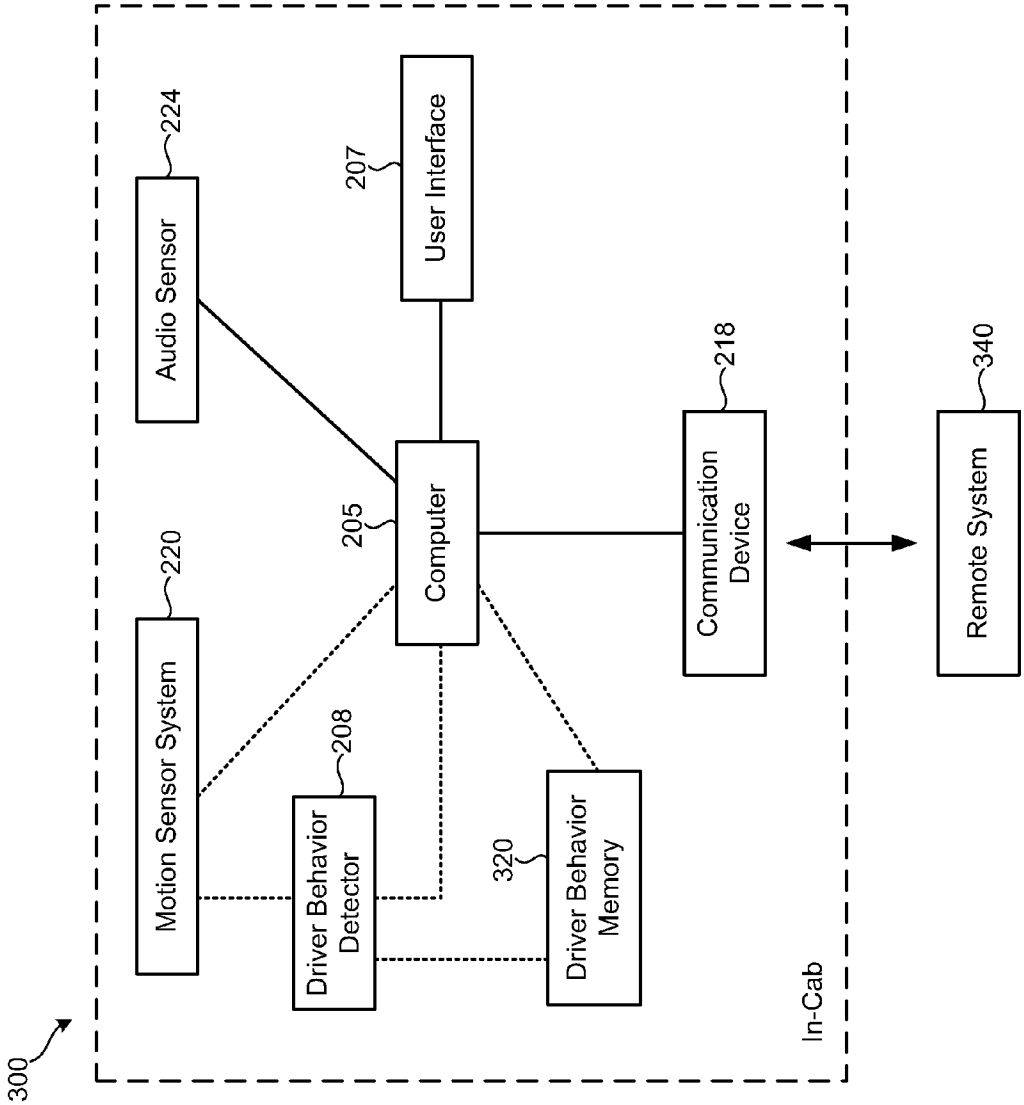

300
Audio Sensor
224
Motion Sensor System
220
User Interface
207
Computer
205
Driver Behavior Detector
208
Driver Behavior Memory
320
Communication Device
218
In-Cab
Remote System
340

FIGURE 4

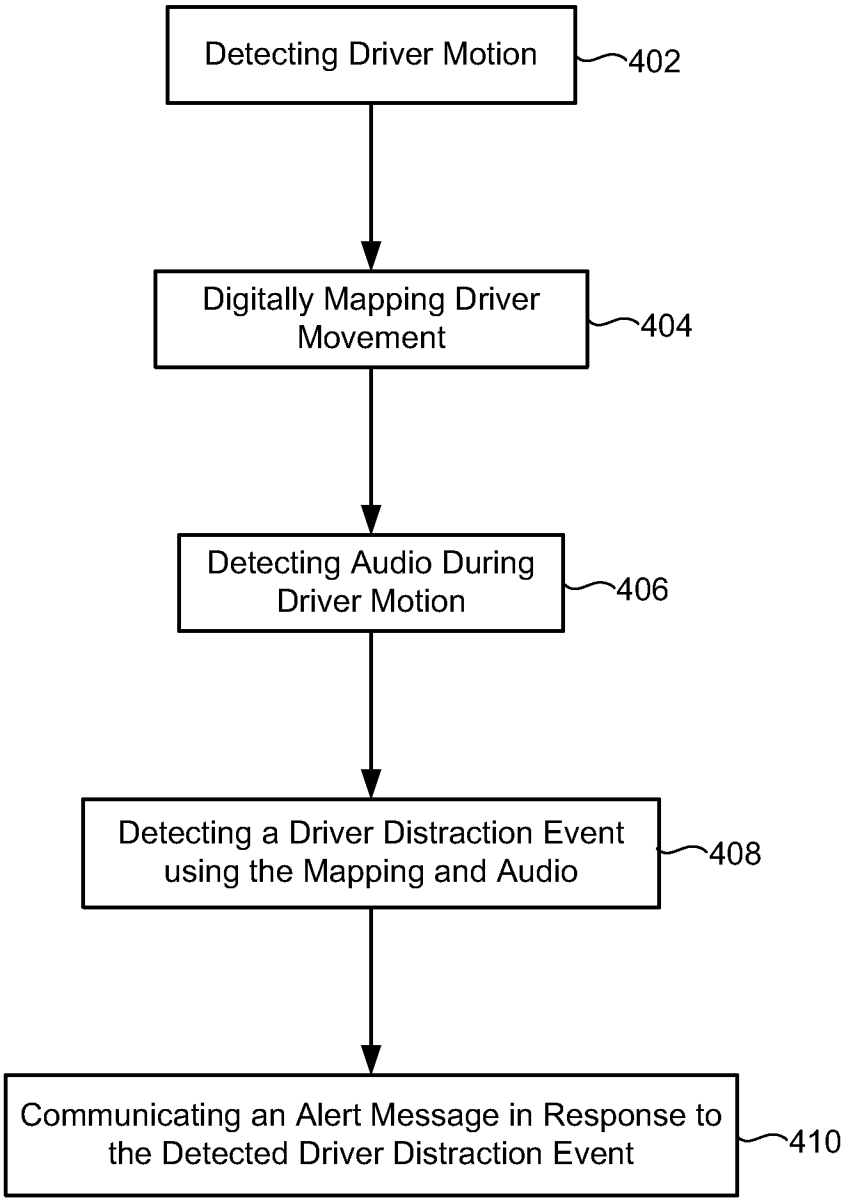

Detecting Driver Motion
402
Digitally Mapping Driver Movement
404
Detecting Audio During Driver Motion
406
Detecting a Driver Distraction Event using the Mapping and Audio
408
Communicating an Alert Message in Response to the Detected Driver Distraction Event
410

FIGURE 5

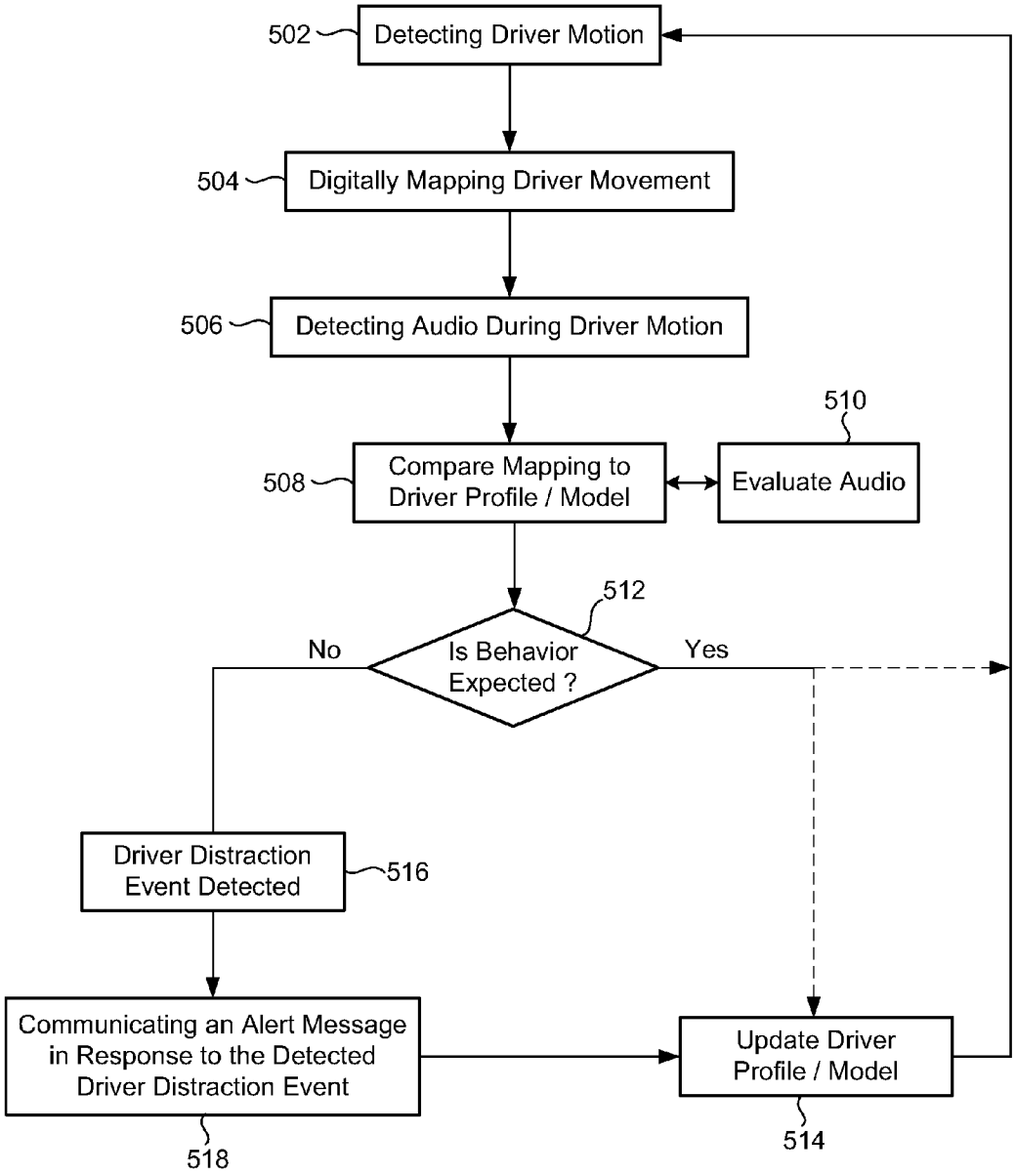

502
Detecting Driver Motion
504
Digitally Mapping Driver Movement
506
Detecting Audio During Driver Motion
510
508
Compare Mapping to Driver Profile / Model
Evaluate Audio
512
No
Is Behavior Expected ?
Yes
Driver Distraction Event Detected
516
Communicating an Alert Message in Response to the Detected Driver Distraction Event
Update Driver Profile / Model
518
514

FIGURE 6

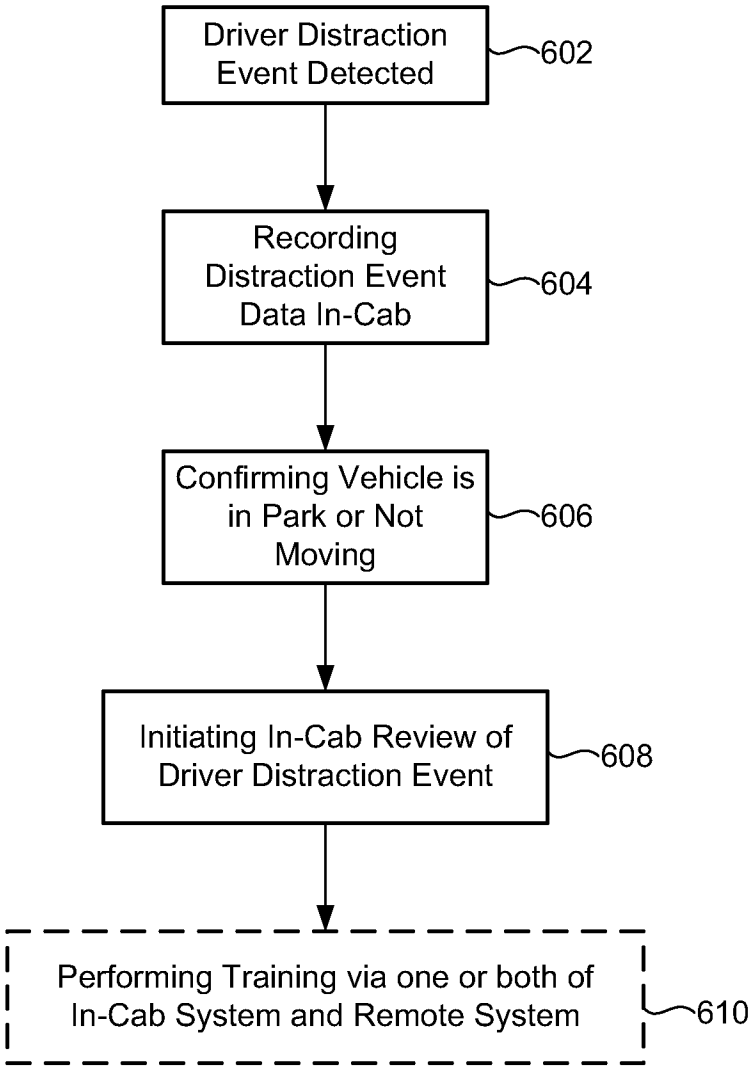

Driver Distraction Event Detected
602
Recording Distraction Event Data In-Cab
604
Confirming Vehicle is in Park or Not Moving
606
Initiating In-Cab Review of Driver Distraction Event
608
Performing Training via one or both of In-Cab System and Remote System
610

FIGURE 7

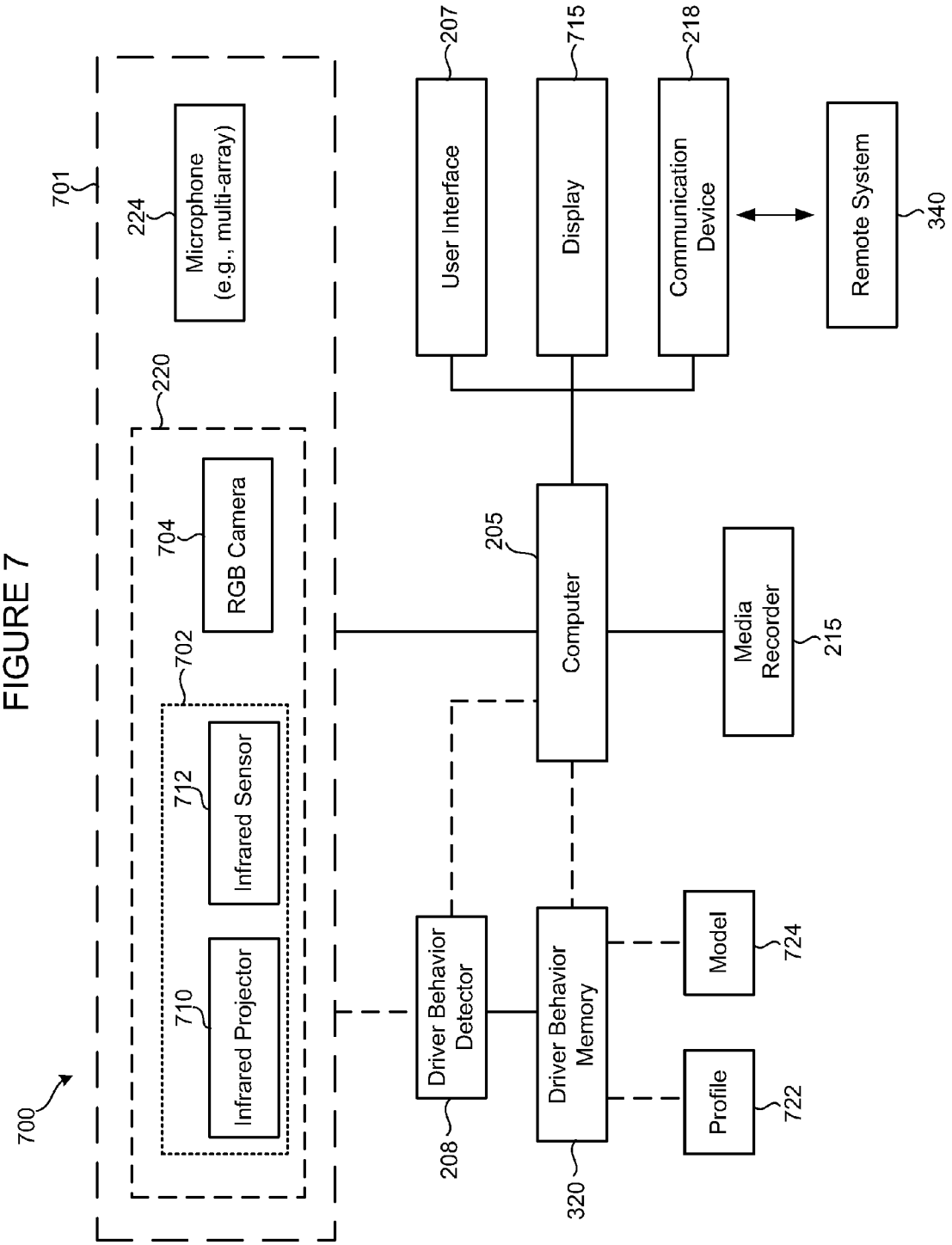

700
701
224
Microphone (e.g., multi-array)
220
704
RGB Camera
702
712
Infrared Sensor
710
Infrared Projector
207
User Interface
715
Display
218
Communication Device
Remote System
340
205
Computer
Media Recorder
215
Driver Behavior Detector
208
Driver Behavior Memory
320
Model
724
Profile
722

FIGURE 8

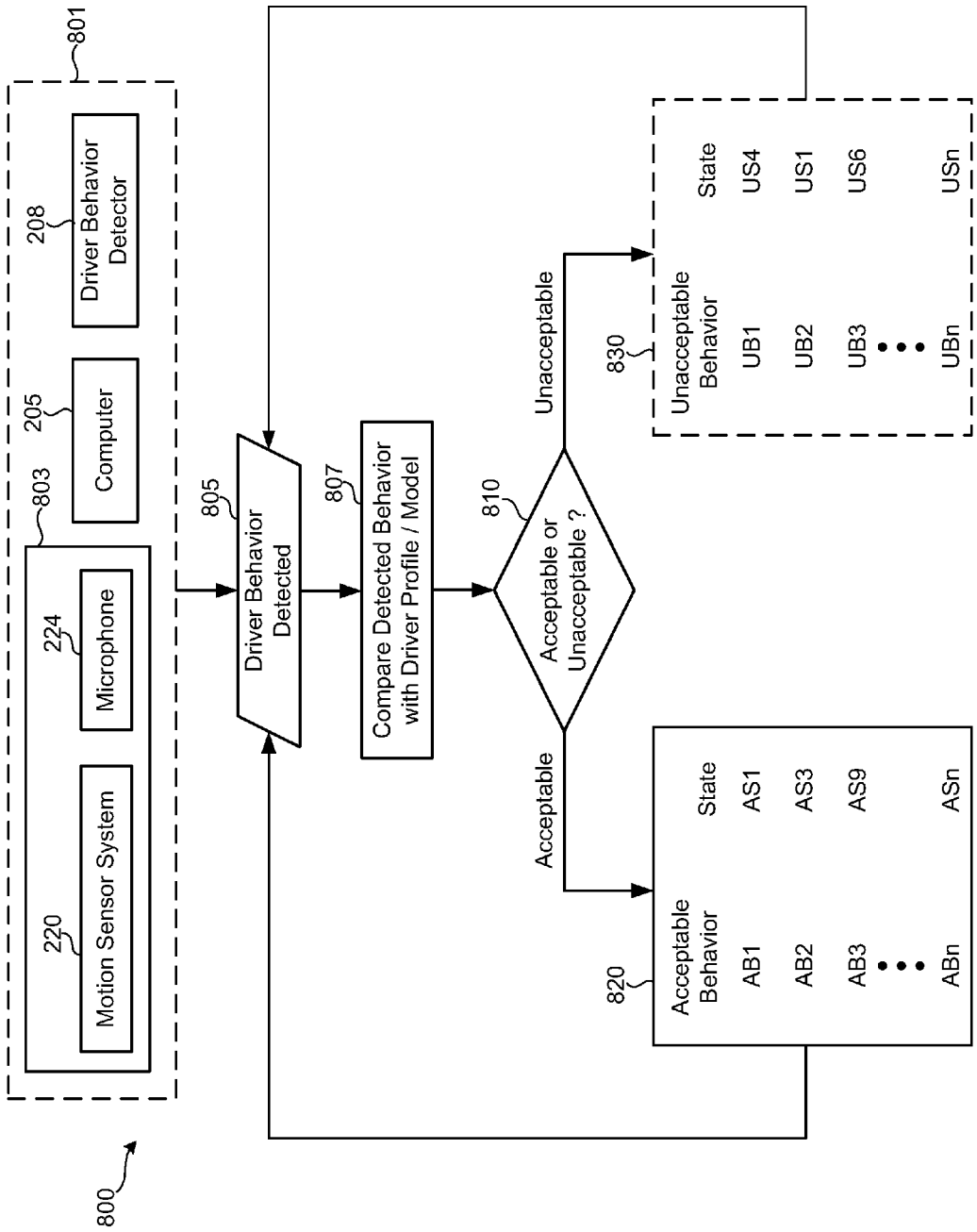
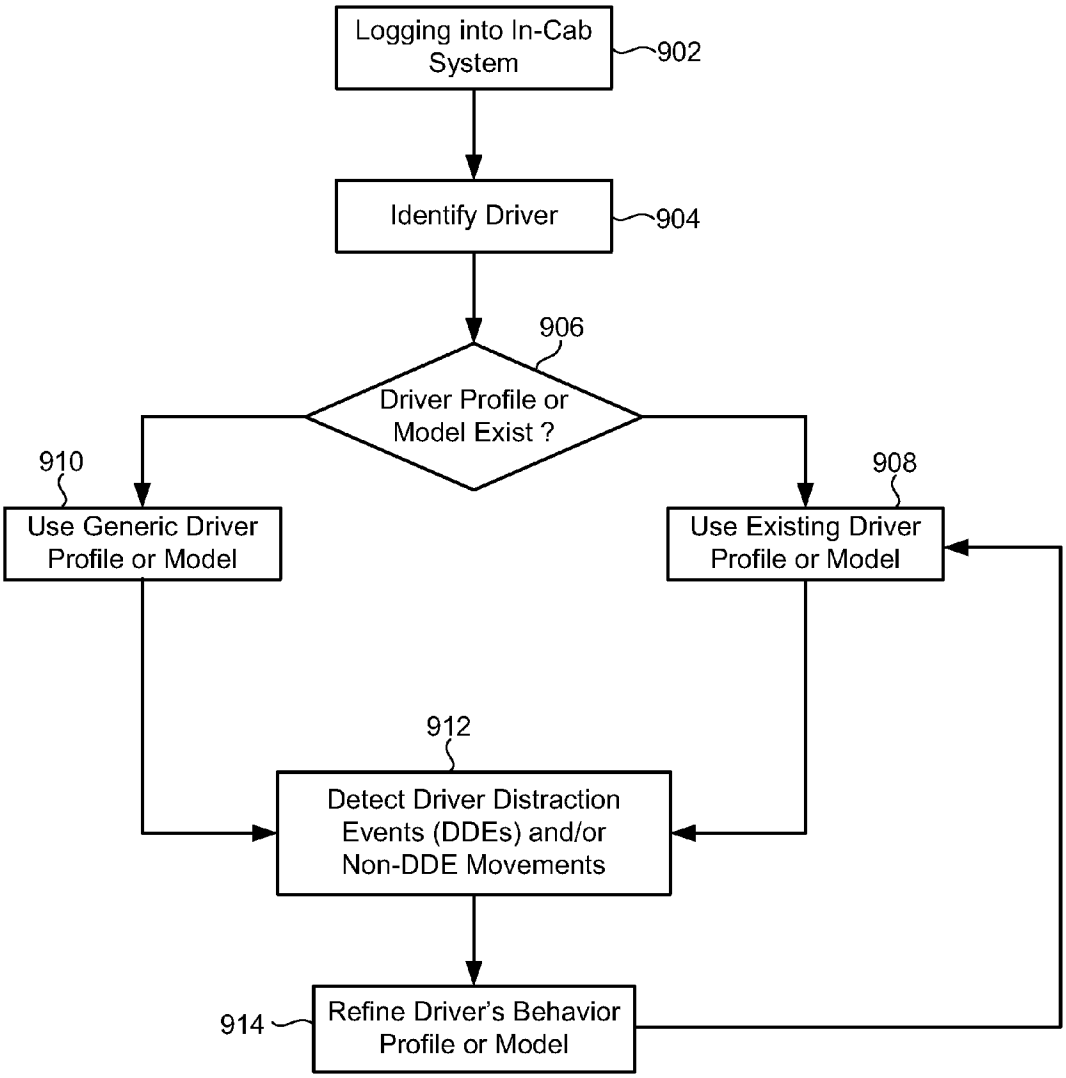

800
801
803
Motion Sensor System
220
Microphone
224
Computer
205
Driver Behavior Detector
208
805
Driver Behavior Detected
807
Compare Detected Behavior with Driver Profile / Model
810
Acceptable or Unacceptable ?
Acceptable
Unacceptable
820
Acceptable Behavior
AB1
AB2
AB3
ABn
State
AS1
AS3
AS9
ASn
830
Unacceptable Behavior
UB1
UB2
UB3
UBn
State
US4
US1
US6
USn

FIGURE 9


Logging into In-Cab System
902
Identify Driver
904
906
Driver Profile or Model Exist ?
910
Use Generic Driver Profile or Model
908
Use Existing Driver Profile or Model
912
Detect Driver Distraction Events (DDEs) and/or Non-DDE Movements
914
Refine Driver's Behavior Profile or Model

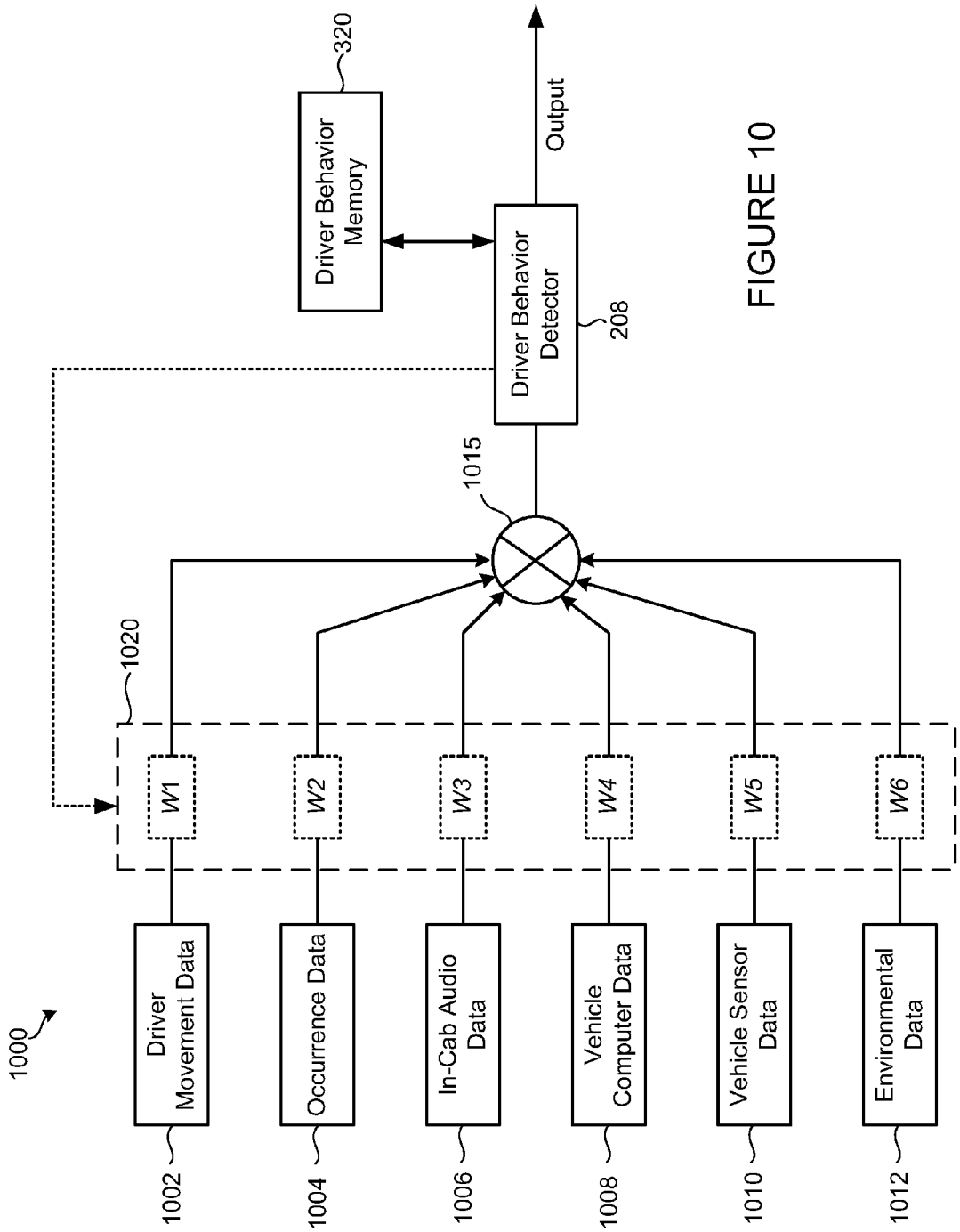
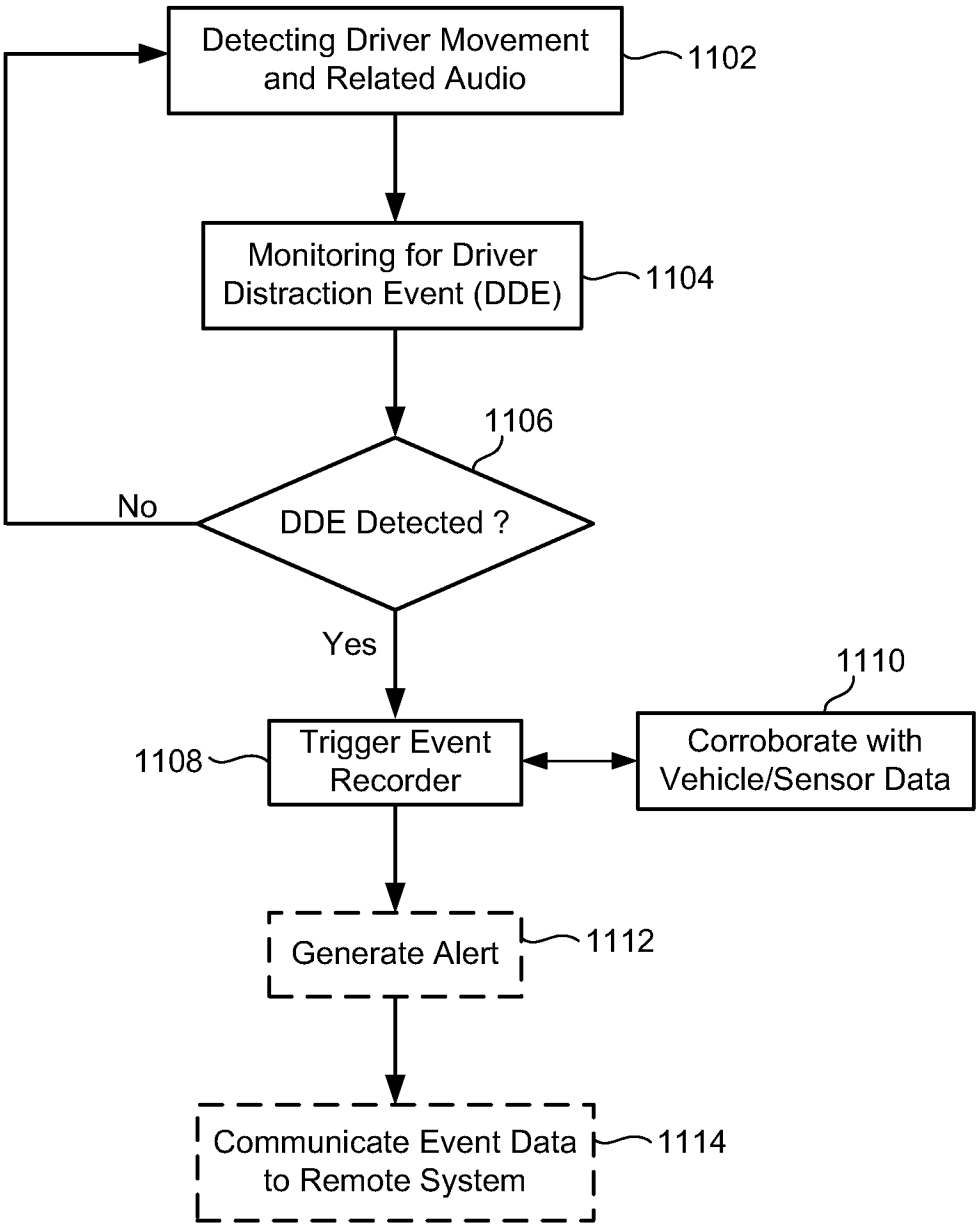

1000
Driver Movement Data
1002
Occurrence Data
1004
In-Cab Audio Data
1006
Vehicle Computer Data
1008
Vehicle Sensor Data
1010
Environmental Data
1012
W1
W2
W3
W4
W5
W6
1020
1015
Driver Behavior Detector
208
Driver Behavior Memory
320
Output

FIGURE 10

FIGURE 11


Detecting Driver Movement and Related Audio
1102
Monitoring for Driver Distraction Event (DDE)
1104
1106
No
DDE Detected ?
Yes
1110
1108
Trigger Event Recorder
Corroborate with Vehicle/Sensor Data
Generate Alert
1112
Communicate Event Data to Remote System
1114

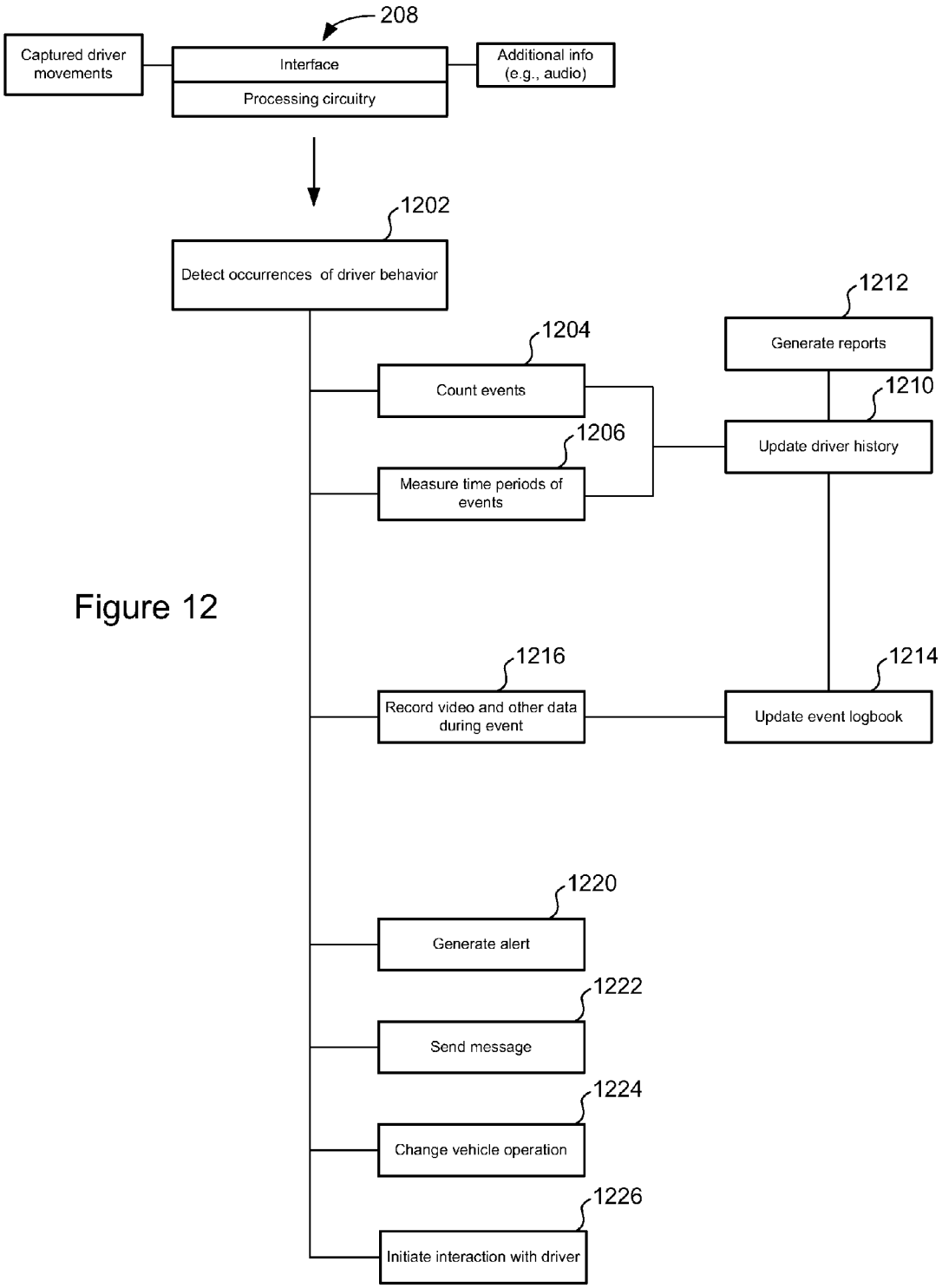

208
Captured driver movements
Interface
Processing circuitry
Additional info (e.g., audio)
1202
Detect occurrences of driver behavior
1212
Generate reports
1204
Count events
1210
Update driver history
1206
Measure time periods of events
1216
Record video and other data during event
1214
Update event logbook
1220
Generate alert
1222
Send message
1224
Change vehicle operation
1226
Initiate interaction with driver

Figure 12

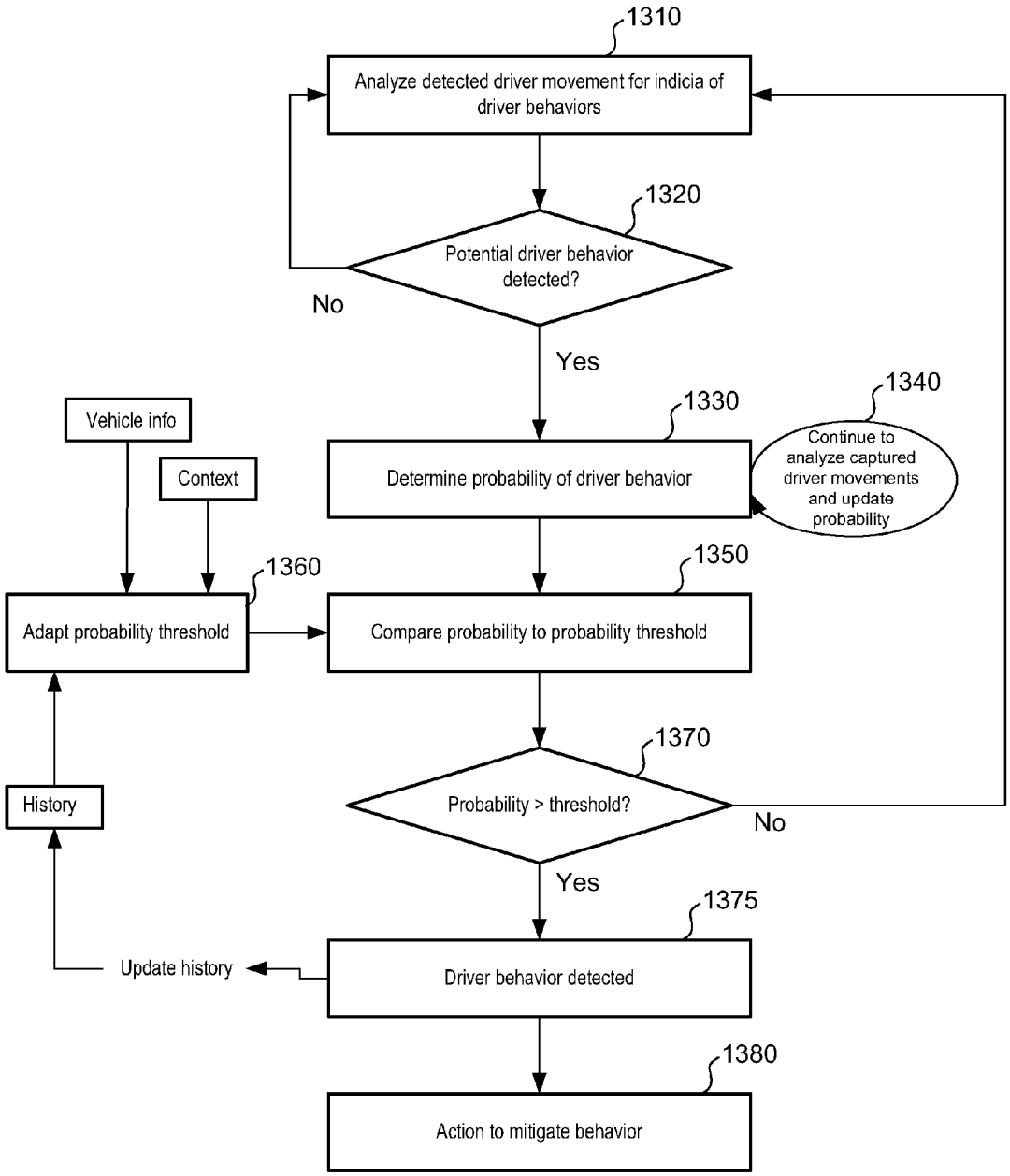

1310
Analyze detected driver movement for indicia of driver behaviors
1320
Potential driver behavior detected?
No
Yes
1330
Determine probability of driver behavior
1340
Continue to analyze captured driver movements and update probability
Vehicle info
Context
1360
Adapt probability threshold
1350
Compare probability to probability threshold
1370
Probability > threshold?
No
Yes
History
1375
Update history
Driver behavior detected
1380
Action to mitigate behavior

Figure 13

Figure 14

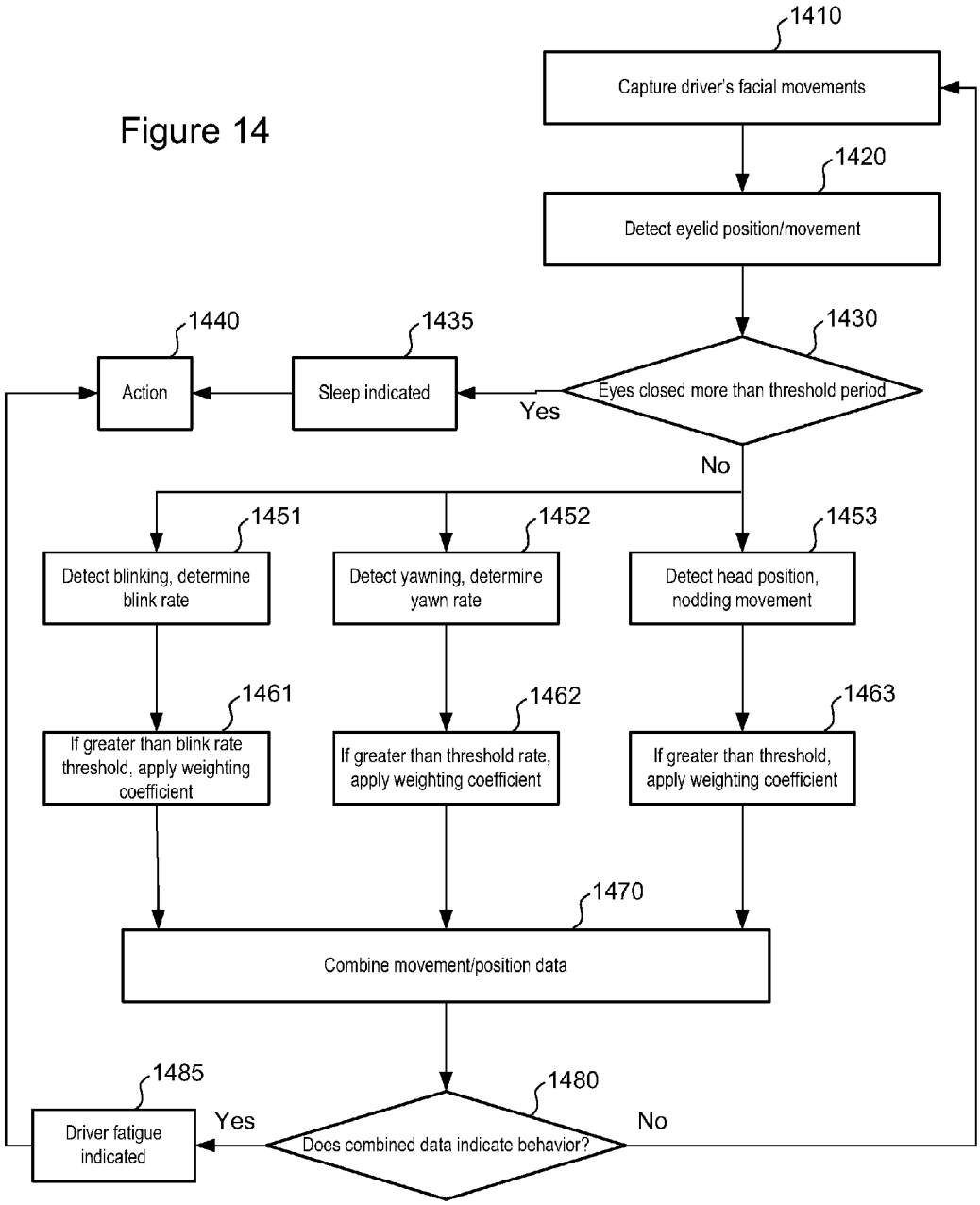
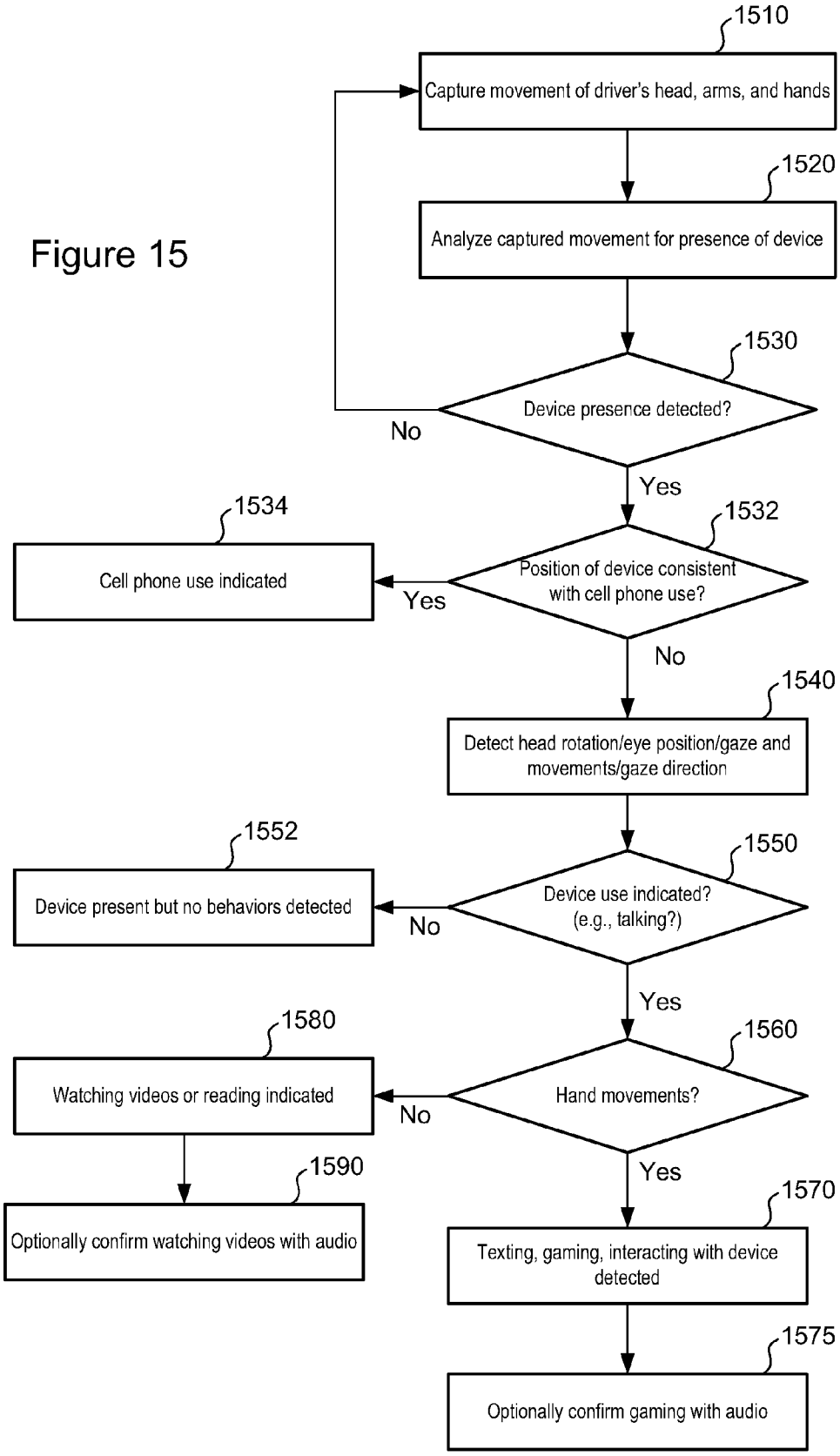

1410
Capture driver's facial movements
1420
Detect eyelid position/movement
1430
Eyes closed more than threshold period
Yes
No
1435
Sleep indicated
1440
Action
1451
Detect blinking, determine blink rate
1452
Detect yawning, determine yawn rate
1453
Detect head position, nodding movement
1461
If greater than blink rate threshold, apply weighting coefficient
1462
If greater than threshold rate, apply weighting coefficient
1463
If greater than threshold, apply weighting coefficient
1470
Combine movement/position data
1480
Does combined data indicate behavior?
Yes
No
1485
Driver fatigue indicated

Figure 15


1510
Capture movement of driver's head, arms, and hands
1520
Analyze captured movement for presence of device
1530
Device presence detected?
No
Yes
1534
Cell phone use indicated
1532
Position of device consistent with cell phone use?
Yes
No
1540
Detect head rotation/eye position/gaze and movements/gaze direction
1552
Device present but no behaviors detected
1550
Device use indicated? (e.g., talking?)
No
Yes
1580
Watching videos or reading indicated
1560
Hand movements?
No
Yes
1590
Optionally confirm watching videos with audio
1570
Texting, gaming, interacting with device detected
1575
Optionally confirm gaming with audio

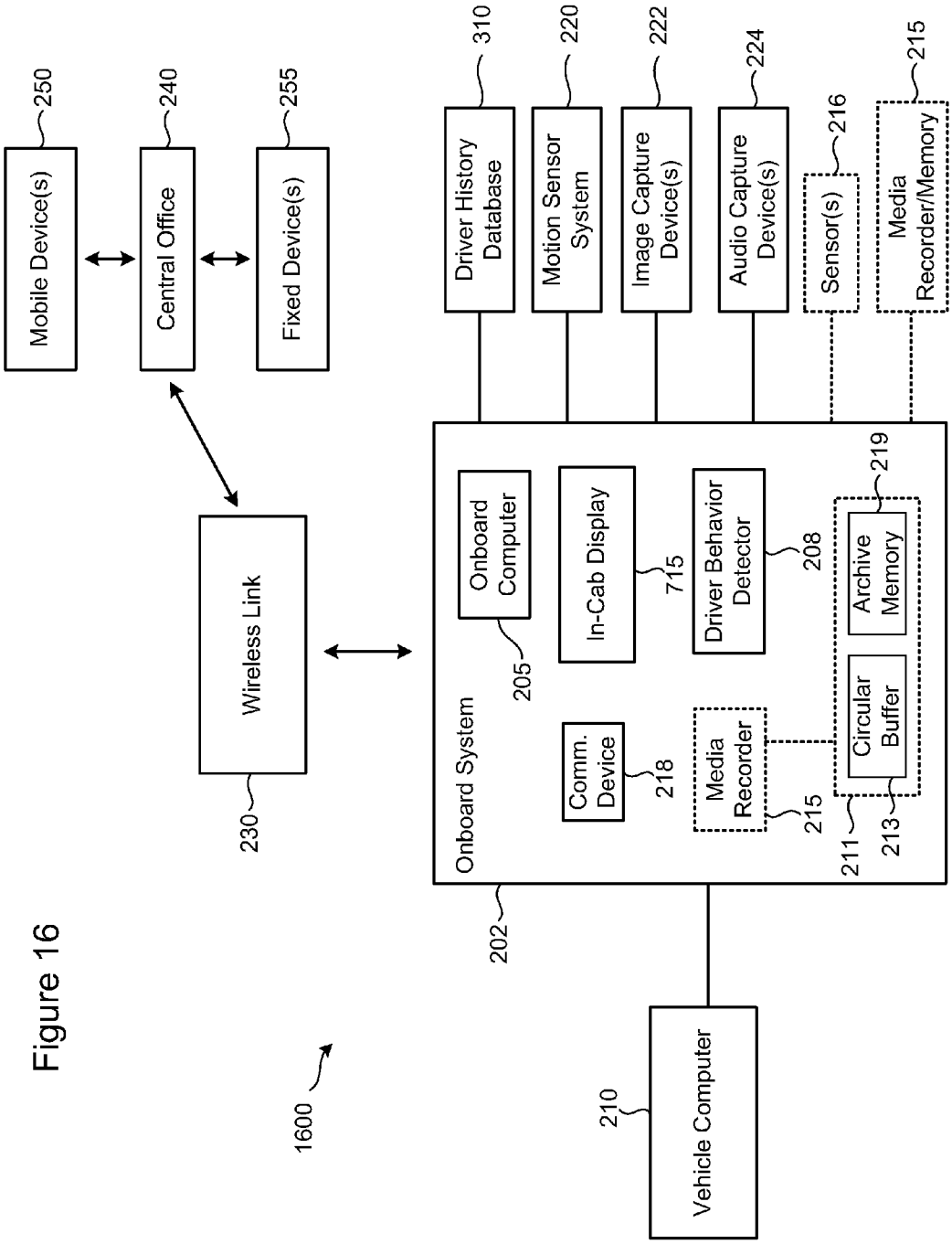

Mobile Device(s)
250
Central Office
240
Fixed Device(s)
255
Wireless Link
230
Driver History Database
310
Motion Sensor System
220
Image Capture Device(s)
222
Audio Capture Device(s)
224
Sensor(s)
216
Media Recorder/Memory
215
Onboard System
202
Onboard Computer
205
In-Cab Display
715
Driver Behavior Detector
208
Archive Memory
219
Circular Buffer
213
Comm. Device
218
Media Recorder
215
211
Vehicle Computer
210
1600

Figure 16

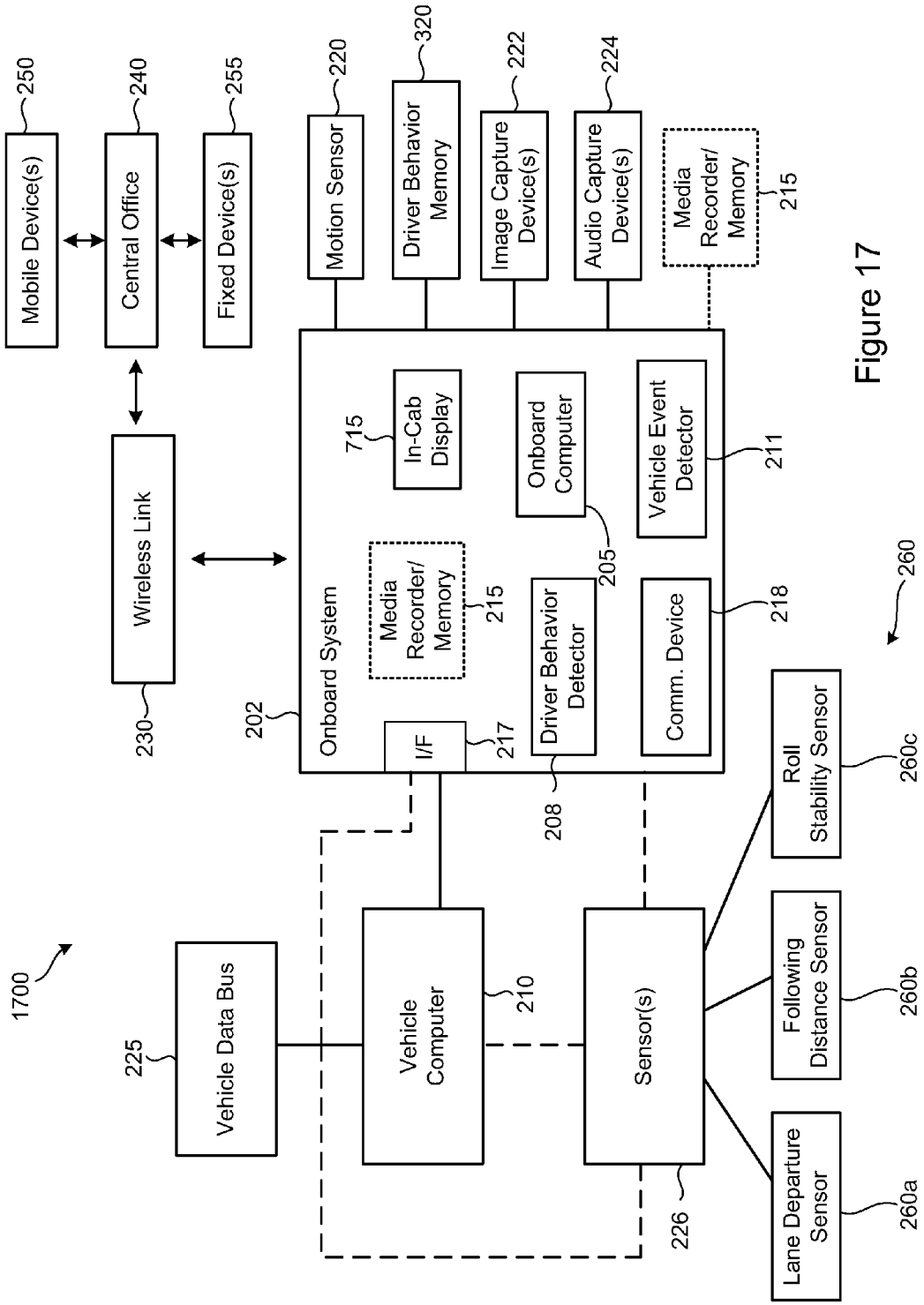

1700
Mobile Device(s)
250
Central Office
240
Fixed Device(s)
255
Wireless Link
230
Motion Sensor
220
Driver Behavior Memory
320
Image Capture Device(s)
222
Audio Capture Device(s)
224
Media Recorder/ Memory
215
Onboard System
202
In-Cab Display
715
Onboard Computer
205
Vehicle Event Detector
211
Media Recorder/ Memory
215
Driver Behavior Detector
208
Comm. Device
218
I/F
217
Vehicle Data Bus
225
Vehicle Computer
210
Sensor(s)
226
Roll Stability Sensor
260c
Following Distance Sensor
260b
Lane Departure Sensor
260a
260

Figure 17

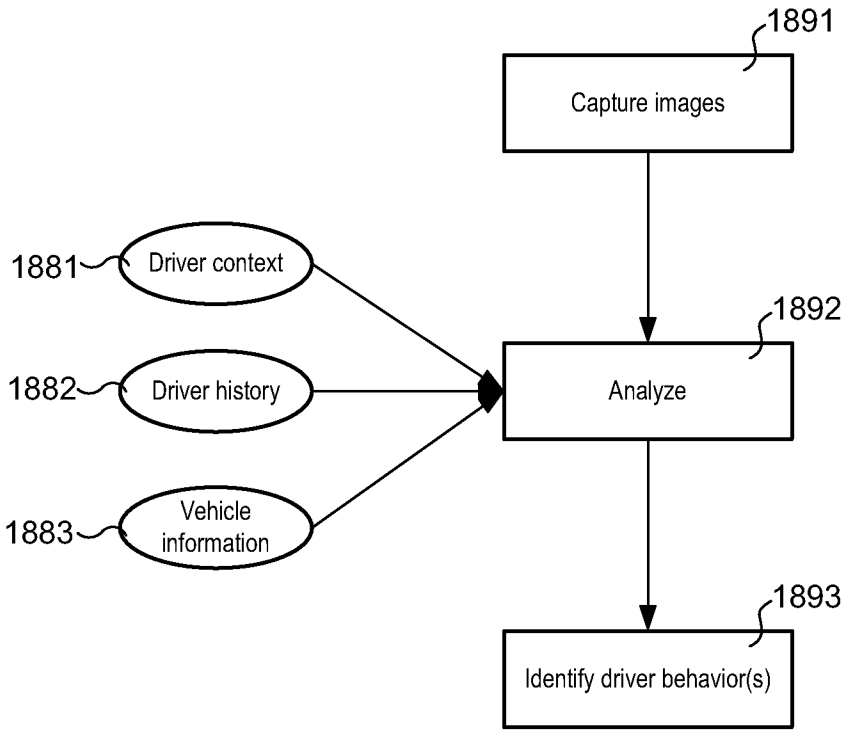

1891
Capture images
1881
Driver context
1892
1882
Driver history
Analyze
1883
Vehicle information
1893
Identify driver behavior(s)

Figure 18

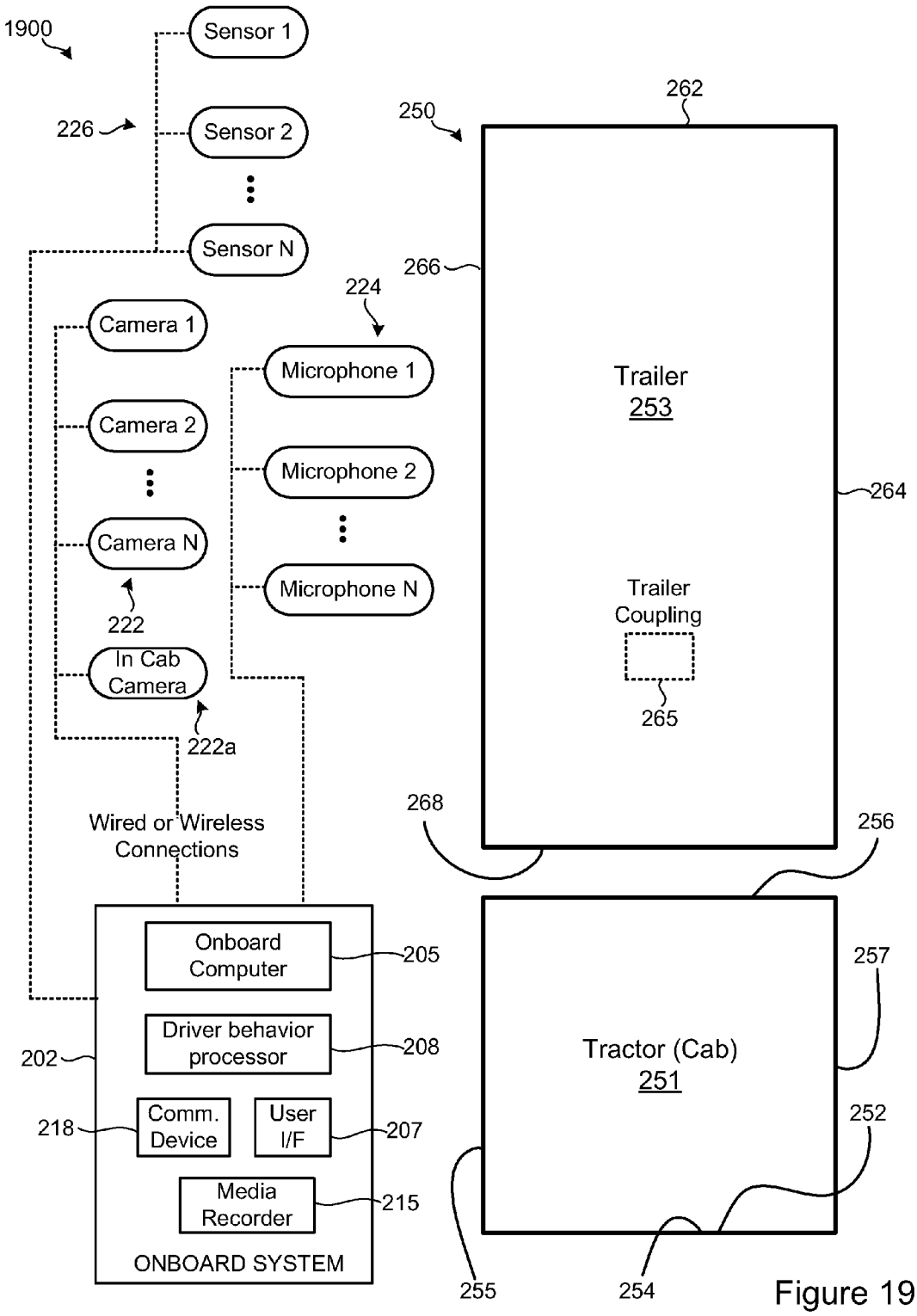

1900
Sensor 1
226
Sensor 2
Sensor N
250
262
266
224
Camera 1
Microphone 1
Camera 2
Microphone 2
Camera N
Microphone N
222
In Cab Camera
222a
Trailer
253
264
Trailer Coupling
265
268
256
Wired or Wireless Connections
Onboard Computer
205
Driver behavior processor
208
202
Comm. Device
User I/F
218
207
Media Recorder
215
ONBOARD SYSTEM
Tractor (Cab)
251
257
252
255
254

Figure 19

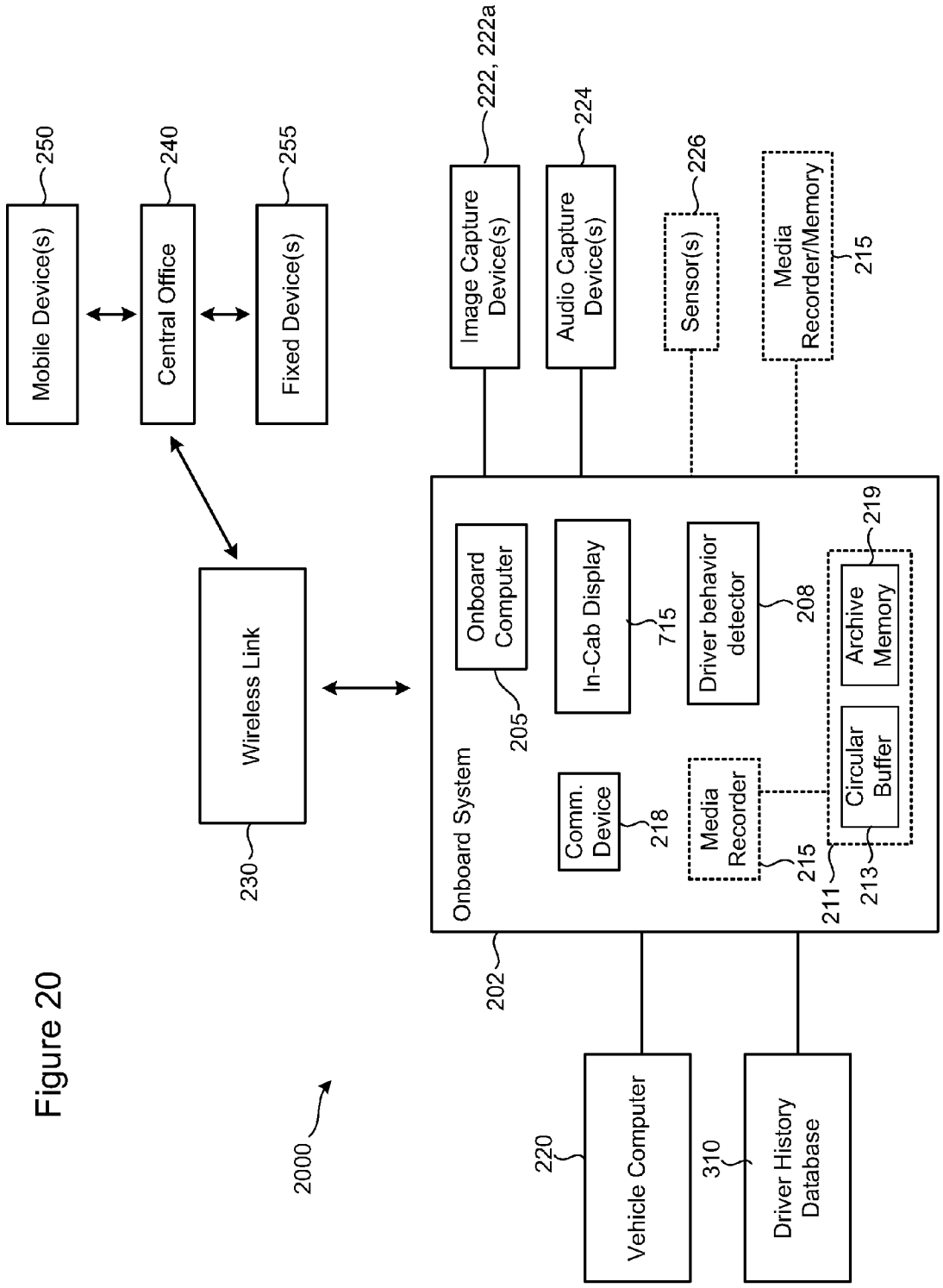

Mobile Device(s)
250
Central Office
240
Fixed Device(s)
255
Wireless Link
230
Image Capture Device(s)
222, 222a
Audio Capture Device(s)
224
Sensor(s)
226
Media Recorder/Memory
215
Onboard System
202
Onboard Computer
205
In-Cab Display
715
Driver behavior detector
208
Comm. Device
218
Media Recorder
215
Circular Buffer
213
Archive Memory
219
211
Vehicle Computer
220
Driver History Database
310
2000

Figure 20

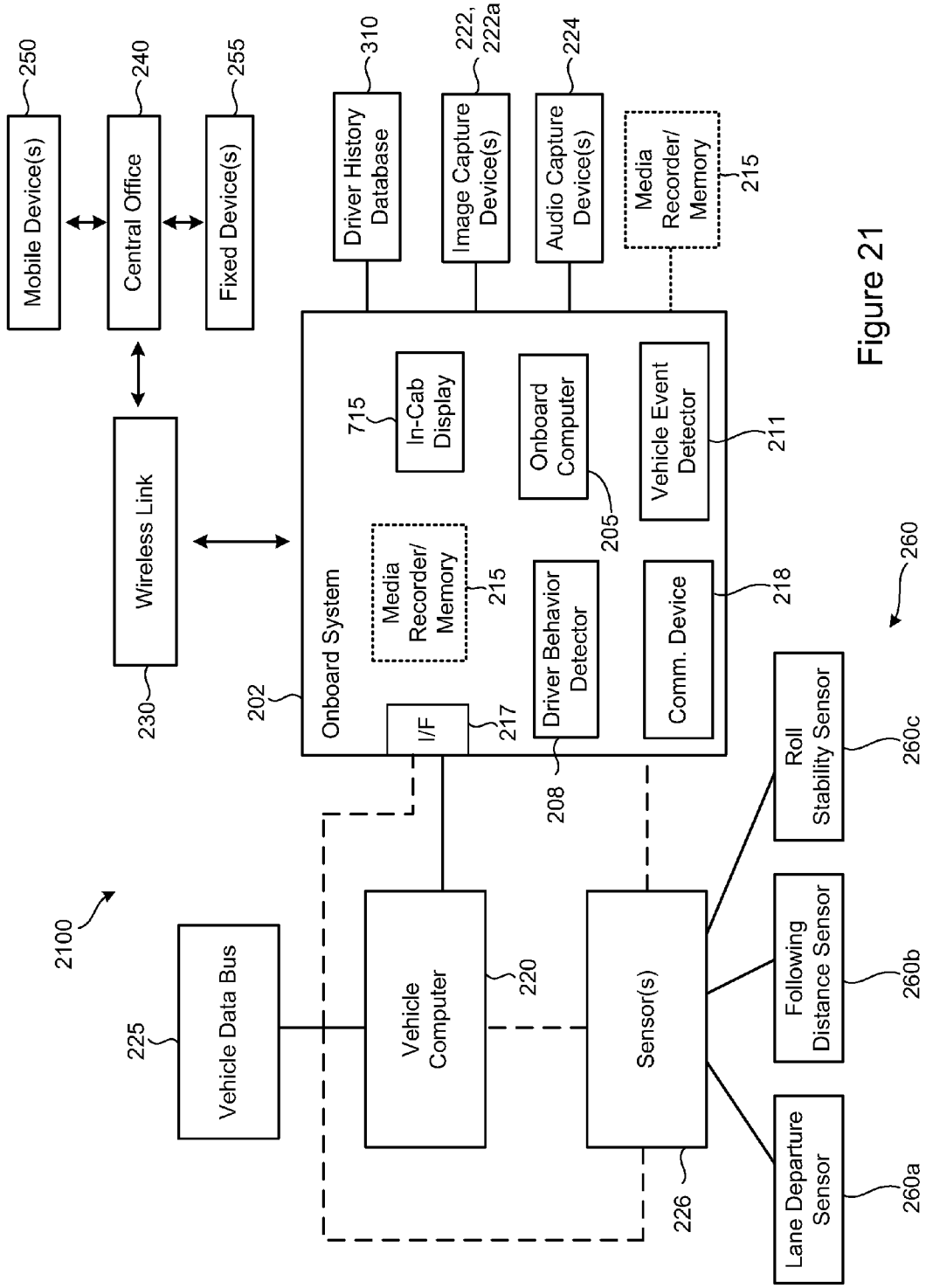

Mobile Device(s)
250
Central Office
240
Fixed Device(s)
255
Wireless Link
230
Driver History Database
310
Image Capture Device(s)
222, 222a
Audio Capture Device(s)
224
Media Recorder/ Memory
215
Onboard System
202
In-Cab Display
715
Onboard Computer
205
Vehicle Event Detector
211
Media Recorder/ Memory
215
Driver Behavior Detector
208
Comm. Device
218
I/F
217
2100
Vehicle Data Bus
225
Vehicle Computer
220
Sensor(s)
226
Roll Stability Sensor
260c
Following Distance Sensor
260b
Lane Departure Sensor
260a
260

Figure 21

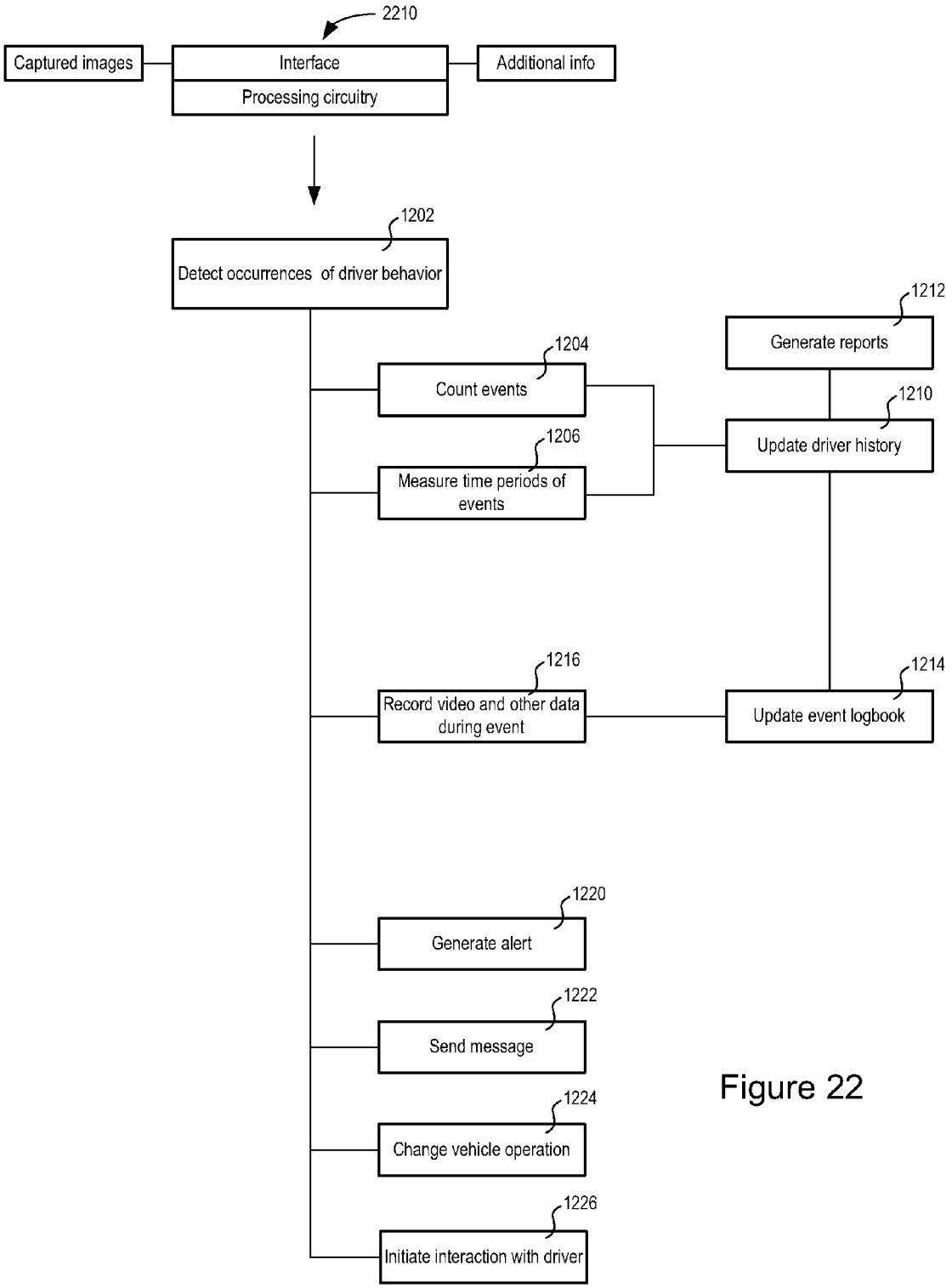

2210
Captured images
Interface
Processing circuitry
Additional info
1202
Detect occurrences of driver behavior
1212
Generate reports
1204
Count events
1210
Update driver history
1206
Measure time periods of events
1216
Record video and other data during event
1214
Update event logbook
1220
Generate alert
1222
Send message
1224
Change vehicle operation
1226
Initiate interaction with driver

Figure 22

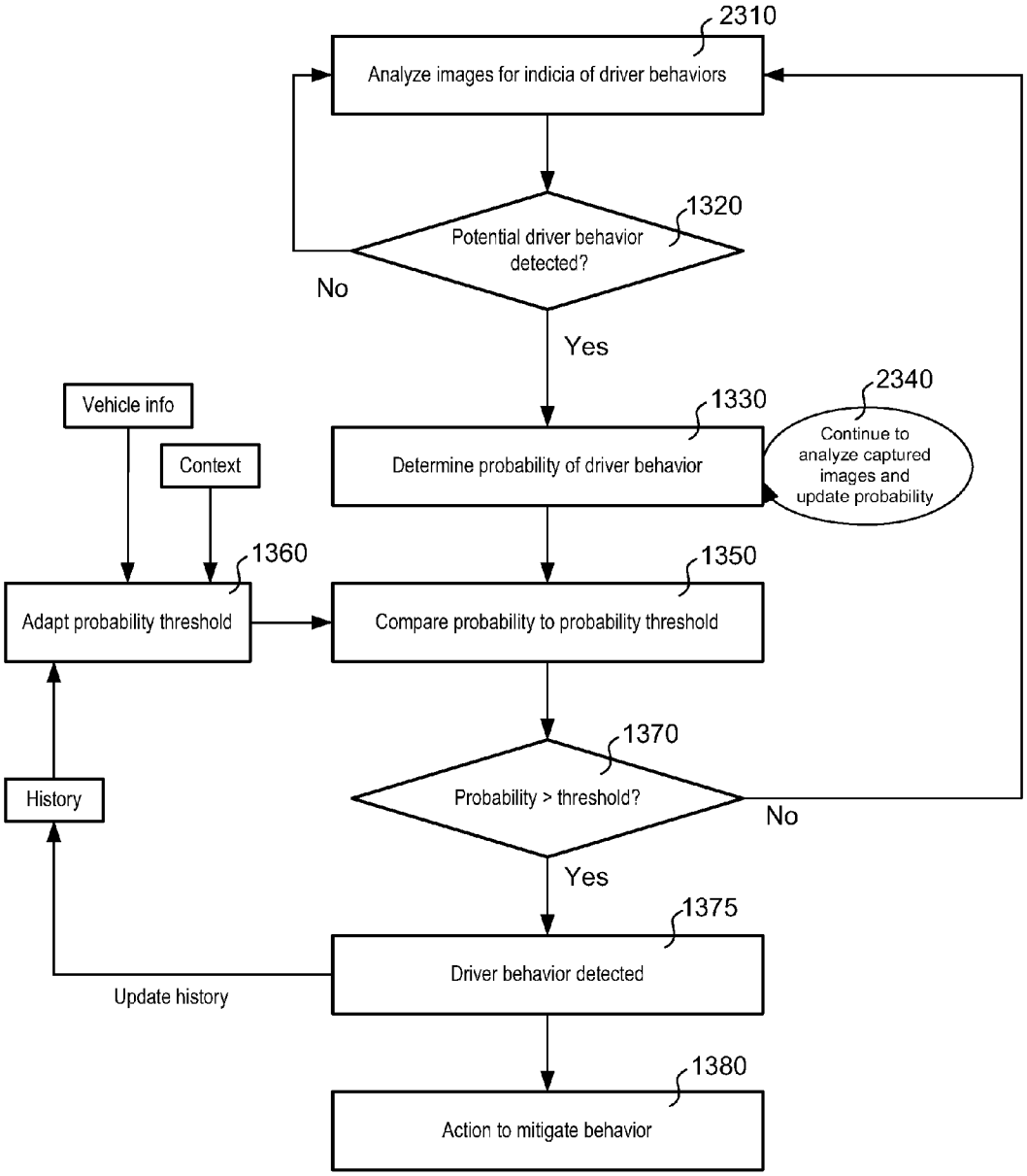

2310
Analyze images for indicia of driver behaviors
1320
Potential driver behavior detected?
No
Yes
2340
Vehicle info
1330
Continue to analyze captured images and update probability
Context
Determine probability of driver behavior
1360
1350
Adapt probability threshold
Compare probability to probability threshold
1370
History
Probability > threshold?
No
Yes
1375
Driver behavior detected
Update history
1380
Action to mitigate behavior

Figure 23

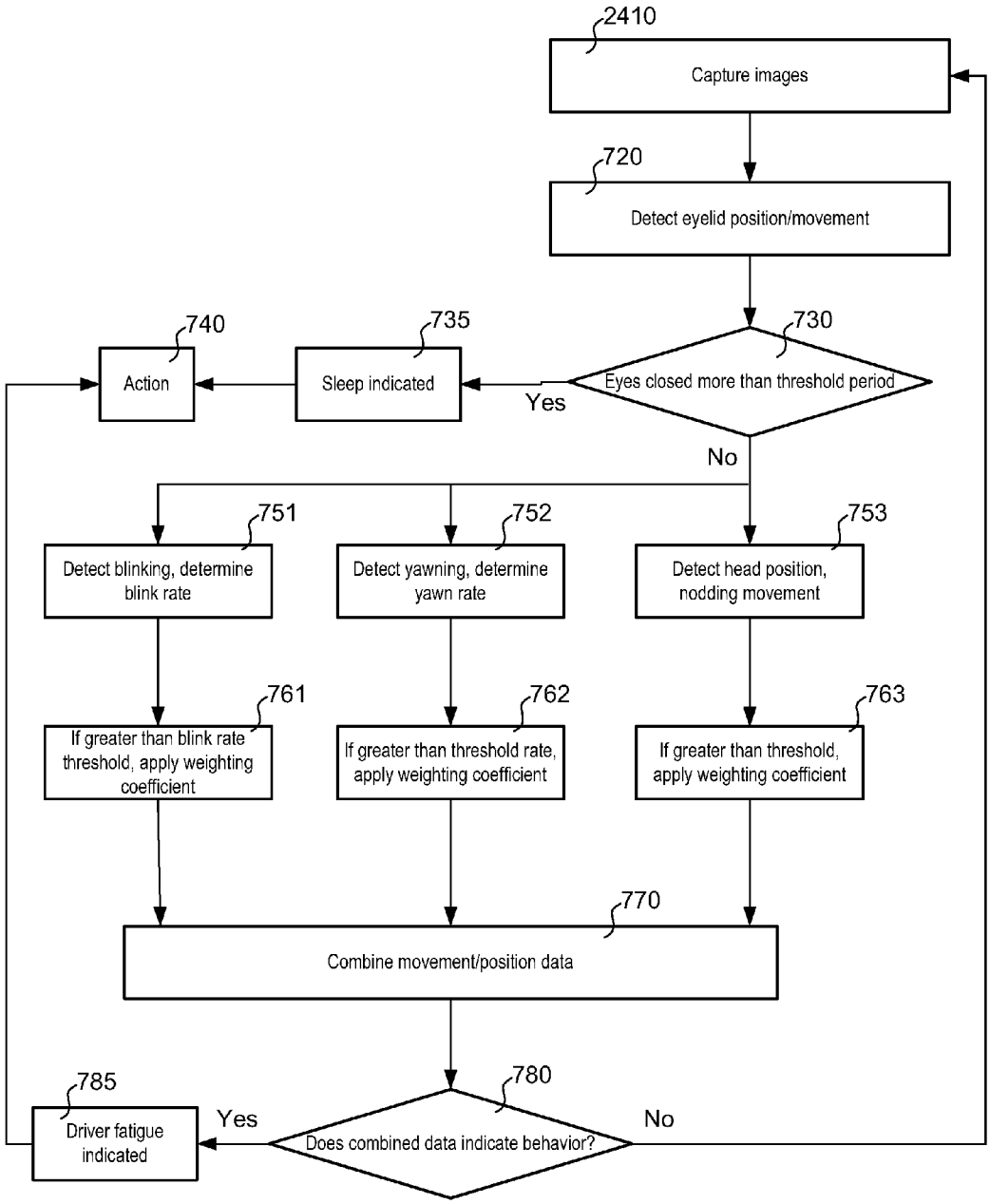

2410
Capture images
720
Detect eyelid position/movement
730
Eyes closed more than threshold period
Yes
No
735
Sleep indicated
740
Action
751
Detect blinking, determine blink rate
752
Detect yawning, determine yawn rate
753
Detect head position, nodding movement
761
If greater than blink rate threshold, apply weighting coefficient
762
If greater than threshold rate, apply weighting coefficient
763
If greater than threshold, apply weighting coefficient
770
Combine movement/position data
780
Does combined data indicate behavior?
Yes
No
785
Driver fatigue indicated

Figure 24

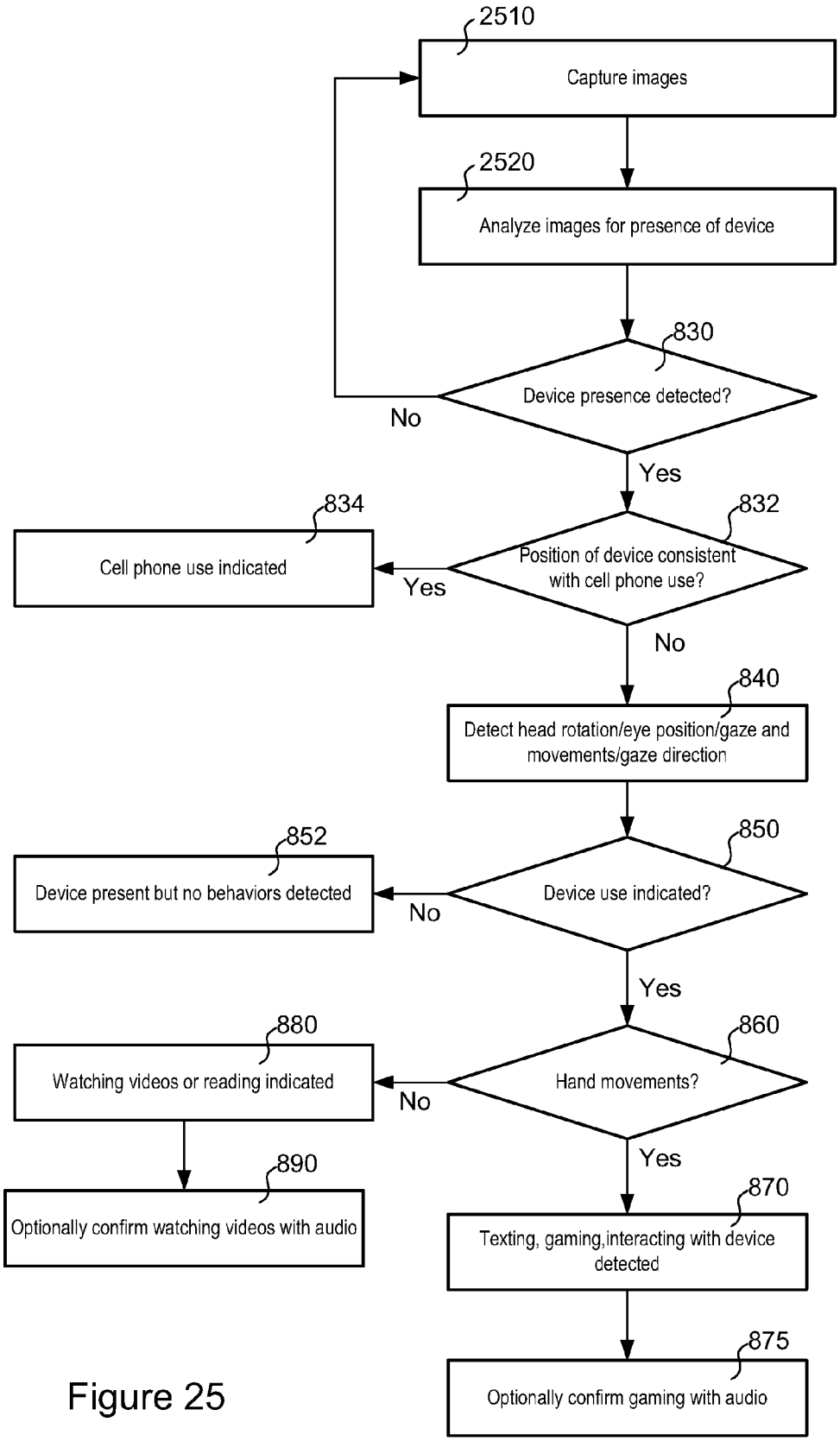

2510
Capture images
2520
Analyze images for presence of device
830
Device presence detected?
No
Yes
834
Cell phone use indicated
Yes
832
Position of device consistent with cell phone use?
No
840
Detect head rotation/eye position/gaze and movements/gaze direction
852
Device present but no behaviors detected
No
850
Device use indicated?
Yes
880
Watching videos or reading indicated
No
860
Hand movements?
Yes
890
Optionally confirm watching videos with audio
870
Texting, gaming,interacting with device detected
875
Optionally confirm gaming with audio

Figure 25

DETECTION OF DRIVER BEHAVIORS USING IN-VEHICLE SYSTEMS AND METHODS

RELATED PATENT DOCUMENTS

This application claims the benefit of Provisional Patent Application Ser. Nos. 62/038,711, filed on Aug. 18, 2014, and 62/118,353 filed on Feb. 19, 2015, to which priority is claimed pursuant to 35 U.S.C. §119(e), and which are incorporated herein by reference in their respective entireties.

TECHNICAL FIELD

This application relates generally to devices, systems, and methods pertaining to detection of driver behaviors.

SUMMARY

Embodiments of the disclosure are directed to a system comprising a motion sensor system configured for deployment in a cab of a vehicle and to generate substantially in real-time a digital mapping of driver movement during operation of the vehicle. A computer is configured for deployment in the cab and coupled to the motion sensor system. A driver behavior detector is coupled to the computer and configured to detect a driver distraction event using the driver movement mapping. A communication device at the vehicle is configured to communicate an alert message to one or both of a user interface device in the cab and a remote system in response to the detected driver distraction event.

Other embodiments are directed to a system comprising a motion sensor system configured for deployment in a cab of a vehicle and to generate substantially in real-time a digital mapping of driver movement during operation of the vehicle. An audio sensor is configured for deployment in the cab and configured to generate an audio signal responsive to driver movement during operation of the vehicle. A computer is configured for deployment in the cab and coupled to the motion sensor system and the audio sensor. A driver behavior detector is coupled to the computer and configured to detect a driver distraction event using the driver movement mapping and the audio signal. A communication device at the vehicle is configured to communicate an alert message to one or both of a user interface device in the cab and a remote system in response to the detected driver distraction event.

Further embodiments are directed to a method comprising generating substantially in real-time a digital mapping of driver movement during operation of a vehicle, and generating an audio signal responsive to driver movement during operation of the vehicle. The method also comprises detecting a driver distraction event using the driver movement mapping and the audio signal, and communicating an alert message to one or both of a user interface device in the vehicle and a remote system in response to the detected driver distraction event.

Some embodiments involve systems and/or methods for use with a vehicle comprising a tractor and a trailer. A system includes one or more image capture devices arranged to capture images of a driver. A driver behavior detector receives the captured images and additional information comprising at least one of driver information and vehicle information. The driver behavior detector analyzes the captured images in conjunction with the additional information and identifies one or more driver behaviors based on the analysis.

Some embodiments involve a system for detecting active driver behaviors, such as those involving the use of an electronic or other device. The system includes one or more image capture devices, each image capture device configured to capture images of a driver. A driver behavior detector is configured to analyze the captured images and to identify one or more active driver behaviors based on analysis of the captured images.

According to some embodiments, a driver behavior detector includes interface circuitry configured to receive captured images and additional information comprising at least one of stored driver information, current context information, and vehicle information. The driver behavior detector includes processing circuitry that analyzes the captured images in conjunction with the additional information and identifies one or more driver behaviors based on the analysis.

Further embodiments are directed to various methods implemented by systems of the present disclosure.

The above summary is not intended to describe each disclosed embodiment or every implementation of the present disclosure. The figures and the detailed description below more particularly exemplify illustrative embodiments.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a conceptual diagram of an approach for identifying driver behaviors based on captured driver motion and audio data according to various embodiments;

FIG. **2** is a block diagram of an apparatus for implementing embodiments that determine driver behavior in accordance with the disclosure;

FIG. **3** illustrates a system for acquiring motion and audio information which is used to detect driver behavior in accordance with various embodiments;

FIG. **4** illustrates a method of detecting driver behavior in accordance with various embodiments;

FIG. **5** illustrates a method of detecting driver behavior in accordance with various embodiments;

FIG. **6** illustrates a method of detecting driver behavior in accordance with various embodiments;

FIG. **7** illustrates a system for detecting driver behavior in accordance with various embodiments;

FIG. **8** illustrates a system which includes a driver movement sensor that operates in conjunction with a driver behavior profile or model to refine the profile or model over time in accordance with various embodiments;

FIG. **9** is a flow chart showing various processes involving use of a driver behavior profile or model in accordance with various embodiments;

FIG. **10** illustrates an embodiment of a system for detecting driver behavior in accordance with various embodiments;

FIG. **11** illustrates a flow chart showing various processes involving driver behavior detection within the context of an onboard event detection methodology in accordance with various embodiments;

FIG. **12** is a diagram that conceptually illustrates operation of system that includes driver behavior detection in accordance with various embodiments;

FIG. **13** is a flow diagram illustrating a method of identifying driver behaviors in accordance with various embodiments;

FIG. **14** is a flow diagram illustrating a process of detecting and responding to fatigue/sleep-related driver behaviors using a data fusion approach in accordance with various embodiments;

FIG. **15** is a flow diagram illustrating a method for identifying active driver behavior involving the use of a device, e.g., cell phone, tablet, computer, book, ebook and the like in accordance with various embodiments;

FIG. **16** is a block diagram of a system for acquiring and processing driver movement information which may be used for driver behavior identification in accordance with various embodiments;

FIG. **17** is a block diagram of a system for acquiring and processing driver movement information which may be used for driver behavior identification in accordance with various embodiments;

FIG. **18** is a conceptual diagram of an approach for identifying driver behaviors based on captured images according to various embodiments;

FIG. **19** is a block diagram of an apparatus for implementing image intelligence to determine driver behavior in accordance with various embodiments;

FIG. **20** is a block diagram of a system for acquiring and processing video information which may be used for identifying driver behaviors in accordance with various embodiments;

FIG. **21** is a block diagram of a system for acquiring and processing image information and identifying driver behaviors in accordance with various embodiments;

FIG. **22** is a diagram that conceptually illustrates operation of a system in accordance with various embodiments;

FIG. **23** is a flow diagram illustrating a method of identifying and responding to driver behaviors in accordance with various embodiments;

FIG. **24** is a flow diagram illustrating a process of detecting and responding to fatigue/sleep related driver behaviors in accordance with some embodiments; and

FIG. **25** is a flow diagram illustrating a method for identifying active driver behaviors involving the use of an electronic or other type of device in accordance with some embodiments.

The figures are not necessarily to scale. Like numbers used in the figures refer to like components. However, it will be understood that the use of a number to refer to a component in a given figure is not intended to limit the component in another figure labeled with the same number.

DETAILED DESCRIPTION

Driver behavior including fatigue-related behavior due to insufficient sleep, impaired ability due to drug and alcohol use, and active driver behaviors, such as texting, telephoning, watching videos, gaming, eating, etc., while driving can lead to unsafe driving and even an increase in traffic accidents. Embodiments disclosed herein involve capturing driver movement, and in some embodiments related audio data and/or other contemporaneous information, and using this data to identify various types of driver behaviors including fatigue-related behaviors and active behaviors including interaction by the driver with a device, such as an electronic device, e.g., cellphone, tablet, laptop computer, ebook reader, or a non-electronic device, such as a book, magazine, or newspaper.

FIG. **1** is a conceptual diagram of an approach for identifying driver behaviors based on captured driver motion and optionally audio data according to various embodiments. In some embodiments, driver motion within the cab of a vehicle is captured **102** using a motion sensor system that is positioned within the cab. In some implementations, the motion sensor system is positioned to capture motion of the driver's head and face, while in other implementations movement of the driver's torso, and/or driver's limbs and hands are also captured. Various embodiments involve capturing audio data **104** contemporaneously with the driver motion data. The audio data **104** can be captured by a microphone arrangement provided in the cab of the vehicle.

In some embodiments, the driver motion and audio data are analyzed **130** in conjunction with additional information that may include, but is not limited to, driver context **120**, driver history **122**, driver behavior **124**, and/or vehicle information **126**. The additional information may be acquired from a remote system, such as one that supports or is communicatively coupled to a transportation management system (TMS), or a multiplicity of remote systems or sources. The vehicle information **126** may include data acquired from the vehicle's computer or communication/network bus and/or one or more sensors (e.g., lane departure sensor, following distance sensor, roll stability sensor) provided in or on the vehicle. As discussed herein, driver context **120** involves a set of current conditions in which the driver is operating. For example, driver context conditions may include length of time that the driver has been on the road (e.g., hours of service (HOS) data), length of time since the driver last slept, weather conditions, temperature, heading direction, position of the sun, road conditions, date and time of day/night, traffic conditions, driver seatbelt usage, and/or any other current conditions that relate to and/or can influence driver behavior.

Driver history **122** includes historical information about the driver. For example, a driver's history may include years of experience, type of experience, history of traffic accidents, items from an employment personnel record, history of speeding and/or other traffic violations, number, severity, and length of previously identified occurrences of various driver behaviors. Severity of the previously identified occurrence of the driver behaviors may involve a rating of the potential danger of the occurrence, for example. In some embodiments, the system may collect and store a driving profile for a particular driver as part of a driver's history. For example, the driver's driving profile may include how quickly the driver accelerates or decelerates, usual speeds for particular driving conditions, e.g., night driving, driving in rain or snow, etc., how often the driver swerves or crosses the center line, and the like. The driver history **122** may include governmental CSA (Compliance, Safety, Accountability) scoring data in addition to other driver data.

Driver behavior **124** includes a profile, template, and/or a model that describes one or more attributes that are particular to the manner in which a specific driver behaves. Representative driver behaviors include the driver's normal blink rate, gaze direction, limb and/or torso position and/or movements, etc. If the driver's behavior deviates substantially from the driver profile/template or model, it may be more likely that the driver is engaging in an unusual (e.g., suspect) or unacceptable driver behavior. Embodiments of the disclosure are directed to systems and method for assessing driver behavior in real-time using onboard resources, and for providing real-time feedback (e.g., an alert, messaging, training) in response to detecting unacceptable driving behavior using onboard resources.

Vehicle information **126** relates to information about the operation of the vehicle and can be obtained from cameras and/or sensors attached to the vehicle and/or from the vehicle computer and/or other sensors. Vehicle information

can include proximity of the vehicle to objects and/or other vehicles beside, behind, and/or in front of the vehicle, recent lane departure information, roll stability information, swerve information, sudden acceleration/deceleration, braking and/or shifting information, vehicle RPM, and/or vehicle speed, for example.

Driver motion data and contemporaneously related audio data are captured and analyzed **130**, optionally in conjunction with the additional information, to identify **140** one or more driver behaviors. The captured driver motion and related audio data are analyzed and driver behavior identified by circuitry denoted herein as a "driver behavior detector." For example, the driver behavior detector may comprise hardware running software and/or firmware configured to implement driver behavior detection. In some embodiments, the driver behavior detector may be implemented as part of an onboard computer of a vehicle. In other embodiments, the captured driver motion and related audio data and optionally at least some of the additional information is transmitted from the vehicle to an external computer, e.g., the central office processor or TMS processor, which analyzes the captured driver motion and related audio data, optionally in conjunction with the additional data, to identify driver behaviors. In some embodiments, some portions of driver behavior detection, such as motion detection, image processing, and/or behavior recognition, classification, and detection, may be implemented by the vehicle's onboard system and some portions of the driver behavior detector such as analysis of the processed data, optionally in conjunction with additional data, may be implemented by an external processor. As such, some embodiments are directed to an onboard driver behavior detection system and method which is fully implemented using onboard resources, while other embodiments utilize at least some resources external to the vehicle.

In some embodiments, the detected driver behaviors are behaviors related to fatigue or falling asleep. These driver behaviors can be indicated by movements such as excessive yawning, blinking, and/or head nodding. In some embodiments, the driver behaviors are active behaviors (in contrast to fatigue-related behaviors), such as texting, emailing, using a cell phone, using a computer, gaming, web surfing, eating, grooming, reading, watching videos, etc. The active behaviors can be associated with the presence of a device and movements and/or positions that are consistent with interaction with the device. For example, movements/positions consistent with driver interaction with a device can include gaze directions, eye and/or retina movements, e.g., back and forth from road to device, finger/hand movements consistent with touch or keypad interaction, head rotations, e.g., alternately toward road and toward a device, etc.

FIG. **2** is a block diagram of an apparatus **200** for implementing embodiments that determine driver behavior in accordance with the disclosure. The apparatus **200** may be deployed on a vehicle **250** comprising a tractor **251** and a trailer **253** on which various electronic components are respectively mounted. The electronic components include an onboard system **202** which is preferably mounted in the tractor **251** of the vehicle **250**. The onboard system **202** is shown to include an onboard computer **205** (which can include a microprocessor, controller, reduced instruction set computer (RISC), or other central processing module), a user interface **207**, and a driver behavior detector **208**. The user interface **207** includes one or more output devices and/or one or more input devices configured for interaction with an operator. The output devices may comprise an in-cab display (conventional or touch-screen) which can be mounted in the vehicle cab (e.g., fixedly or as a removable handheld device such as a table), one or more alert devices, e.g., auditory alert device, such as a speaker, a visual alert device, such as a blinking light or image on the display, a haptic alert device, e.g., a vibratory mechanism. The one or more input devices may comprise a keypad, function buttons, joystick, scrolling mechanism (e.g., mouse, trackball), touch pad/screen, or other user entry mechanisms. The onboard system further comprises a communication device **218**, and a media recorder **215** (e.g., a digital video recorder). The onboard system includes a memory, which may be integral or coupled to a processor of the onboard computer **205**, can store firmware, executable software, and algorithms, and may further comprise or be coupled to a subscriber interface module (SIM), wireless interface module (WIM), smart card, or other fixed or removable memory device/media.

The electronic components further include one or more cameras **222** (in some embodiments including in-cab cameras, such as a forward-looking/traffic viewing camera), a microphone arrangement **224** (at least one microphone or microphone array is located in the cab), and one or more sensors **226**. The electronic components also include a motion sensor system **220**, which is configured to capture driver movements. According to various embodiments, the motion sensor system **220** comprises a three-dimensional motion sensor configured to generate substantially in real-time a digital mapping of the driver's movement, such as head, eye, retina, torso, arm, and hand movement. In some embodiments, the motion sensor system is configured to generate a three-dimensional skeletal outline of one or more body parts of the driver, such as the driver's head, eye, retina, torso, arm or hand. The motion sensor system **220**, cameras **222**, microphones **224**, and sensors **226** are communicatively coupled to the onboard system **202** via wired or wireless connections. It is understood that a given vehicle **250** may be equipped with some, but not necessarily all, of the data acquisition devices shown in FIG. **2** and that other data acquisition devices can be mounted to the vehicle **250** and coupled to the onboard system **202**.

The various data acquisition devices illustrated in FIG. **2** can be mounted at different locations in, on, and/or around the trailer **253** and tractor **251** of the vehicle **250**. All locations on the interior and exterior surfaces of the trailer **253** and tractor **251** are contemplated. According to various embodiments, the tractor **251** includes a cab in which the motion sensor system **220**, microphones **224**, and sensors **226** are mounted. For example, the motion sensor system **220** can be mounted on the dashboard **252** or on or adjacent the rearview mirror **254** (or elsewhere) and directed toward the driver's seat area so as to be able to capture driver movement while the driver is operating the vehicle **250**. The motion sensor system **220** is mounted in the cab so that its field of view includes one or more of the driver's head, driver's face, driver's torso, and driver's limbs (e.g., hands). In some embodiments, the driver behavior detector **108** or other component may be configured to change the field of view of the motion sensor system **220** to facilitate capturing driver movement to identify driver behaviors. In some embodiments, a camera **222** can be positioned on the dashboard **252** or rearview mirror **254** (or elsewhere) and oriented in a forward-looking direction to view traffic ahead of the vehicle **250**. A camera **222** may be mounted on the dashboard **252** or rearview mirror **254** (or elsewhere) and directed toward the passenger seat within the cab of the tractor **251**.

The tractor **251** can include one or more exterior cameras **222**, microphones **224**, and/or sensors **226** according to various embodiments, such as a camera **222** mounted on a left side **257**, a right side **255**, and/or a rear side **256** of the tractor **251**. The exterior cameras **222** can be mounted at the same or different heights relative to the top or bottom of the tractor **251**. The trailer **253** can include any number of cameras **222** positioned in or on the various surfaces of the trailer **253**. For example, a single or multiple (e.g., stereoscopic) cameras **222** can be positioned on a rear surface **262** of the trailer **253**, allowing for driver viewing in a rearward direction of the vehicle **250**. One or more cameras **222** can be positioned on a left and a right side surface **264** and **266** of the trailer **253**, allowing for driver viewing in a rearward and/or lateral direction of the vehicle **250**. One or more cameras **222** may be positioned on the front surface of the trailer **253**, such as at a lower position to facilitate viewing of the hitch area and hose/conduit connections between the trailer **253** and the tractor **251**. A camera **222** may also be situated at or near the trailer coupling location **265** or at or near other locations along the lower surface of the trailer **253**, such as near fuel hoses and other sensitive components of the trailer **253**.

Turning now to FIG. **3**, there is illustrated a system **300** for acquiring motion and audio information which is used to detect driver behavior in accordance with various embodiments. The system **300** includes a motion sensor system **220** and an audio sensor **224**, each of which is communicatively coupled to a computer **205**, such as an onboard computer provided in a cab of the vehicle. The computer **205** may be implemented as a processing device integral or separate from an onboard computer provided at the vehicle. Also coupled to the computer **205** is a driver behavior memory **320** and a user interface **207**. The driver behavior memory **320** can be configured to store one or more of a driver behavior profile, template, or model, as will be discussed in greater detail hereinbelow. The computer **205** is coupled to a communication device **218** which is configured to wirelessly communicate with a remote system **340**. In some embodiments, the system **300** further includes a forward-looking motion sensor system configured for deployment in the cab and configured to sense substantially in real-time movement of a human located in front of the vehicle while the vehicle is in park. The forward-looking motion sensor system can be configured, for example, to generate substantially in real-time a skeletal mapping of the person moving in front of the vehicle while the vehicle is in park. Such embodiments can generate an alert when a person is passing in front of the vehicle while the vehicle is in park.

Referring to FIG. **4**, there is illustrated a method of detecting driver behavior in accordance with various embodiments. The embodiment shown in FIG. **4** involves detecting **402** driver motion, and digitally mapping **404** driver movement based on the detected motion. The embodiment shown in FIG. **4** further involves detecting audio **406** during driver motion. Using the digital mapping and audio, a driver distraction event is detected **408**. In response to detecting the driver distraction event, and alert response, such as a message, is communicated **410**, such as within the vehicle cab and/or to a remote system. In some embodiments, an alert message communicated to the remote system comprises text and/or graphical data, but not camera or image data. It has been determined that driver acceptance of in-cab surveillance systems is significantly reduced where driver video or still images are captured and transmitted to a remote system for evaluation. Although embodiments of the present disclosure may use one or more cameras for detecting driver behavior and assessing vehicle operation, the camera data need not itself be transmitted to the remote system, but is instead used internally of the vehicle to evaluate driver behaviors. For example, some embodiments can be implemented to generate an alert message for transmission to a remote system that comprises an informational message devoid of photographic or video data as a requirement. In other embodiments, an alert message transmitted to the remote system can be devoid of photographic or video data but include a three-dimensional skeletal outline of the driver's face.

FIG. **5** illustrates a method of detecting driver behavior in accordance with various embodiments. The embodiment shown in FIG. **5** involves detecting **502** driver motion, digitally mapping **504** driver movement, and detecting **506** audio during driver motion. The embodiment also involves comparing **508** the digital mapping to a driver profile, template, and/or model. Audio, captured contemporaneously with the detected driver motion, is evaluated **510**. The contemporaneous audio data provides additional information which can facilitate the determination of whether or not detected driver motion (based at least in part on the comparison **508**) corresponds to acceptable or unacceptable behavior.

If the system determines that the detected driver motion corresponds to expected driver behavior **512**, the system continues to detect for driver motion **502**. In some embodiments, captured expected driver behavior can be used to update **514** the driver's personal profile, template, or model. If the system determines that the detected driver motion does not correspond to expected driver behavior **512**, the system determines that a driver distraction event has been detected **516**. In response to the detected driver distraction event, an alert response is generated, such as a message, and communicated **518** within the vehicle cab and/or to a remote system. It is noted that the system may take other remedial action, such as illuminating or sounding a visual or audible alarm/device within the cab, activating a tactile or haptic transducer that stimulates alertness by the driver, activates the driver's cell phone or PDA, and/or modifies vehicle operation (e.g., applies brakes, flashes lights, sounds horn). As a further response to detecting **516** a driver distraction event, the driver's profile, template, and/or model is updated **514**, followed by continuance of driver motion detection **502**.

FIG. **6** illustrates a method of detecting driver behavior in accordance with various embodiments. In the embodiment shown in FIG. **6**, a driver distraction event is detected **602** in a manner previously described. The driver distraction event is recorded **604** at the vehicle, such as by use of an in-cab media recording device. Various forms of data are recorded **604**, including, but not limited to, digital mapping driver movement data, audio data, image data (e.g., motion video and/or still photos) acquired by one or more cameras within the cab, image data acquired by one or more cameras mounted in or on the tractor and/or trailer of the vehicle, vehicle computer and/or network data, and one or more sensors mounted to the vehicle. The recorded distraction event data can be communicated to a remote system and, as is described hereinbelow, used within the vehicle for enhancing driver safety and awareness.

Continuing with the methodology shown in FIG. **6**, the system confirms **606** that the vehicle is in park or is in a non-moving state. The system initiates in-cab review **608** of the driver distraction event, such as presenting visual and textual information on a display within the cab and playing contemporaneous audio information through a speaker in the

cab. The in-cab review **608** can be implemented solely by the onboard system or in conjunction with a remote system. The methodology shown in FIG. **6** can optionally involve performing driver training **610** via one or both of the onboard system and a remote system. Driver training **610** may involve real-time communication and review of pertinent acquired data with a trainer at a remote system location. Alternatively, driver training **610** may be solely conducted by the onboard system, which can include review of pertinent data acquired prior to, during, and after the detected driver distraction event.

FIG. **7** illustrates a system for detecting driver behavior in accordance with various embodiments. The system **700** shown in FIG. **7** includes a driver movement sensor **701** which includes a motion sensor system **220** and a microphone arrangement **224**. The driver movement sensor **701** is coupled to a computer **205**, which can be a computer of an in-cab telematics system. Alternatively, or in addition, the driver movement sensor **701** can be coupled to a dedicated processor arrangement. The computer **205** is shown coupled to a user interface **207**, a display **715**, and a communication device **218** which facilitates wireless communication with the remote system **340**. The computer **205** is also coupled to a media recorder **215**, which can include a digital video recorder for example. Also coupled to computer **205** is a driver behavior detector **208** which interacts with a driver behavior memory **320**. The driver behavior memory **320** is configured to store one or both of a driver profile **722** (also referred to as a template) and/or a driver model **724**.

In some embodiments, the microphone arrangement **224** includes one or more independent microphones, while in other embodiments the microphone arrangement **224** includes a multi-array microphone (also referred to as a microphone array). The multi-array microphone **224** comprises a number (e.g., 4-24) of individual microphones (e.g., omnidirectional microphones) that can be supported on a common support structure or distributed around the cab of the vehicle. The multi-array microphone **224** may also be implemented with beamforming and adaptive steering technology to facilitate enhanced ambient noise rejection and/or locating of audio signal sources within the cab.

The motion sensor system **220** includes a motion sensor **702** and an RGB camera **704**. The motion sensor **702** includes an infrared emitter (e.g., infrared laser projector) **710** and an infrared sensor (e.g., receiver or detector) **712**. The RGB camera **704** is used to produce a color image of the driver's body or specified body parts. According to some embodiments, a Kinect® sensor (e.g., Kinect® for Windows®) or components of a Kinect® sensor can be used to construct the motion sensor system **200**. The Kinect® Software Development Kit (e.g., SDK 2.0) can be used to integrate a Kinect® sensor as part of an in-cab driver movement sensing system according to various embodiments.

The motion sensor **702** is configured to determine a position and changes in position of the driver's body or specified body parts (e.g., yaw, pitch, roll of a body part, such as the driver's head or face). The motion sensor **702** can include its own processor or employ that of the computer **205**. In some embodiments, the motion sensor processor and the computer **205** cooperate to detect driver movements and classify driver behavior based on the detected movements. Inferring driver body position (or body part position) is a two-stage process according to some embodiments. A first stage involves computing a depth map, and a second stage involves inferring body position based on the depth map. The motion sensor **702** is used to compute a depth map of the driver's body or body parts using structured light. For example, the motion sensor **702** can be configured to project a speckle pattern of infrared laser light onto the driver's body or body parts (e.g., face, torso, arms, hands). Deformation of the speckle pattern projected onto the driver's body is sensed and analyzed to compute depth information. Notably, neither the RGB camera **704** nor other camera that may be positioned within the cab is used for the depth computation according to various embodiments. In some embodiments, the response from the projection of structured light onto the driver is used with two known computer vision techniques, depth from focus and depth from stereo, to compute depth information.

Depth computations can be performed using available software and hardware, such as a 3D scanner and associated software provided by PrimeSense® (e.g., PrimeSense®'s Carmine and Capri sensors, and PrimeSense® NiTE Middleware). PrimeSense®'s NiTE Middleware, for example, represent suitable software that can analyze data from 3D scanner hardware, such as a PrimeSense® scanner, providing gesture and skeleton tracking. The software can identify the driver, track driver movements, and provide the framework API for implementing Natural-Interaction UI controls based on gestures. For example, the system can interpret specific driver gestures which may be considered unacceptable or dangerous behaviors, such as texting or otherwise interacting with a cell phone or other portable electronic device while driving the vehicle.

After the depth map has been computed by the processor of the driver movement sensor **701** or the computer **205**, a machine learning algorithm is implemented to infer body position and changes to body position based on the depth map. According to some embodiments, body parts and the position of body parts is inferred using a randomized decision forest, learned from use of a multitude of training examples. Representative training examples include images of known skeleton orientations that are associated with suspect or unacceptable driving behavior. For example, training examples can include images of humans holding a cell phone at a distance from the face and images of the cell phone placed against the ear while in the sitting position. Training examples can include images of a sitting human interacting with a cell phone, such as reaching for and grasping the phone, moving the phone from an extended position to a position near or on the face, tilting of the head with the phone held to the ear, and interacting with the keypad using the fingers, etc. Examples of other training images include holding and/or manipulating a tablet, book or newspaper in a person's lap or on/near the steering wheel, and holding an object with two hands rather than one. Training images can be developed for a myriad of head orientations indicative of distracted driving. Other training images can be developed for different eye (e.g., squinting or closed) and mouth positions (e.g., yawning) that are indicative of distracted driving. A library of training examples for any number of suspect or unacceptable driving behaviors can be developed for a "generic" driver and then refined for particular drivers over time through actual use of the driver movement sensor **701** during vehicle operation.

According to some embodiments, the driver behavior detector **208** is configured to cooperate directly with the driver movement sensor **701**. In other embodiments, the driver behavior detector **208** is configured to cooperate with the computer **205** which is coupled to the driver movement sensor **701**. In either configuration, the driver behavior detector **208** is coupled to a driver behavior memory **320** which stores one or both of a driver behavior profile **722** and

a driver behavior model **724**. In some embodiments, a driver behavior profile **722** is supported in the driver behavior memory **320** and comprises a number of templates that can be representative of expected or unexpected driver behavior, depending on the particular implementation. According to some implementations, for example, the driver behavior profile **722** can include a large number of templates indicative of suspect or unacceptable driver positions, which can be compared against actual driver body positions detected by the motion sensor **702**. If no template matches (e.g., within a predetermined tolerance or confidence factor) are found, then it is assumed that the actual driver behavior is acceptable. In other implementations, for example, the driver behavior profile **722** can include a large number of templates indicative of acceptable driver positions, which can be compared against actual driver body positions detected by the motion sensor **702**. If no template matches are found, then it may be assumed that the actual driver behavior is suspect or unacceptable, typically when other corroborating information (e.g., vehicle data) also suggests undesirable driver behavior is occurring.

In some embodiments, a driver behavior model **724** is developed based on acceptable and unacceptable driver behaviors (e.g., driver body positions). A model **724** of acceptable and unacceptable driver behaviors, such as driver body positions, can be developed using images of such driver body positions. The driver behavior memory **320** stores images of both acceptable and unacceptable driver body positions according to some embodiments. A computer program or algorithm is implemented to determine whether an actual driver body position captured by the motion sensor **702** is more likely associated with acceptable or unacceptable driver behavior. In this regard, the computer program or algorithm produces a binary output of either acceptable or unacceptable driver behavior based on an input driver body position or range of body positions captured by the motion sensor **702**.

According to some embodiments, a support vector machine (SVM) can be implemented to distinguish between acceptable and unacceptable driver behaviors based on input driver body position data captured by the motion sensor **702**. An SVM can be configured to learn which driver behaviors are acceptable and which are unacceptable, and this active learning by the SVM can be used to refine the driver behavior model **724** over time. In this regard, the SVM is a behavior classifier, discriminating between acceptable and unacceptable or suspect driver behavior. SVMs can use outcomes from past driver behavior determinations and other data to predict whether a current driver behavior is likely to be acceptable or unacceptable. Those skilled in the art will understand that SVMs are implemented to determine the optimal hyperplane for linearly separable patterns, and can be extended to patterns that are not linearly separable by transformations of original data to map into new space. A driver behavior model **724** can be implemented using active learning by an SVM in accordance with various and known techniques, including those disclosed in U.S. Published Application Ser. No. 2004/0034612 which is incorporated herein by reference.

FIG. **8** illustrates a system **800** that includes a driver movement sensor **801** that operates in conjunction with a driver behavior profile or model to refine the profile or model over time in accordance with various embodiments. The driver movement sensor **801** shown in FIG. **8** includes a motion sensor system **803** which comprises a motion sensor system **220** and microphone **224** (e.g., microphone array). The driver movement sensor **801** also includes a computer or processor **205** and a driver behavior detector **208**. In response to detecting driver movement by the motion sensor system **803**, the driver behavior detector **208** generates an output indicating that a driver behavior of interest has been detected **805**. The detected driver behavior is compared **807** with a driver behavior profile or model **807**, which may be either a generic profile/model or an individualized profile/model developed for a particular driver.

A determination is made as to whether the detected driver behavior is acceptable or unacceptable **810**. If acceptable, a first profile or model **820** is updated with the currently detected driver behavior, so as to refine the first profile or model **820**. For example, the first profile or model **820** includes a number of different acceptable behavior templates or models, such as AB**1**, AB**2**, . . . ABn. Each of the templates or models have an associated state, AS**1**, AS**2**, . . . ASn, indicating how many updates have been made to each template or model. For example, template or model AB**1** is in initial state, AS**1**, which can be a default or a generic state. Template or model AB**3** is in a more refined state, AS**9**, having been updated a total of nine times thus far in this illustrative example. It is noted that the first profile or model **820** of acceptable driver behavior is used in some embodiments (e.g., an SVM embodiment), while in other embodiments, the first profile or model **820** may be excluded.

If the detected driver behavior is unacceptable **810**, for example, a second profile or model **830** is updated with the currently detected driver behavior, so as to refine the second profile or model **830**. For example, the second profile or model **830** includes a number of different acceptable behavior templates or models, such as UB**1**, UB**2**, . . . UBn. Each of the templates or models have an associated state, US**1**, US**2**, . . . USn, indicating how many updates have been made to each template or model. For example, template or model UB**1** has a state of US**4**, indicating that it has been updated a total of four times thus far. Template or model UB**3** is in a more refined state, US**6**, having been updated a total of six times thus far in this illustrative example. With each iteration through the flow chart shown in FIG. **8**, the driver behavior profile or model is improved through a learning mechanism implemented by the onboard system.

FIG. **9** is a flow chart showing various processes involving use of a driver behavior profile or model in accordance with various embodiments. The processes shown in FIG. **9** involve logging in **902** to the in-cab (on-board) system, and identifying the driver **904**. The driver can be identified using several techniques, including one or a combination of taking a snapshot of the driver's face using an in-cab camera, such as the RGB camera of the onboard driver movement system, voice recognition, and user ID and password verification, among others. For example, the driver's facial image can be transmitted to the central office and used to verify the identity of the driver that is logging into the system. After identifying the driver, a check **906** is made to determine if a behavior profile or model exists for the now-identified driver.

In some cases, a behavior profile or model for a particular driver may already be available in the onboard system, in cases where the driver is operating the same vehicle or has operated the vehicle in the past. In cases were a behavior profile or model exists, the existing profile or model is accessed by the onboard system. The behavior profile or model stored in the onboard system is preferably also stored and maintained in a server at the central office. Because a particular driver may operate different vehicles, it is useful to have driver profiles/models maintained and updated at the central office. In this way, an aggregate driver profile or

model can be maintained and refined over time at the central office. As such, an existing driver profile or model stored in the onboard system of a particular vehicle can be updated as part of the driver login procedure. In other cases, a behavior profile or model for a particular driver may not exist either in the onboard system or on the server at the central office. In such cases, a generic driver profile or model is used **910**. The generic driver profile/model may already be available in the onboard system (e.g., as a default) or can be downloaded to the onboard system from the central office.

Using the pre-existing or generic driver profile or model available in the onboard system, driver distraction events (DDEs) are detected **912**. In some embodiments (e.g., an SVM embodiment), non-DDE movements are also detected **912**. The detected DDEs and, in some embodiments, the non-DDE movements, can be used to refine **914** a specific driver's behavior profile or model. It is noted that the generic driver profile or model can subsequently be redefined as the particular driver's personal driver profile model for current and future use.

FIG. **10** illustrates an embodiment of a system for detecting driver behavior using a data fusion approach in accordance with various embodiments. The system **1000** shown in FIG. **10** accepts a number of data inputs from disparate sources in order to produce a determination of driver behavior with enhanced accuracy. In the embodiment shown in FIG. **10**, a driver behavior detector **208** is coupled to a driver behavior memory **320** and receives input data from a summer **1015**. The summer **1015** is coupled to the outputs of an array of weights (W**1**-W**6**) **1020**. Each of the weights **1020** is configured to weight the output of one of the disparate data sources. In the illustrative example shown in FIG. **10**, the disparate data sources include driver movement data **1002**, occurrence data **1004** (e.g., number of times a particular driver movement or behavior is detected), in-cab data **1006**, vehicle computer data **1008**, vehicle sensor data **1010**, and environmental data **1012**. Each of the weights **1020** can be set at a value W ranging between 0 and 1.0 (e.g., 0% and 100%), for example. The values W of the weights **1020** can be initially set to a default value and refined over time based on experience by the driver behavior detector **208**.

FIG. **11** illustrates a flow chart showing various processes involving driver behavior detection within the context of an onboard event detection methodology in accordance with various embodiments. The processes shown in FIG. **11** involve detecting **1102** driver movement and (optionally) related audio, and monitoring **1104** for a driver distraction event (DDE). If a DDE is detected **1106** based on detected driver movement and related audio if used, an onboard event recorder is triggered **1108**. Triggering the event recorder can involve corroborating **1110** the occurrence of the detected DDE using vehicle and/or sensor data. In response to triggering the event recorder **1108**, data before, during, and after the distraction event is recorded and an alert is generated **1112**. The alert can be communicated to the driver and/or the remote system. Data associated with the DDE can be communicated **1114** to the remote system.

According to a related DDE monitoring embodiment, an in-cab audio sensor (e.g., microphone array) can be configured to operate in a listening mode, and the onboard computer can be configured to generate a trigger signal in response to an output of the audio sensor while operating in the listening mode. The audio sensor can be configured to detect audio signals indicative of suspect or unacceptable driver behavior, such as talking for extended periods of time indicative of cell phone usage or keystroke sounds indicative of keypad interaction. In response to the trigger signal, the motion sensor system is configured to generate substantially in real-time a digital mapping of the driver's face, and the driver behavior detector is configured to detect a DDE based on one or both of the digital mapping of the driver's face and the output of the audio sensor. According to this embodiment, the triggering input data source is the audio sensor and the corroborating input data source is the motion sensor system.

FIG. **12** is a diagram that conceptually illustrates operation of a system that includes driver behavior detection in accordance with various embodiments. The system includes a driver behavior detector **208** configured to detect occurrences of a set of driver behaviors based on detected driver movements, and optionally contemporaneous audio and other information (e.g., captured images of an area surrounding the driver and/or the vehicle, contextual information, etc.), wherein the captured driver movements can be analyzed in conjunction with the optional additional information. The driver behavior detector **208** includes an interface configured to receive driver movement data from a driver movement sensor and to receive the additional information, e.g., driver history information, driver context information, and/or vehicle information. The interface can be configured to receive information from a variety of sources over a number of different types of interface schemes and/or protocols, e.g., serial and/or parallel bus, wireless and/or wired channels, etc. The driver behavior detector **208** further includes processing circuitry configured to analyze the detected driver movements in conjunction with the additional information and to detect **1202** driver behaviors based on the analysis.

An occurrence of driver behavior may be considered an event that extends over some time period. For example, a texting event may extend over a period of seconds or minutes. The system may optionally be configured to count **1204** the number of detected driver behavior events, e.g., total number of all types of driver behavior events and/or number of events for each type of detected event detected, etc. For example, and in accordance with some embodiments, an onboard computer can be configured to compare a digital mapping of driver movement generated by an in-cab motion sensor system to an expected behavior profile developed from previously acquired digital mappings of the driver's movements. The computer can be configured to count repeated occurrences where the digital mapping of driver movement matches the expected behavior profile, compare the count to a threshold, and determine that a potential driver distraction event is an actual driver distraction event in response to the count meeting or exceeding the threshold. The system may optionally be configured to measure **1206** the time period of each detected driver behavior event.

After a driver behavior event is detected, a driver history database can be updated **1210** with information about the recently detected event. For example, the count of driver behavior events for the driver can be incremented and information about the length and/or severity of the recently detected event can be stored. Information relating to the driver context and/or vehicle information during the driver behavior event can be stored and associated with the driver behavior event.

In some implementations, information about the driver behavior event can be summarized and stored in the driver history database in a summary format. The summarized information, e.g., date, time, type, duration, severity, for each detected event can be stored in an electronic driver behavior logbook that is updated **1214** for each detected

driver behavior and is searchable by field, e.g., type of event, date, severity of event, etc. The driver behavior detector may control a media recorder configured to record video and/or store information and sensor data related to the detected driver behavior. Additional details of each occurrence of a driver behavior, including video, audio, and/or sensor information may be recorded **1216** and/or stored. In some embodiments, the logbook summary can be displayed to a user and the additional event details accessed using menus or links provided on the logbook summary screen. Information stored in the driver history and/or logbook can be used to generate **1212** reports for providing feedback to the driver and/or other users (e.g., located remotely at a central office) about detected driver behaviors.

Some driver behavior events result in dangerous conditions that require immediate feedback. For these types of events, the system may generate **1220** an alert, such as one or more of an auditory, visual, or haptic alert. In some embodiments, the system may send **1222** a communication of some type, e.g., SMS text message, email, automated telephone message, etc., to the driver and/or central office in response to detecting a driver behavior. In some embodiments, the system may change **1224** vehicle operation, for example, by slowing the vehicle, engage or disengaging cruise control, limiting the vehicle speed, initiating autopilot, e.g., guiding the vehicle by GPS and/or the vehicle cameras, disabling power to the vehicle, altering environmental controls in the cab, e.g., by one or more of changing air flow, lowering temperature, increasing radio volume and/or other modifications to the environment to make the driver less fatigued, honking the horn, and preventing the vehicle from starting and/or moving, among others.

In some embodiments, the system may initiate **1226** an interactive session with the driver. The interactive session may involve voice interaction that alerts the driver to the driver behavior and requests a voice response from the driver. In some scenarios, startling a driver with a harsh alert could be dangerous and a voice interaction, e.g., a voice telling the driver to wake up or pay attention and/or requesting a response, may be less startling to a fatigued driver. If the system does not receive the expected driver response, then another type of alert and/or a change in the vehicle operation may be initiated. In some implementations, the interactive session may continue until the driver stops the vehicle and/or takes one or more additional actions, e.g., breathalyzer, waiting period, sleep, contacting the central office, participating in a training, e.g., displayed over an in-cab display, stowing an electronic device, etc., before the system allows the vehicle to start or move. Additional information related to in-cab training is disclosed in U.S. Provisional Patent Application Ser. No. 62/038,725, filed Aug. 18, 2014, which is incorporated herein by reference.

FIG. **13** is a flow diagram illustrating a method of identifying driver behaviors in accordance with various embodiments. Detected driver movements are continuously or periodically analyzed **1310** for evidence of one or more driver behavior events of interest. Evidence of a driver behavior event of interest in driver motion data or images can include, for example, driver movements that show an electronic device in view of, or being held by, the driver and driver positions and/or movements involving interaction with the electronic device. The driver movements may be head movements, e.g., head rotation downward or toward an electronic device, facial movements, gaze direction, e.g., eyes looking away from the road and/or toward the electronic device, torso movements and/or limb/hand movements, e.g., movements associated with gaming or texting.

If a potential driver behavior of interest is detected **1320**, based on the analysis of the detected driver movements and optionally contemporaneous audio, a probability representative of confidence in the likelihood that the potential driver behavior is an actual driver behavior of interest is determined **1330**. The system continues **1340** to analyze the captured driver movements and/or collects and analyzes subsequently acquired driver movements and continues to update the probability. The probability of the occurrence of the driver behavior event is compared **1350** to a threshold probability. The probability threshold can be determined and/or adapted **1360** based on one or more of driver history, vehicle information, driver context and/or previously detected and similar driver behavior. The system may confirm driver identity prior to accessing the driver history, e.g., by facial recognition based on the images captured by the RGB camera of the driver movement system or other camera in the cab if available.

In some embodiments, the vehicle information may influence the probability threshold. In some implementations, vehicle information can be obtained from one or more detection devices that are attached to the vehicle, such as one or more of a camera oriented to detect proximity of the vehicle to an object behind the vehicle, a camera oriented to detect proximity of the vehicle to an object beside the vehicle, a camera oriented to detect proximity of the vehicle to an object in front of the vehicle, a lane departure detector, a roll stability detector, swerve detector, and an acceleration/deceleration detector, and the like. In some implementations, the vehicle information can be obtained from the vehicle computer and may include one or more of braking information, gear shifting information, vehicle RPM, vehicle speed and/or other information obtained from the vehicle computer.

For example, if the vehicle information indicates accelerations and decelerations of the vehicle within a relatively short period of time, the probability threshold for a driver behavior may be decreased. In some embodiments, the context information may influence the probability threshold. For example, if the vehicle information indicates accelerations and decelerations of the vehicle within a relatively short period of time and the context information indicates that the vehicle is in an area of stop and go traffic, the probability threshold may not be decreased (e.g., may be increased). In contrast, if the vehicle is in a low traffic area, the probability threshold can be decreased. In some embodiments, if the recent operation of the vehicle does not substantially match the driver profile stored as part of the driver history, the probability threshold may be decreased.

If the probability of the driver behavior event is greater **1370** than the probability threshold, then a driver behavior (e.g., driver distraction event) is detected **1375**. The driver history is updated to include information about the detected driver behavior. As previously discussed, the system may take action **1380** to mitigate the driver behavior, e.g. generate an alert, send a message, change vehicle operation, etc.

Table 1 below provides an example of some possible driver behaviors of interest arranged horizontally and movements/positions arranged vertically, with Xs in Table 1 indicating the relevant movements that indicate a particular behavior.

TABLE 1

	DRIVER BEHAVIORS					
		Interacting with device				
MOVEMENTS/ POSITIONS	Fatigue	Texting, gaming, emailing, web surfing	Watching videos	Non-hands free telephoning	Reading	Eating
Yawning	X					
Blink rate	X					
Eyes closed	X					
Lateral head rotation		X	X		X	
Vertical head rotation	X	X	X		X	
Hand movements		X				X
Hand position				X		
Eye position		X	X		X	X
Eye movements		X	X		X	X
Presence and location of device		X	X	X	X	

Detection of one or more of the movements/positions associated with a driver behavior of interest may not necessarily mean that the driver is engaging in that behavior. For example, the driver behavior detector may detect excessive blinking, e.g., blink rate greater than a threshold, without necessarily identifying fatigue. The driver behavior detector may be configured so that a driver behavior is identified based on a combination of several different types of movements that occur over a period of time. In contrast, some driver behaviors may be detected by a single movement, e.g., eyes closed continuously for a relatively short time can indicate that the driver has fallen asleep.

Various techniques for analyzing human activity from images have been studied and implemented, as referenced, for example, in *Human Activity Analysis, a Review*, Aggarwal, J. K., and Ryoo, M. S, ACM Computing Surveys, Vol. 43, No. 3, Article 16, and *Machine Recognition of Human Activities: A Survey*, Turaga, Paven et. al, IEEE Transactions on Circuits and Systems for Video Technology, Vol. 18, No. 11. Such techniques are useful for modeling and identifying both fatigue-related and active (non-fatigue related) driver behaviors. Techniques for identifying fatigue-related driver behaviors are described in U.S. Pat. No. 6,927,694 which is incorporated herein by reference in its entirety.

FIG. **14** is a flow diagram illustrating a process of detecting and responding to fatigue/sleep-related driver behaviors using a data fusion approach in accordance with various embodiments. Driver facial movements are captured **1410** by the driver movement sensor and analyzed **1420** for eyelid positions and movements. If eyelids remain closed **1430** for period of time greater than a threshold period, this is an indication that the driver is falling asleep **1435** and an alert **1440** is generated and/or other appropriate action is taken. Otherwise, if eyelids do not remain closed longer than the threshold period, the system checks for movements and/or positions related to fatigue, including blinking **1451**, yawning **1452**, and head movements/nodding **1453**. Optionally, each of the movements/positions is associated with a weighting coefficient indicating the influence of the movement/position in making the driver behavior determination. Optionally, each of the movements/positions is associated with a confidence coefficient indicating a confidence that the movement/position was correctly detected.

In the representative example shown in FIG. **14**, if blinking is detected **1461** at a rate greater than a threshold blink rate, then the blinking indicator is set to 1 and the weighting coefficient for blinking is applied. If yawning is detected **1462** at a rate greater than a threshold rate, then the yawning indicator is set to 1 and the weighting coefficient for yawning is applied. If head position/nodding is detected **1463** at a value greater than a threshold rate, then the head position/nodding indicator is set to 1 and the weighting coefficient is applied. The movement/position indicators may optionally be modified by a confidence coefficient that quantifies the confidence of correct detection of a particular movement/position. The movement/position indicators modified by their respective weighting factors and/or confidence coefficients are combined **1470** and are compared to an overall threshold value. If the combination of the movement indicators is greater than the overall threshold value, then the driver fatigue is indicated **1485** and appropriate action is taken **1440**.

For example the combination of the movement/position data may be mathematically expressed:

$$f(x,y,z)=W_1C_1x+W_2C_2y+W_3C_3z,$$

where x, y, and z are variable indicators that represent blinking, yawning, and nodding, respectively, and can have values of 0 or 1, wherein 1 indicates that the movement is detected, and 0 indicates that the movement/position is not detected, W_1, W_2, W_3 are weighting factors associated the importance of the movement/position, and C_1, C_2, C_3 are confidence coefficients quantifying a confidence that the movement/position is present.

FIG. **15** is a flow diagram illustrating a method for identifying active driver behavior involving the use of a device, e.g., cell phone, tablet, computer, book, ebook and the like. Driver movements of the head, arms, and hands are captured **1510** by the driver movement sensor and analyzed **1520** for the presence of a device. The device may be recognized from the captured driver movements by template or model matching techniques, for example. A suitable approach for device recognition may be to search RGB camera images for straight edges of the device, and/or to determine pixel brightness that would indicate a display. The approach for determining the presence of a device may be different for dark conditions vs. daylight conditions.

In the illustrated example, if a device is detected **1530**, the system optionally determines if the device position is consistent with **1532** non-hands free cell phone use. For example, the system may determine the position of the device in relation to the driver's head and/or may determine the position of the driver's hand relative to the device and head. For example, non-hands free cell phone use may be indicated **1534** if the device is within a predetermined distance from the driver's head, if the driver's hand is proximate to the device, and/or if the driver is talking, which can sensed by the in-cab microphone.

If the device position is not consistent with cell phone use, the system checks for **1540** one or more of head rotation, eye position, eye movements and/or gaze direction. If the head rotation, eye position, eye movements and/or gaze direction are inconsistent **1550** with device use, then the system determines **1552** that a device is present in the cab, however, the driver is not using the device. Determining if the driver is using a device based on head rotation, eye position, eye movements and/or gaze direction may be implemented, for example, using template or model comparison techniques or

a data fusion technique with weighting factors and/or confidence coefficients as previously discussed.

If device use is indicated **1550**, the system determines if hand movements consistent with some device usages are present **1560**. If so, the driver is likely texting, gaming, or interacting **1570** with the device in a way that involves hand motions. The system may confirm **1575** behaviors such as gaming by determining if sounds indicating electronic gaming are detected.

If hand movements are not detected **1560**, and device use is indicated **1550** by head or eye/retina movements/positions, etc., then the driver is likely to be watching videos or reading **1580**. Behaviors that involve sound, such as video watching, may be confirmed **1590** based on audio data.

FIG. **16** is a block diagram of a system **1600** for acquiring and processing driver movement information which may be used for driver behavior identification in accordance with various embodiments. According to the representative embodiment shown in FIG. **16**, the system **1600** includes an onboard system **202** which is provided at the vehicle. As previously discussed, among various components, the onboard system **202** includes an onboard computer **205**, an in-cab display **715**, and a driver behavior detector **208**. The onboard system **202** is communicatively coupled to a motion sensor system **220** of a type previously described hereinabove. The onboard system **202** is also communicatively coupled to a vehicle computer **210**, and to a central office **240** via one or more communication links, such as a wireless link **230** via a communication device **218**. The communication device **218** can be configured to facilitate over-the-air (OTA) programming and interrogation of the onboard system **202** by the central office **240** via the wireless link **230** and/or other links.

Connectivity between the onboard system **202** and the central office **240** may involve a number of different communication links, including cellular, satellite, Wi-Fi®, and land-based communication links. The central office **240** provides for connectivity between mobile devices **250** and/or fixed (e.g., desktop) devices **255** and one or more servers of the central office **240**. The central office **240** can be an aggregation of communication and data servers, real-time cache servers, historical servers, etc. In one embodiment, the central office **240** includes a computing system that represents at least the communication/data servers and associated computing power needed to collect, aggregate, process and/or present the data, including driver movement data and optionally video data associated with vehicle or driver behavior events. The computing system of the central office **240** may be a single system or a distributed system, and may include media drives, such as hard and solid-state drives, CD-ROM drives, DVD drives, and other media capable of reading and/or storing information.

In some embodiments, the onboard system **202** incorporates a media recorder **215**, such as a digital media recorder (DMR), a digital video recorder (DVR), or other multimedia storage device. In other embodiments, the onboard system **202** is communicatively coupled to a separate media recorder **215** via an appropriate communication interface. The media recorder **215** can include one or more memories of the same or different technology. For example, the media recorder **215** can include one or a combination of solid-state (e.g., flash), hard disk drive, optical, and hybrid memory (combination of solid-state and disk memories). Memory of the media recorder **215** can be non-volatile memory (e.g., flash, magnetic, optical, NRAM, MRAM, RRAM or ReRAM, FRAM, EEPROM) or a combination of non-volatile and volatile (e.g., DRAM or SRAM) memory. Because the media recorder **215** is designed for use in a vehicle, the memory of the media recorder **215** is limited. As such, various known memory management techniques, such as that described below, can be employed to capture and preserve meaningful event-based data, including driver movement data.

The media recorder **215** is configured to receive and store at least driver movement data, and preferably other forms of media including video, still photographic, audio, and data from one or more sensors, among other forms of information. In addition, data produced by one or more image capture devices **212** (still or video cameras), one or more audio capture devices **214** (microphones or other acoustic transducers), and one or more sensors **216** (e.g., radar, infrared sensor, RF sensor or ultrasound sensor) can be communicated to the onboard system **202** and stored in the media recorder **215** and/or memory **211**.

In addition to storing various forms of media data, the media recorder **215** can be configured to cooperate with the onboard computer **205** and/or the driver behavior detector **208** to process the various forms of data useful for identifying driver behaviors. The various forms of data stored on the media recorder **215** (and/or memory **211**) can include driver movement data, video, still photography, audio, sensor data, and various forms of vehicle data acquired from the vehicle computer **210**. In some implementations, the onboard computer **205** or other processor cooperates with the media recorder **215** to package disparate forms of event-related data for transmission to the central office **240** via the wireless link **230**. The disparate forms of data may be packaged using a variety of techniques, including techniques involving one or more of encoding, formatting, compressing, interleaving, and integrating the data in a common or separate file structures.

According to some embodiments, the memory of the media recorder or other memory **211** (optional) of the onboard system **202** is configured to manage media and other data using a loop memory or circular buffer management approach, whereby data can be acquired in real-time and overwritten with subsequently captured data. In response to a predetermined event (e.g., triggered by driver movement data or vehicle/sensor data), the data associated with the event (data stored prior to, during, and after a detected event) can be transferred from a circular buffer **213** to archive memory **219** within a memory **211** of the onboard system **202**. The archive memory **219** is preferably sufficiently large to store data for a large number of events, and is preferably non-volatile, long-term memory. The circular buffer **213** and archive memory **219** can be of the same or different technology. Archived data can be transmitted from the archive memory **219** to the central office **240** using different transfer strategies. For example, one approach can be based on lowest expected transmission cost, whereby transmission of archived data is delayed until such time as a reduced cost of data transmission can be realized, which can be based on one or more of location, time of day, carrier, required quality of service, and other factors. Another approach can be based on whether real-time (or near real-time) access to the onboard event data has been requested by the driver, the central office **240** or a client of the central office **240**, in which case archive memory data is transmitted to the central office **240** as soon as possible, such as by using a data streaming technique.

A database **310** is communicatively accessible by the driver behavior detector **208** and stores driver history information which may be obtained from various external databases and/or data sources, e.g., central office personnel

records, law enforcement databases, the vehicle computer **210**, and/or the onboard computer **205**, etc., and organized in the database as a driver history. For example, the driver history information may include, but is not limited to years of experience of the driver, certifications and/or education of the driver, type of experience (e.g., what types of vehicles the driver has experience driving), history and details of traffic accidents, driver profile, items from an employment personnel record, medical history, prescribed pharmaceuticals, history of speeding and/or other traffic violations, number and/or length of previously identified occurrences of various driver behaviors.

FIG. **17** is a block diagram of a system **1700** for acquiring and processing driver movement information which may be used for driver behavior identification in accordance with various embodiments. In the representative embodiment shown in FIG. **17**, the system **1700** includes an onboard system **202** communicatively coupled to a vehicle computer **210** via an interface **217** and to a central office **240** via a wireless link **230** (and possibly other links). The central office **240** is coupled to the onboard system **202** via a cellular link, satellite link and/or a land-based link, and can be communicatively coupled to various mobile entities **250** and fixed devices **255**. The onboard system **202** includes an in-cab display **715**, an onboard computer **205**, driver behavior detector **208** (which in some embodiments may comprise the processor of the onboard computer **205** running driver behavior detection software), vehicle event detector **211**, and a communications device **218**. The onboard system **202** incorporates a media recorder **215** or, alternatively or in addition, is coupled to a separate media recorder **215** or memory system via an appropriate communication interface. In some embodiments, information acquired by the vehicle event detector **211** is obtained from the vehicle computer **210** via the interface **217**, while in other embodiments the onboard system **202** is coupled to the vehicle data bus **225** or to both the vehicle computer **210** and data bus **225**, from which the needed information is acquired for the vehicle event detector **211**. In further embodiments, the vehicle event detector **211** operates on data received from the central office **240**, such as information stored in a transportation management system supported at or coupled to the central office **240**.

According to the embodiment shown in FIG. **17**, a variety of vehicle sensors **226**, **260** are coupled to one or both of the onboard system **202** and/or the vehicle computer **210**, such as via the vehicle data bus **225**. A representative, non-exhaustive listing of useful vehicle sensors **226**, **260** include a lane departure sensor **260***a* (e.g., a lane departure warning and forward collision warning system), a following distance sensor **260***b* (e.g., a collision avoidance system), and a roll stability sensor **260***c* (e.g., an electronic stability control system). Representative lane departure warning and forward collision warning systems include Mobileye—5 Series, Takata—SAFETRAK, and Bendix—SAFETYDIRECT. Representative electronic stability control systems include Bendix—(ESP) Electronic Stability Program, and Meritor—(RSC) Roll Stability Control. Representative collision avoidance systems include Bendix—WINGMAN and Merito—ONGUARD. Each of these sensors **260***a*, **260***b*, **260***c* or sensor systems is shown respectively coupled to the vehicle computer **210** and/or the vehicle data bus **225**. In some embodiments, one or more of the vehicle sensors **226**, **260** can be directly coupled to the onboard system **202**.

According to various embodiments, the event detector **211** includes a trip recorder that may be implemented as a software program executable by the onboard computer **205**. In some embodiments, the trip recorder collects various types of vehicle and/or sensor data, and compares the collected data with various thresholds to determine if a vehicle event has occurred. In some embodiments, the trip recorder may detect a driving event (triggered by vehicle and/or sensor data) and the driver movement system (driver movements) may be used to corroborate the driving event indicated by the trip recorder. For example, the trip recorder can collect one or more of vehicle data from the vehicle computer **210**, sensor data from one or more vehicle sensors **226**, **260** image and audio data from one or more image and audio capture devices **222**, **224**, and data acquired from a transport management system via the central office **240**. The vehicle event detector **211** analyzes the data acquired by the trip recorder for possible violation of one or more predetermined event parameter violations. Before declaring an actual violation of one or more predetermined driving event parameter violations, the vehicle event detector **211** interrogates the driver movement system to determine if captured driver movement data is consistent or inconsistent with the possible violation of a predetermined driving event parameter. In other embodiments, the driver movement system may detect a driving event (triggered by driver movements indicating a distracted driver event) and the trip recorder may be used to corroborate the driving event indicated by the driver movement system.

The vehicle data collected by the trip recorder can include sudden acceleration, sudden deceleration, vehicle fault codes (safety related codes, codes indicative of onerous repair costs), shifting behavior data (engine RPM versus speed for evaluating shifting behavior), and electronic driver log data. Other vehicle can be collected by the trip recorder, including vehicle electronic control module (ECM) data (e.g., ECM emissions, fuel, air, speed, fluid pressures, and temperatures) and vehicle fault codes. The sensor data collected by the trip recorder can include roll stability, lane departure, following distance, tire pressure and tire pressure exception data, refrigeration system (e.g., fuel, temperature), trailer information system, seatbelt usage, ambient temperature, GPS, heading, and date/time. Video and still image data from one or more image capture devices **222** and audio data from one or more audio capture devices **224** can be collected by the trip recorder. Various types of TMS data can be collected by the trip recorder (or other device in the vehicle), including driver ID and certification data, driver HOS status and CSA scoring data, cargo or load information (e.g., hazmat data, value, weight, volume, special handling requirements), route and mapping information (e.g., bridge clearance, hazmat restrictions, road conditions), fuel stop scheduling, and vehicle maintenance and equipment information.

Thresholds for each of these representative event parameters can be established and/or modified by an authorized user of the onboard system **202**, such as a fleet owner, during system installation and/or during operation by way of the central office **240**. Thresholds for driver movements considered suspect/inappropriate and, in some embodiments, those considered to be appropriate/acceptable, can be established and/or modified by an authorized user of the onboard system **202**, such as a fleet owner, during system installation and/or during operation by way of the central office **240**. The vehicle event detector **211** can be configured to analyze the various vehicle computer data, sensor data, image and audio data, TMS data, driver movement data, and other data to determine if a threshold associated with any of the predetermined established vehicle event parameters or driver movement parameters has been exceeded. If so, the vehicle

event detector **211** declares an event violation and, in response, vehicle alert data is transmitted from the onboard system **202** to one or both of an output device in the cab (e.g., display, lights, speaker, vibratory element) and the central office **240** via the communications device **218**. The vehicle alert data can include a variety of data surrounding the vehicle event, for example, a predetermined amount of data prior to and after the declared vehicle event can be collected and transmitted as vehicle alert data to the central office **240**.

Some embodiments described herein involve the use of images to enhance various aspects of cargo transport. The images may comprise still or video images captured using cameras located in various positions in, on, and/or around a vehicle. The use of one or more of types of images to enhance vehicle operation, driver behavior, and/or to inform management of cargo and cargo vehicles is referred to herein as "image intelligence." Embodiments discussed hereinbelow involve the use of captured images to identify various types of driver behaviors including fatigue-related behaviors and active behaviors including those active behaviors that include interaction by the driver with a device, such as an electronic device, e.g., cellphone, tablet, laptop computer, ebook reader, or a non-electronic device, such as a book, magazine, or newspaper.

FIG. **18** is a conceptual diagram of an approach for identifying driver behaviors based on captured images. In some embodiments, images of a driver are captured **1891** using one or more video and/or still cameras that may be positioned in the cab of a vehicle or in other locations. In some implementations, at least some of the cameras are positioned to capture images of the interior of the cab, images of areas within view of the driver, images of the driver's head and face, the driver's torso, and/or the driver's limbs and hands. In some embodiments, the images are analyzed **1892** in conjunction with additional information that may include, but is not limited to, driver context **1881**, driver history **1882**, and/or vehicle information **1883**, examples of which are provided hereinabove. The additional information may be acquired from a remote system, such as one that supports or is communicatively coupled to a transportation management system (TMS), or a multiplicity of remote systems or sources.

The captured images are analyzed in conjunction with the additional information to identify **1893** one or more driver behaviors. The captured images are analyzed and driver behavior identified by a driver behavior detector. As was discussed previously, the driver behavior detector may comprise hardware running software and/or firmware configured to implement driver behavior detection. In some embodiments, the driver behavior detector may be implemented as part of an onboard computer of a vehicle, in some embodiments the captured images and/or a least some of the additional information is transmitted from the vehicle to an external computer, e.g., the central office processor or TMS processor, which analyzes the captured images in conjunction with the additional data to identify driver behaviors. In some embodiments, some portions of driver behavior detection, such as images processing and/or pattern recognition, may be implemented by the vehicle's onboard system and some portions of the driver behavior detector such as analysis of the processed image data in conjunction with additional data, may be implemented by an external processor.

FIG. **19** is a block diagram of an apparatus **1900** for implementing image intelligence to determine driver behavior in accordance with various embodiments. The apparatus **1900** may be deployed on a vehicle **250** comprising a tractor **251** and a trailer **253** on which various electronic components are respectively mounted. The electronic components include an onboard system **202** which is preferably mounted in the tractor **251** of the vehicle **250**. The onboard system **202** is shown to include an onboard computer **205** (a microprocessor, controller, reduced instruction set computer (RISC), or other central processing module), a user interface **207**, and optionally includes a driver behavior detector **208**. The user interface **207** includes one or more output devices and/or one or more input devices configured for interaction with an operator, examples of which are described hereinabove. The onboard system further comprises a communication device **218**, and a media recorder **215**. The onboard system includes a memory, which may be integral or coupled to a processor of the onboard computer **205**, can store firmware, executable software, and algorithms, and may further comprise or be coupled to a subscriber interface module (SIM), wireless interface module (WIM), smart card, or other fixed or removable memory device/media.

The electronic components further include one or more cameras **222** (in some embodiments including in-cab cameras **222***a*), one or more microphones **224** (at least one may be located in the cab), and one or more sensors **226**. The cameras **222**, microphones **224**, and sensors **226** are communicatively coupled to the onboard system **202** via wired or wireless connections. It is understood that a given vehicle **250** may be equipped with some, but not necessarily all, of the data acquisition devices shown in FIG. **19** and that other data acquisition devices can be mounted to the vehicle **250**.

The various data acquisition devices illustrated in FIG. **19** can be mounted at different locations in, on, and/or around the trailer **253** and tractor **251** of the vehicle **250**. All locations on the interior and exterior surfaces of the trailer **253** and tractor **251** are contemplated. In some embodiments, the tractor **251** includes a cab in which one or more in-cab cameras **222***a* and optionally microphones **224** and sensors **226** are mounted. For example, one or more first in-cab cameras **222***a* can be mounted on the dashboard **252** or rearview mirror **254** (or elsewhere) and directed outwardly in a forward-looking direction to monitor the roadway ahead of the tractor **251**. One or more second in-cab cameras **222***a* can be mounted on the dashboard **252** or rearview mirror **254** (or elsewhere) and directed toward the driver and/or passenger within the cab of the tractor **251**. In some implementations, the second in-cab camera **222***a* can be directed toward the driver, while a third in-cab camera **222***a* can be directed toward the passenger portion of the cab of the tractor **251**. At least some of the in-cab cameras **222***a* may be mounted so that their field of view includes one or more of the driver's head, driver's face, driver's torso, driver's limbs. In some embodiments, the driver behavior detector **208** or other component may be configured to change the field of view and/or focus of at least the in-cab cameras **222***a* to facilitate capturing images to identify driver behaviors.

The tractor **251** can include one or more exterior cameras **222**, microphones **224**, and/or sensors **226** according to various embodiments, such as a camera **222** mounted on a left side **257**, a right side **255**, and/or a rear side **256** of the tractor **251**. The exterior cameras **222** can be mounted at the same or different heights relative to the top or bottom of the tractor **251**. Moreover, more than one camera **222** can be mounted on the left side **257**, right side **255** or rear side **256** of the tractor **251**. For example, single or multiple (e.g., stereoscopic) left and right side cameras **222** can be mounted rearward of the left and/or right doors of the tractor **251** or,

alternatively, the near or on the left and/or right side mirror assemblies of the tractor **251**. A first rear camera **222** can be mounted high on the rear side **256** of the tractor **251**, while a lower rear camera **222** can be mounted at or near the hitch area of the tractor **251**.

The trailer **253** can include any number of cameras **222** positioned in or on the various surfaces of the trailer **253**. For example, a single or multiple (e.g., stereoscopic) cameras **222** can be positioned on a rear surface **262** of the trailer **253**, allowing for driver viewing in a rearward direction of the vehicle **250**. One or more cameras **222** can be positioned on a left and a right side surface **264** and **266** of the trailer **253**, allowing for driver viewing in a rearward and/or lateral direction of the vehicle **250**. One or more cameras **222** may be positioned on the front surface of the trailer **253**, such as at a lower position to facilitate viewing of the hitch area and hose/conduit connections between the trailer **253** and the tractor **251**. A camera **222** may also be situated at or near the trailer coupling location **265** or at or near other locations along the lower surface of the trailer **253**, such as near fuel hoses and other sensitive components of the trailer **253**.

FIG. **20** is a block diagram of a system **2000** for acquiring and processing video information which may be used for driver behavior identification in accordance with various embodiments. The system **2000** shown in FIG. **20** is similar to that illustrated in FIG. **16**, the notable exception being the lack of a motion sensor **220** in the embodiment of FIG. **20**. It can be assumed that the system **2000** shown in FIG. **20** operates similarly to system **1600** of FIG. **16**, and processes image data rather than motion sensor data.

FIG. **21** is a block diagram of a system **2100** for acquiring and processing image information and identifying driver behavior in accordance with various embodiments. The system **2100** shown in FIG. **21** is similar to that illustrated in FIG. **17**, the notable exception being the lack of a motion sensor **220** in the embodiment of FIG. **21** and the addition of a driver history database **310**. It can be assumed that the system **2100** shown in FIG. **21** operates similarly to system **1700** of FIG. **17**, and processes image data rather than motion sensor data.

FIG. **22** is a diagram that conceptually illustrates operation of system that includes driver behavior detection in accordance with various embodiments. The system includes a driver behavior detector **2210** configured to detect occurrences of a set of driver behaviors based on captured images of the driver and optionally captured images of an area surrounding the driver, wherein the captured images are analyzed in conjunction with additional information. The diagram shown in FIG. **22** is similar to that illustrated in FIG. **12**, the notable exception being the capturing of driver images in FIG. **22** rather than driver movements as is shown in FIG. **12**. It can be assumed that the processes shown in FIG. **22** are similar to those described in the context of FIG. **12**, except that image data is processed rather than motion sensor data.

FIG. **23** is a flow diagram illustrating a method of identifying driver behaviors in accordance with various embodiments. Captured images and/or image sequences are continuously or periodically analyzed **2310** for evidence of one or more driver behavior events of interest. Evidence of a driver behavior event of interest in images can include, for example, images and/or images sequences that show an electronic device in view of the driver, driver positions and/or movements associated with the driver behaviors of interest. The driver movements may be head movements, e.g., head rotation downward or toward an electronic device, facial movements, gaze direction, e.g., eyes looking away from the road and/or toward the electronic device, torso movements and/or limb/hand movements, e.g., movements associated with gaming or texting.

The processes shown in FIG. **23** are similar to those illustrated in FIG. **13**, with the exception that image data, rather than motion sensor data, is processed in FIG. **23** (see, e.g., processes **2310** and **2340**). It can be assumed that the processes shown in FIG. **23** are similar to those described in the context of FIG. **13**, except that image data is processed rather than motion sensor data. Driver behaviors may be identified using analysis of images from one or more video cameras according to FIG. **23** to detect certain movements and/or positions of the driver and to detect the presence of an object, e.g., a computer, cell phone, gaming device, book, magazine, ebook reader, etc.

Approaches for detecting driver behaviors can be categorized into non-parametric approaches, volumetric approaches, and parametric approaches. Non-parametric detection extracts features from each frame of a video and attempts to match the trajectory of the extracted features over time to a template representative of a particular driver behavior. For example, the features extracted may comprise joints (wrist joints, finger joints) or facial features (lip corners, eye lid edges, eye pupils). If the trajectory of the feature points is sufficiently correlated to the template, the driver behavior detector indicates that a movement associated with a particular driver behavior has been detected.

A video is a sequence of two dimensional XY images over time. Space-time volumes for driver behavior detection can comprise three dimensional XYT volumes formed by concatenating the two dimensional XY video images along the time axis, T. Volumetric approaches to driver behavior detection compare the space-time volumes of video images to template, e.g., without extracting features.

Parametric approaches to driver behavior detection use a model, e.g., a statistical state-based model, such as a hidden Markov model and/or dynamic Bayesian network, for a particular behavior. The probability of the model generating an observed sequence of feature vectors can be calculated to detect driver behaviors.

FIG. **24** is a flow diagram illustrating a process of detecting and responding to fatigue/sleep-related driver behaviors using a data fusion approach based on captured images from one or more cameras in the cab. The processes shown in FIG. **24** are similar to those illustrated in FIG. **14**, with the exception that image data (e.g., process **2410**), rather than motion sensor data, is processed in FIG. **24**. It can be assumed that the processes shown in FIG. **24** are similar to those described in the context of FIG. **14**, except that image data is processed rather than motion sensor data.

FIG. **25** is a flow diagram illustrating a method for identifying active driver behavior involving the use of a device, e.g., cell phone, tablet, computer, book, ebook and the like. Images are captured **2510** by one or more video cameras and are analyzed **2520** for the presence of a device. The device may be recognized from the captured video images by template matching, for example. A suitable approach for device recognition may be to search the video images for straight edges of the device, and/or to determine pixel brightness that would indicate a display. The approach for determining the presence of a device may be different for dark conditions vs. daylight conditions. The processes shown in FIG. **25** are similar to those illustrated in FIG. **15**, with the exception that image data, rather than motion sensor data, is processed in FIG. **25**. It can be assumed that the processes shown in FIG. **25** are similar to those described in

the context of FIG. **15**, except that image data is processed rather than motion sensor data.

Hardware, firmware, software or a combination thereof may be used to perform the functions and operations described herein. Using the foregoing specification, some embodiments of the disclosure may be implemented as a machine, process, or article of manufacture by using standard programming and/or engineering techniques to produce programming software, firmware, hardware or any combination thereof. Any resulting program(s), having computer-readable program code, may be embodied within one or more computer-usable media such as memory devices or transmitting devices, thereby making a computer program product, computer-readable medium, or other article of manufacture according to the invention. As such, the terms "computer-readable medium," "computer program product," or other analogous language are intended to encompass a computer program existing permanently, temporarily, or transitorily on any computer-usable medium such as on any memory device or in any transmitting device. From the description provided herein, those skilled in the art are readily able to combine software created as described with appropriate general purpose or special purpose computer hardware to create a computing system and/or computing subcomponents embodying various implementations of the disclosure, and to create a computing system(s) and/or computing subcomponents for carrying out the method embodiments of the disclosure.

It is to be understood that even though numerous characteristics of various embodiments have been set forth in the foregoing description, together with details of the structure and function of various embodiments, this detailed description is illustrative only, and changes may be made in detail, especially in matters of structure and arrangements of parts illustrated by the various embodiments to the full extent indicated by the broad general meaning of the terms in which the appended claims are expressed

What is claimed is:

1. A system, comprising:

a motion sensor system configured for deployment in a cab of a vehicle operated by a driver and to generate substantially in real-time a digital mapping of driver movement using structured light during operation of the vehicle, the motion sensor system configured to compute a depth map of a portion of the driver's body using the structured light;

an audio sensor configured for deployment in the cab and configured to generate an audio signal responsive to driver movement during operation of the vehicle, the audio sensor configured to operate in a listening mode;

a computer configured for deployment in the cab and coupled to the motion sensor system and the audio sensor, the computer configured to generate a trigger signal in response to an output of the audio sensor while operating in the listening mode;

a driver behavior detector coupled to the computer and configured to detect a driver distraction event using the driver movement mapping and the audio signal; and

a communication device at the vehicle and configured to communicate an alert message to one or both of a user interface device in the cab and a remote system in response to the detected driver distraction event;

wherein the motion sensor system is configured to generate substantially in real-time the digital mapping of the driver's face in response to the trigger signal.

2. The system of claim **1**, wherein the motion sensor system comprises a three-dimensional motion sensor configured to generate substantially in real-time the digital mapping of the driver's movement.

3. The system of claim **1**, wherein the motion sensor system comprises:

an infrared projector or emitter;

an infrared sensor; and

a camera.

4. The system of claim **3**, wherein the camera comprises an RGB color camera.

5. The system of claim **1**, wherein the audio sensor comprises a multi-array microphone.

6. The system of claim **1**, wherein the computer is configured to:

detect a potential driver distraction event using the digital mapping; and

determine that the potential driver distraction event is an actual driver distraction event using the audio signal.

7. The system of claim **6**, wherein the computer is configured to determine a contextual characteristic of the audio signal, and determine if the contextual characteristic is consistent with distracted driver activity.

8. The system of claim **1**, wherein the motion sensor system is configured to generate a three-dimensional contour or skeletal outline of the driver's face.

9. The system of claim **1**, wherein:

the motion sensor system is configured to detect changes of a retina of the driver; and

the computer is configured to detect the driver distraction event using detected changes of the driver's retina.

10. The system of claim **1**, wherein the alert message communicated to the remote system comprises an informational message devoid of photographic or video data.

11. The system of claim **1**, wherein the alert message communicated to the remote system comprises an informational message and at least some facial mapping data.

12. The system of claim **1**, further comprising an event detector configured to detect vehicle events based on one or both of vehicle computer or bus data and one or more sensors mounted at the vehicle, wherein:

the computer is configured to detect the driver distraction event using the facial mapping, the audio signal, and an output produced by the event detector.

13. The system of claim **1**, further comprising a forward-looking motion sensor system configured for deployment in the cab and configured to sense substantially in real-time movement of a person located in front of the vehicle while the vehicle is in park.

14. The system of claim **1**, wherein:

output from at least the motion sensor system is stored in a memory deployed at the cab; and

the computer is configured to develop a profile or model for a specific driver of the vehicle using at least the stored motion sensor system output.

15. The system of claim **14**, wherein the computer is configured to refine the profile or model for the specific driver in response to acquisition of data subsequently generated by one or both of the motion sensor system and the driver behavior detector.

16. The system of claim **1**, wherein the computer is configured to:

access, from an in-cab memory, an expected behavior profile or model developed from previously acquired digital mappings of the driver's movements; and

compare the digital mapping of driver movement to the expected behavior profile or model to determine whether a potential driver distraction event is an actual driver distraction event.

17. The system of claim **1**, wherein the computer is configured to:

compare the digital mapping of driver movement to an expected behavior profile or model developed from previously acquired digital mappings of the driver's movements;

count repeated occurrences where the digital mapping of driver movement matches the expected behavior profile or model;

compare the count to a threshold; and

determine that a potential driver distraction event is an actual driver distraction event in response to the count meeting or exceeding the threshold.

18. The system of claim **1**, wherein the computer is configured to:

compare the digital mapping of driver movement to an expected behavior profile or model developed from previously acquired digital mappings of the driver's movements;

measure the duration of repeated occurrences where the digital mapping of driver movement matches the expected behavior profile or model;

compare the measured duration to a threshold; and

determine that a potential driver distraction event is an actual driver distraction event in response to the measured duration meeting or exceeding the threshold.

19. The system of claim **1**, wherein the driver behavior detector is configured to:

receive additional data comprising one or more of vehicle computer data, vehicle sensor data, and environmental data; and

detect a driver distraction event using the driver movement mapping, the audio signal, and the additional data.

20. A system, comprising:

an imaging system configured for deployment in a cab of a vehicle operated by a driver and to generate substantially in real-time a digital image of driver movement during operation of the vehicle using structured light, the imaging system configured to compute a depth map of a portion of the driver's body using the structured light;

an audio sensor configured for deployment in the cab and configured to generate an audio signal responsive to driver movement during operation of the vehicle, the audio sensor configured for operation in a listening mode and to generate a trigger signal in response to detection of audio signals indicative of suspect driver behavior;

a computer configured for deployment in the cab and coupled to the imaging system and the audio sensor, the computer configured to cause the imaging system to generate the digital image of driver movement in response to the trigger signal;

a driver behavior detector coupled to the computer and configured to detect a driver distraction event using the driver movement image and the audio signal; and

a communication device at the vehicle and configured to communicate an alert message to one or both of a user interface device in the cab and a remote system in response to the detected driver distraction event.

21. A method, comprising:

generating substantially in real-time a digital mapping of driver movement using structured light during operation of a vehicle, wherein generating the digital mapping comprises computing a depth map of a portion of the driver's body using the structured light;

generating audio signals responsive to driver movement during operation of the vehicle;

generating, in a listening mode, a trigger signal in response to detecting an audio signal indicative of suspect driver behavior;

detecting a driver distraction event using the driver movement mapping and the audio signals; and

communicating an alert message to one or both of a user interface device in the vehicle and a remote system in response to the detected driver distraction event;

wherein the digital mapping of the driver's face is generated substantially in real-time in response to the trigger signal.

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