

## TRANSMITTAL FOR POWER OF ATTORNEY TO ONE OR MORE REGISTERED PRACTITIONERS

NOTE: This form is to be submitted with the Power of Attorney by Applicant form (PTO/AIA/82B) to identify the application to which the Power of Attorney is directed, in accordance with 37 CFR 1.5, unless the application number and filing date are identified in the Power of Attorney by Applicant form. If neither form PTO/AIA/82A nor form PTO/AIA82B identifies the application to which the Power of Attorney is directed, the Power of Attorney will not be recognized in the application.

|                        |                                                                                                                                              |
|------------------------|----------------------------------------------------------------------------------------------------------------------------------------------|
| Application Number     | Not yet assigned                                                                                                                             |
| Filing Date            | Herewith                                                                                                                                     |
| First Named Inventor   | Samuel English Anthony                                                                                                                       |
| Title                  | REDUCING FALSE POSITIVES FOR AUTOMATIC BRAKING OF AUTONOMOUS VEHICLES BASED ON PREDICTION OF HIDDEN CONTEXT ASSOCIATED WITH TRAFFIC ENTITIES |
| Art Unit               | n/a                                                                                                                                          |
| Examiner Name          | n/a                                                                                                                                          |
| Attorney Docket Number | 35447-42480/US                                                                                                                               |

### SIGNATURE of Applicant or Patent Practitioner

|                                                    |                           |                     |                |
|----------------------------------------------------|---------------------------|---------------------|----------------|
| Signature                                          | /Rajendra Panwar/         | Date (Optional)     | March 22, 2019 |
| Name                                               | Rajendra B. Panwar        | Registration Number | 63,165         |
| Title (if Applicant is a juristic entity)          | Attorney for Applicant    |                     |                |
| Applicant Name (if Applicant is a juristic entity) | Perceptive Automata, Inc. |                     |                |

**NOTE:** This form must be signed in accordance with 37 CFR 1.33. See 37 CFR 1.4(d) for signature requirements and certifications. If more than one applicant, use multiple forms.



\*Total of 1 forms are submitted.

This collection of information is required by 37 CFR 1.131, 1.32, and 1.33. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.11 and 1.14. This collection is estimated to take 3 minutes to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. **SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.**

## POWER OF ATTORNEY BY APPLICANT

I hereby revoke all previous powers of attorney given in the application identified in either the attached transmittal letter or the boxes below.

| Application Number | Filing Date |
|--------------------|-------------|
|                    |             |

(Note: The boxes above may be left blank if information is provided on form PTO/AIA/82A.)

☒ I hereby appoint the Patent Practitioner(s) associated with the following Customer Number as my/our attorney(s) or agent(s), and to transact all business in the United States Patent and Trademark Office connected therewith for the application referenced in the attached transmittal letter (form PTO/AIA/82A) or identified above:

00758

OR

☐ I hereby appoint Practitioner(s) named in the attached list (form PTO/AIA/82C) as my/our attorney(s) or agent(s), and to transact all business in the United States Patent and Trademark Office connected therewith for the patent application referenced in the attached transmittal letter (form PTO/AIA/82A) or identified above. (Note: Complete form PTO/AIA/82C.)

**Please recognize or change the correspondence address for the application identified in the attached transmittal letter or the boxes above to:**

☒ The address associated with the above-mentioned Customer Number

OR

☐ The address associated with Customer Number:

OR

☐ Firm or Individual Name

Address

City

State

Zip

Country

Telephone

Email

I am the Applicant (if the Applicant is a juristic entity, list the Applicant name in the box):

PERCEPTIVE AUTOMATA, INC.

- ☐ Inventor or Joint Inventor (title not required below)
- ☐ Legal Representative of a Deceased or Legally Incapacitated Inventor (title not required below)
- ☒ Assignee or Person to Whom the Inventor is Under an Obligation to Assign (provide signer's title if applicant is a juristic entity)
- ☐ Person Who Otherwise Shows Sufficient Proprietary Interest (e.g., a petition under 37 CFR 1.46(b)(2) was granted in the application or is concurrently being filed with this document) (provide signer's title if applicant is a juristic entity)

### SIGNATURE of Applicant for Patent

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

Signature

Date (Optional)

Name

Kshitij "Sid" Misra

Title

Chief Executive Officer

**NOTE:** Signature - This form must be signed by the applicant in accordance with 37 CFR 1.33. See 37 CFR 1.4 for signature requirements and certifications. If more than one applicant, use multiple forms.

☒ Total of 1 forms are submitted.

This collection of information is required by 37 CFR 1.131, 1.32, and 1.33. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.11 and 1.14. This collection is estimated to take 3 minutes to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. **SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.**

If you need assistance in completing the form, call 1-800-PTO-9199 and select option 3. LA EXHIBIT 1007, Page 2

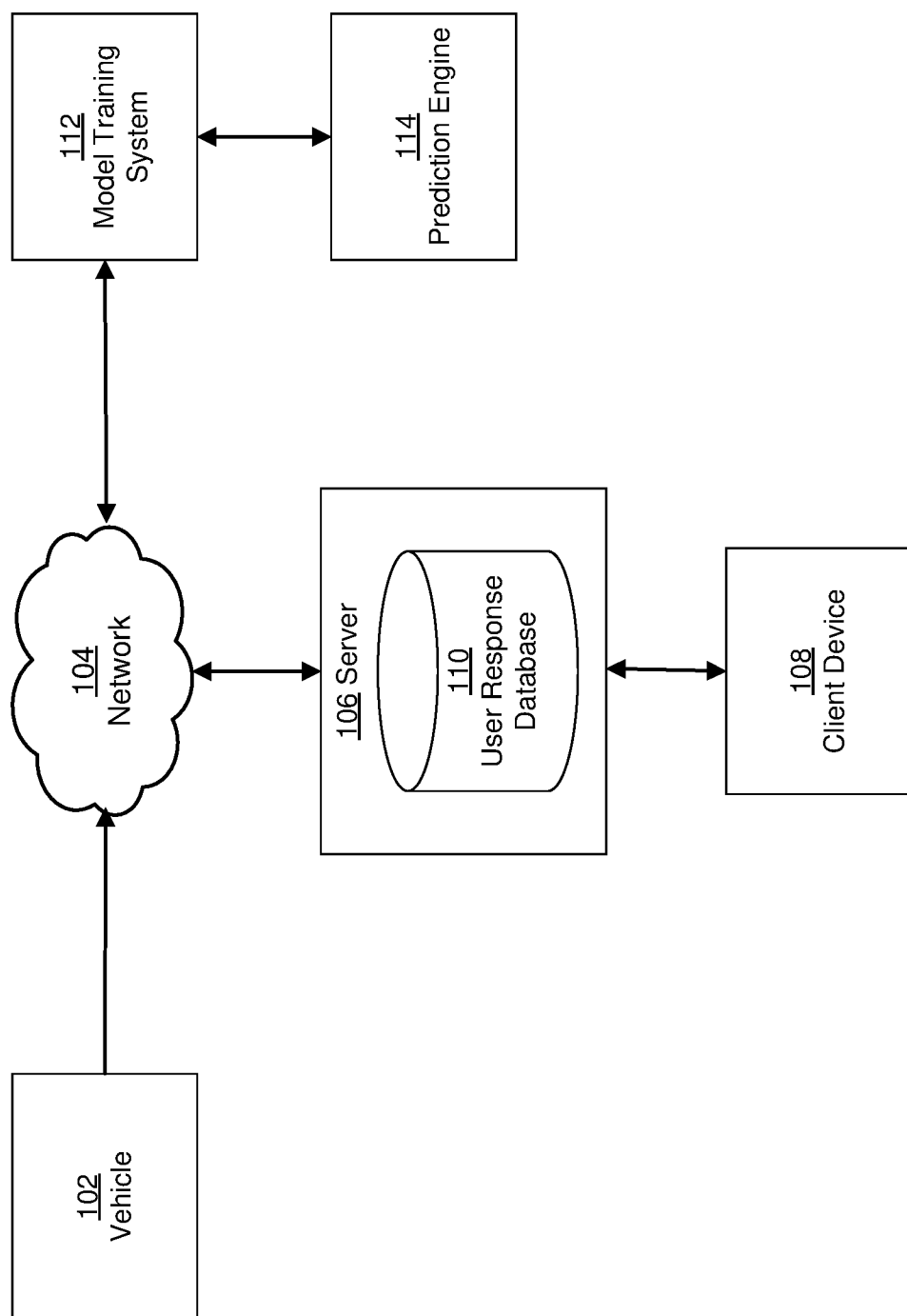


**FIG. 1A**

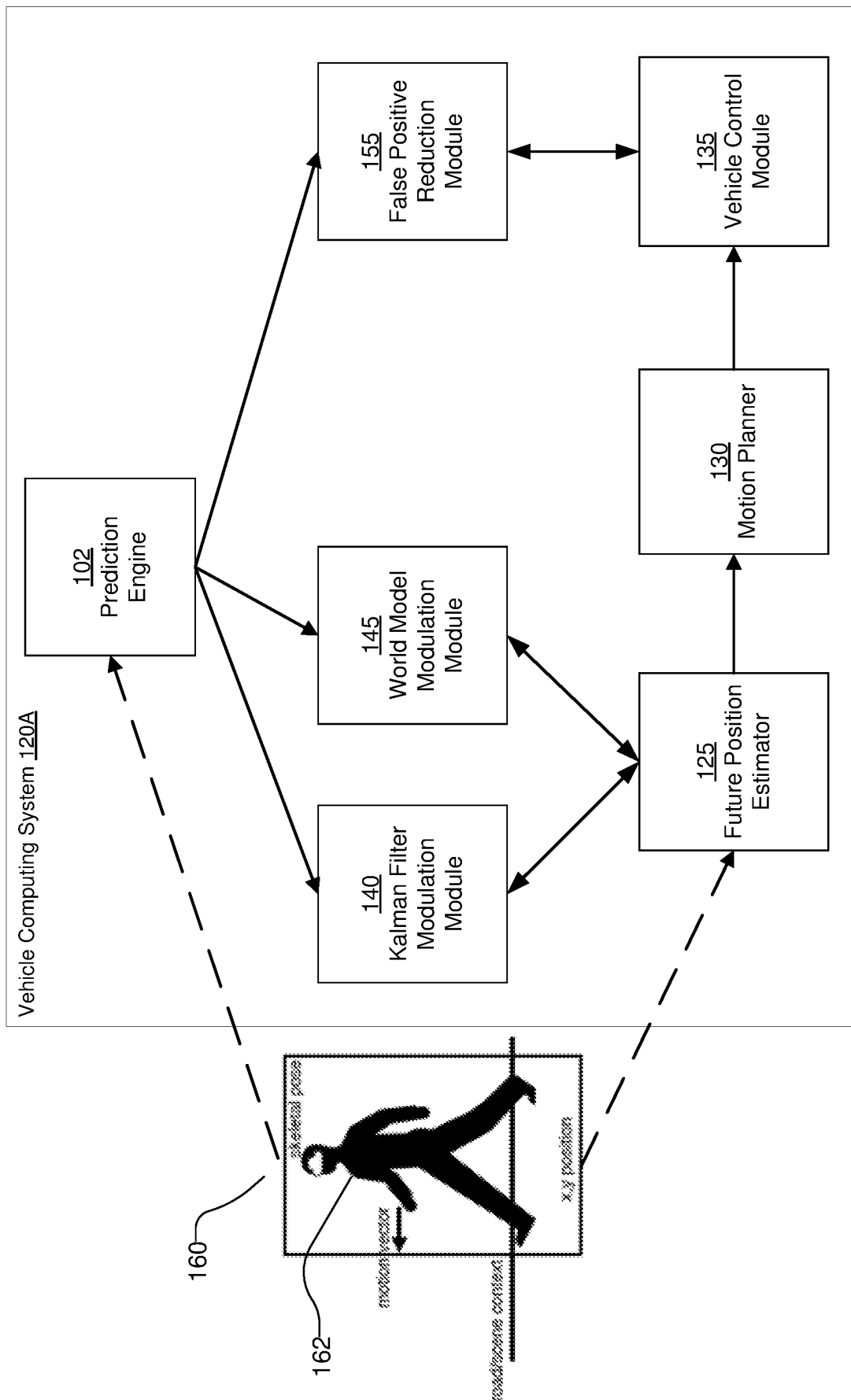


**FIG. 1B**

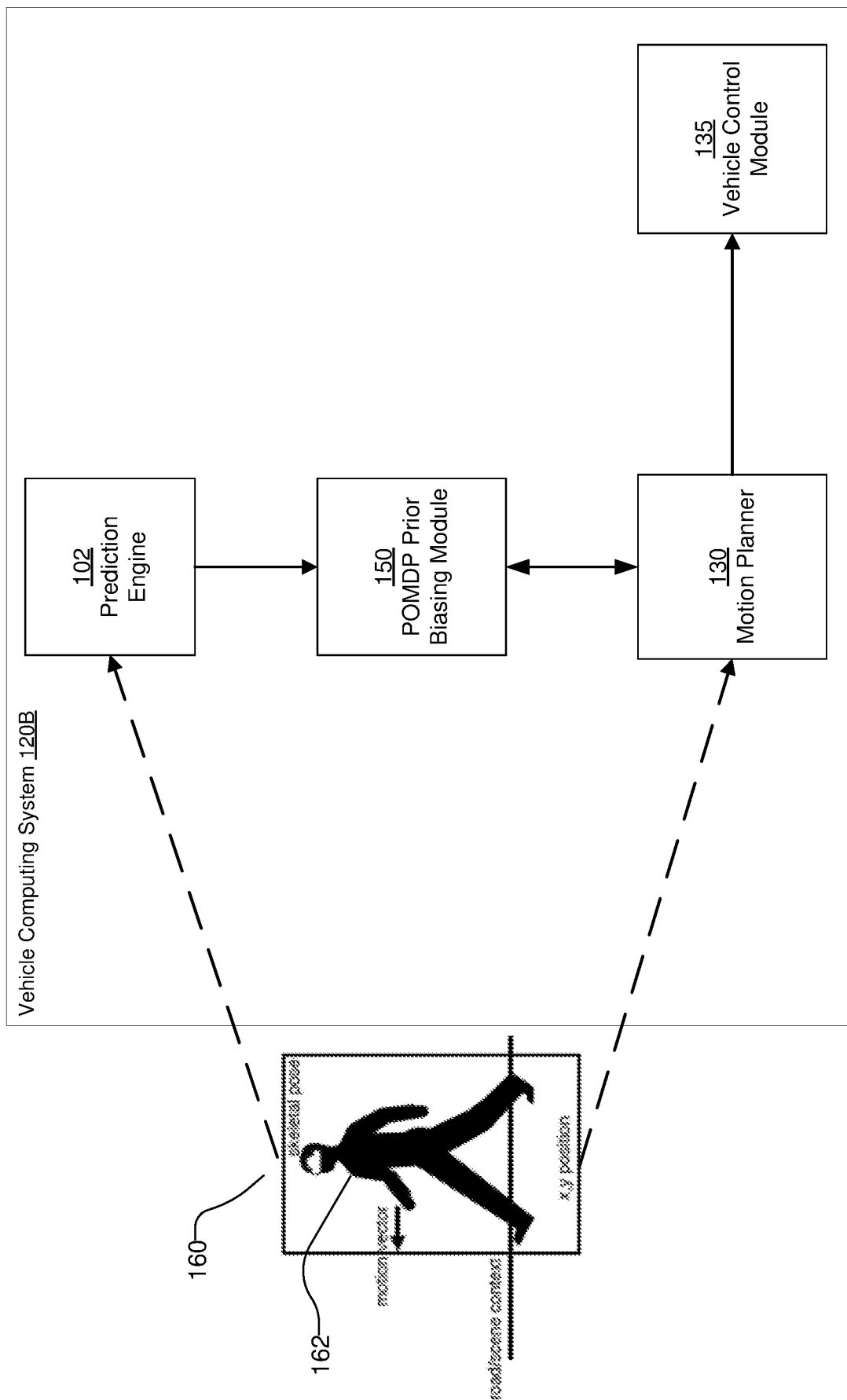


FIG. 1C

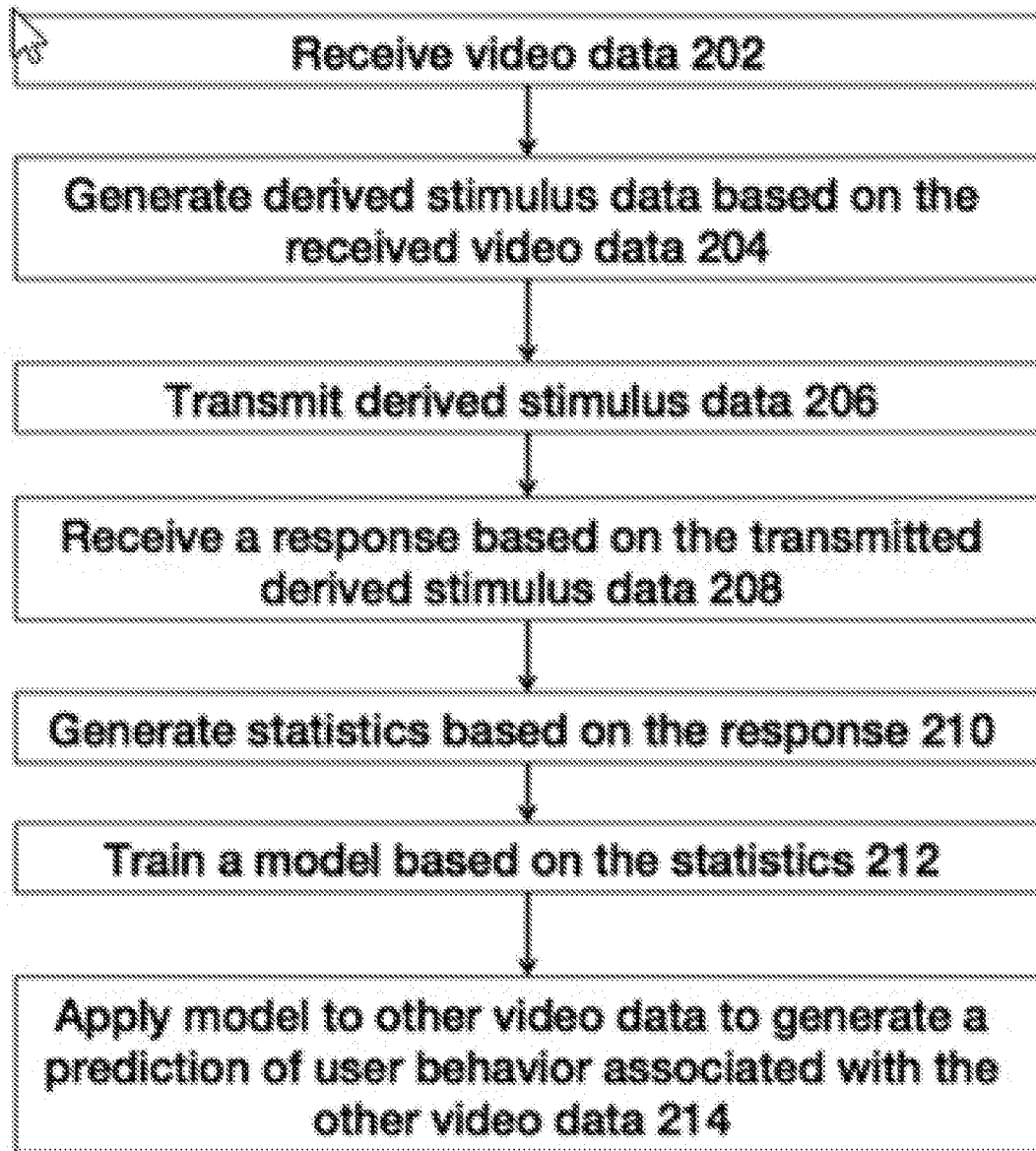


**FIG. 2A**

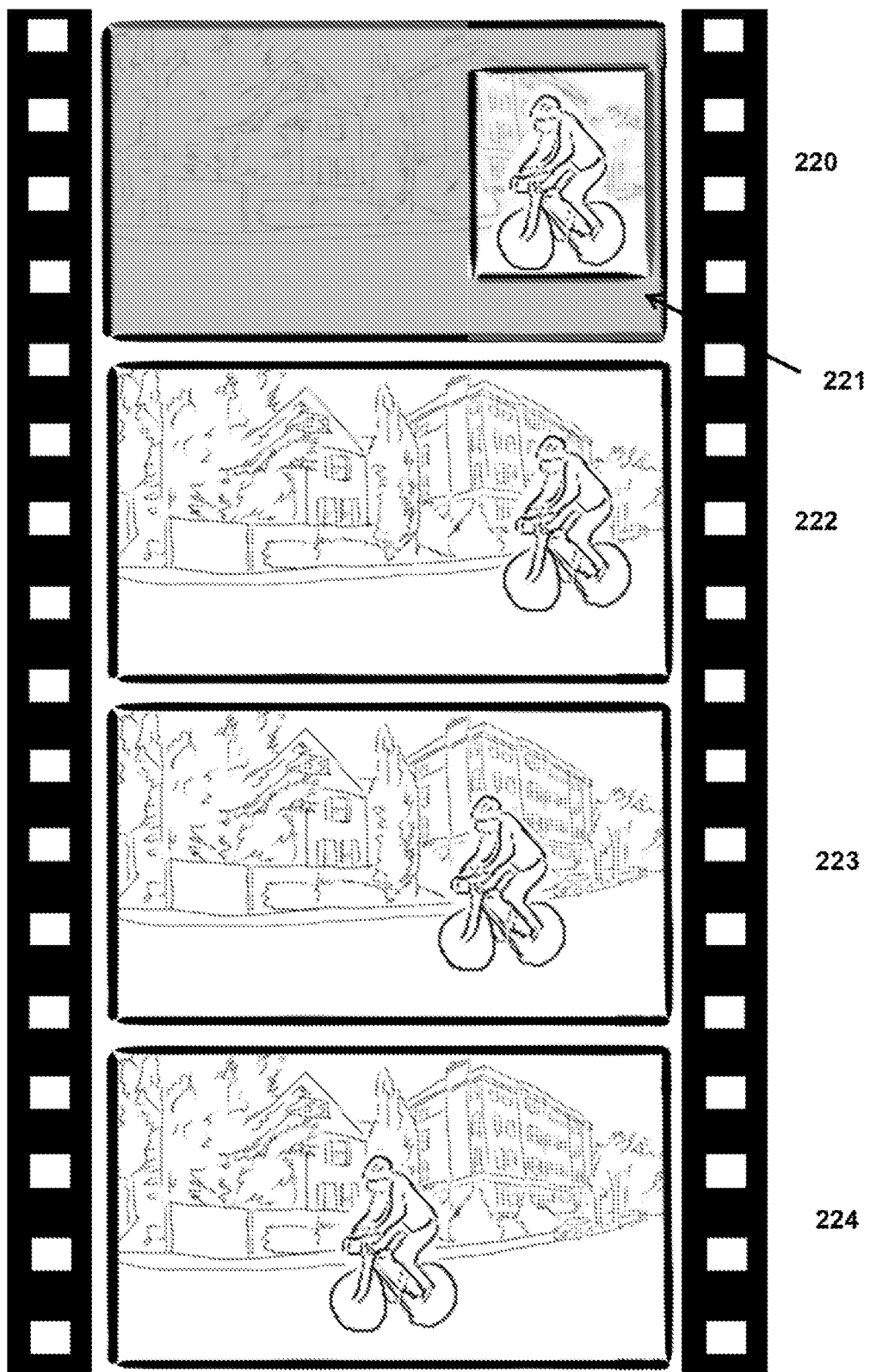


FIG. 2B

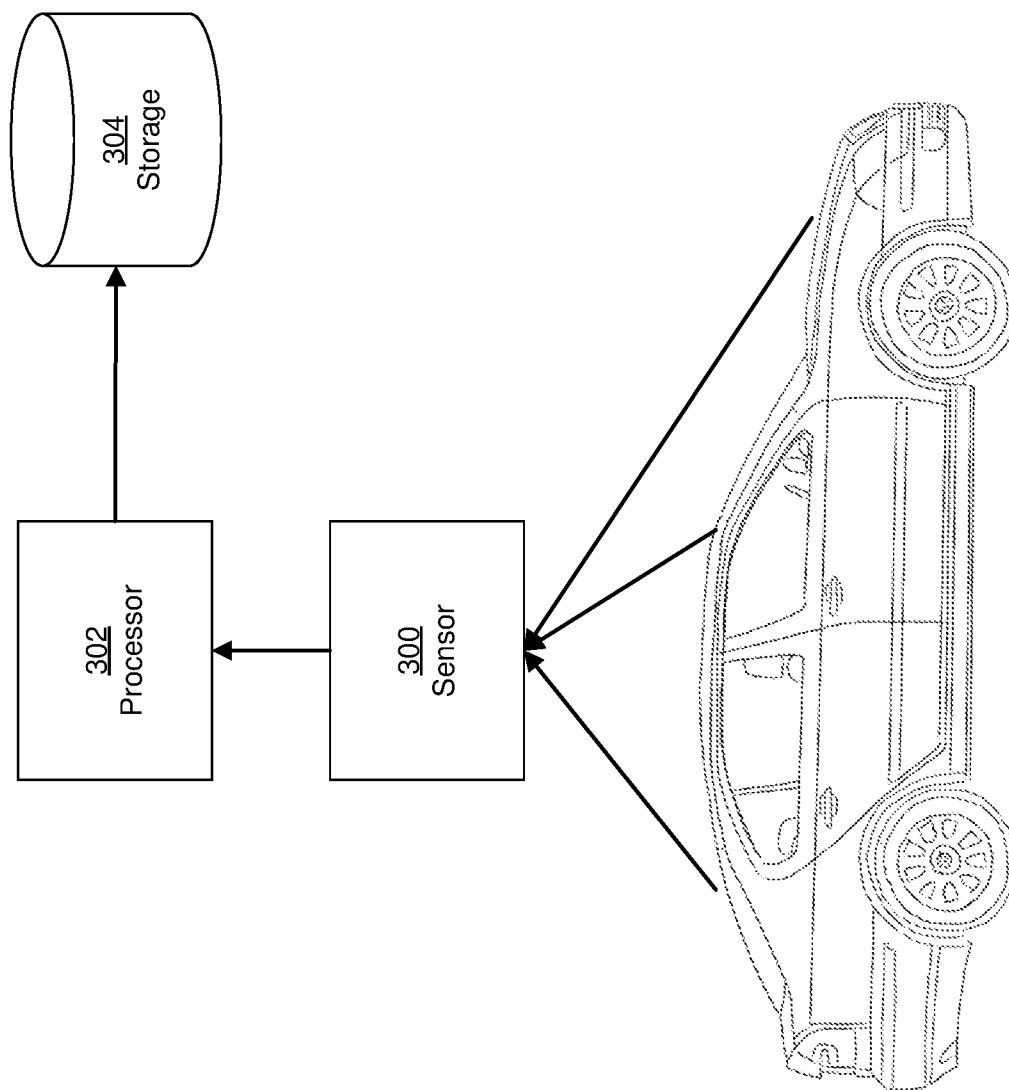


**FIG. 3**

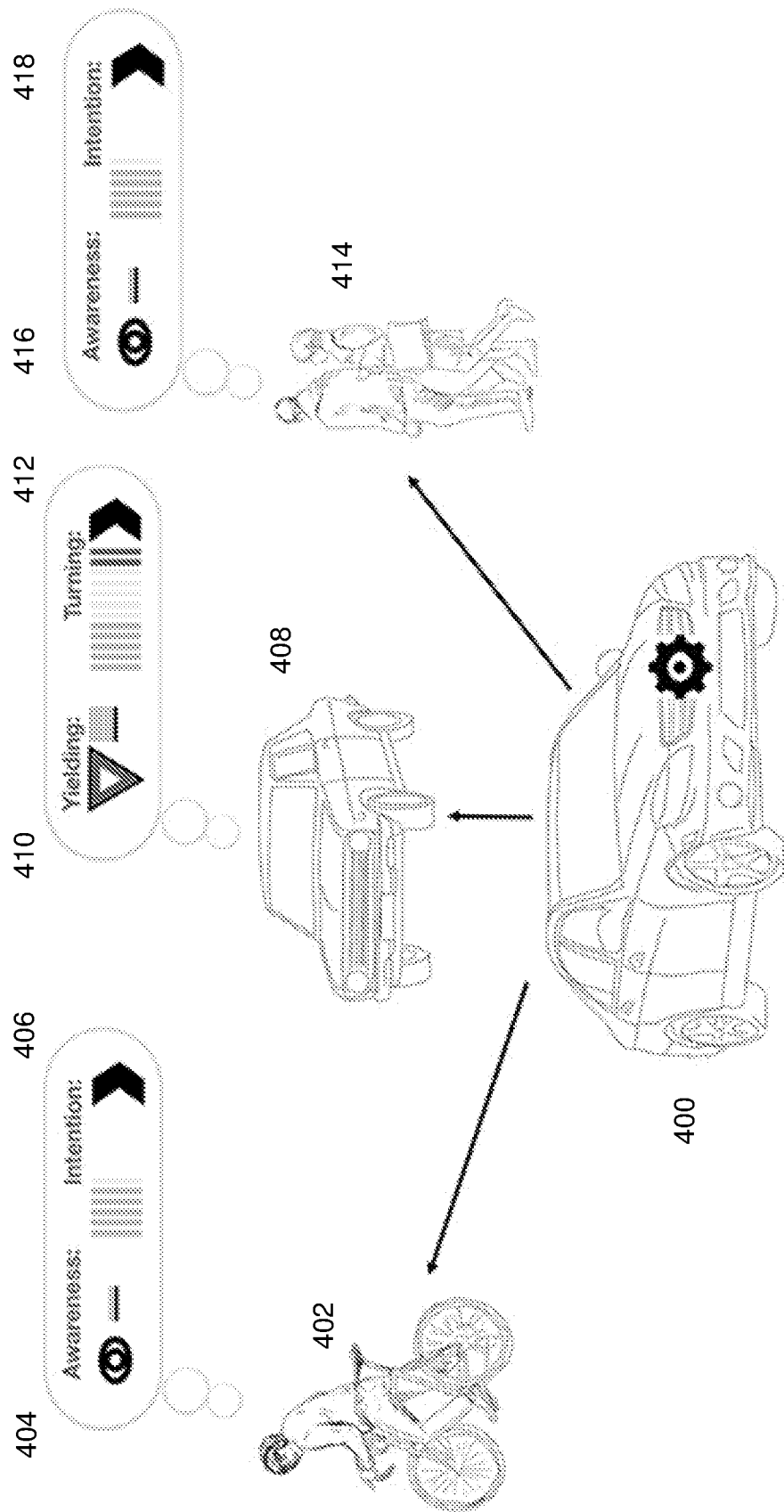


FIG. 4

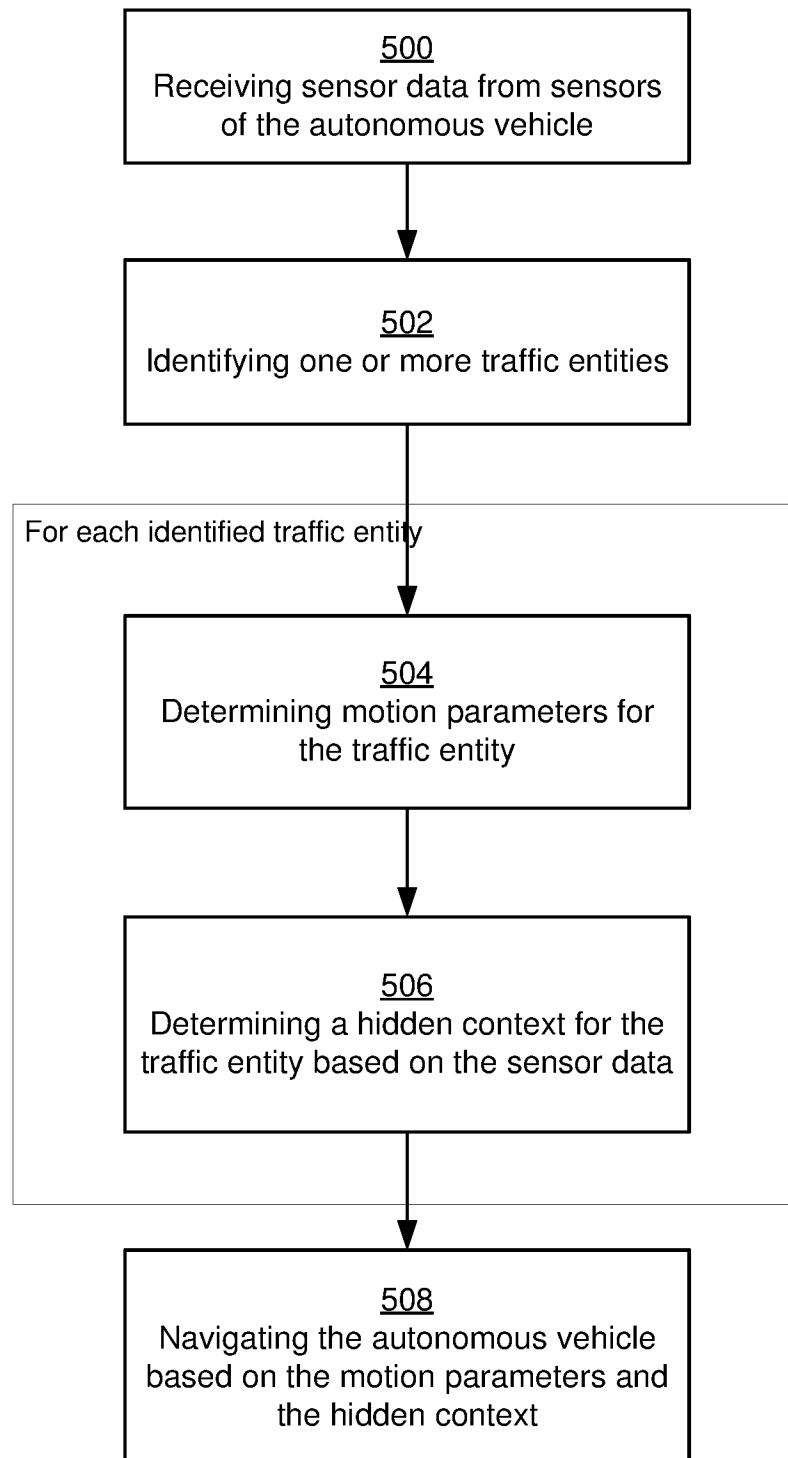


**FIG. 5**

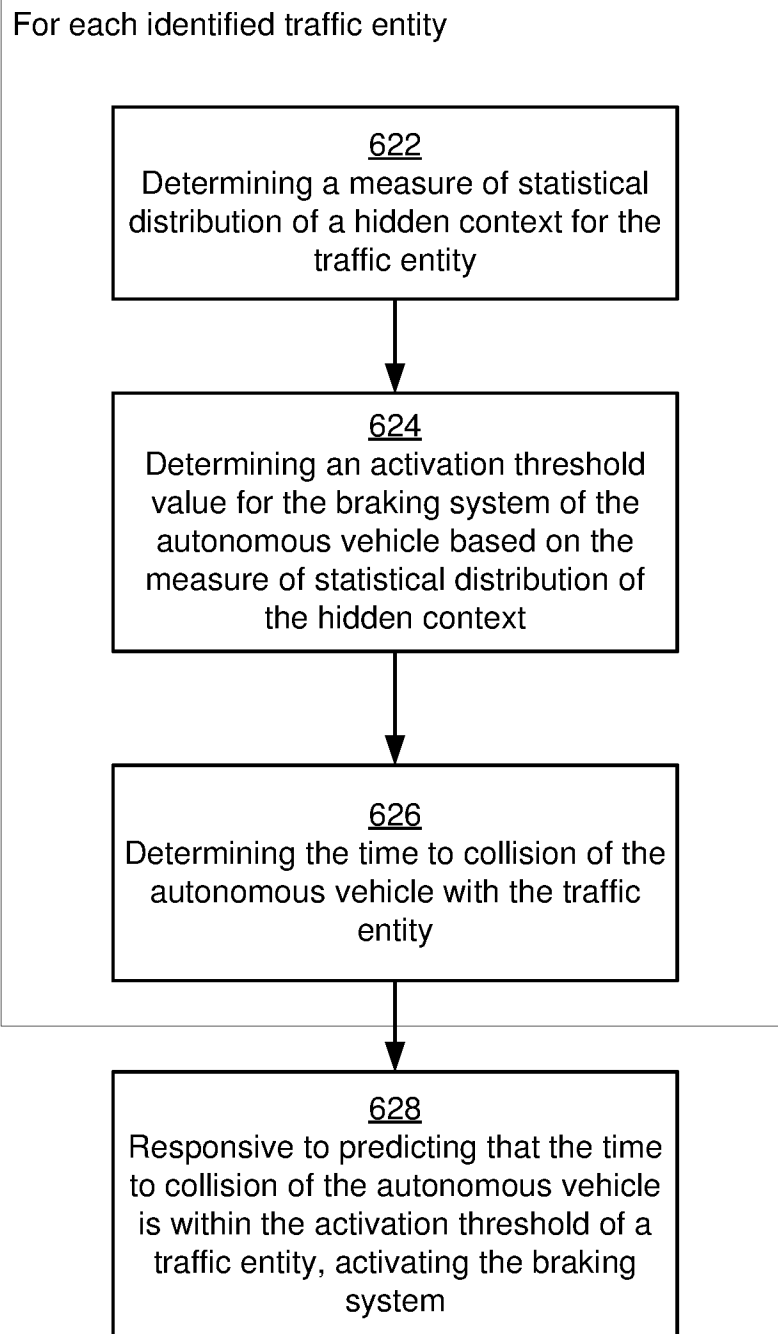


**FIG. 6**

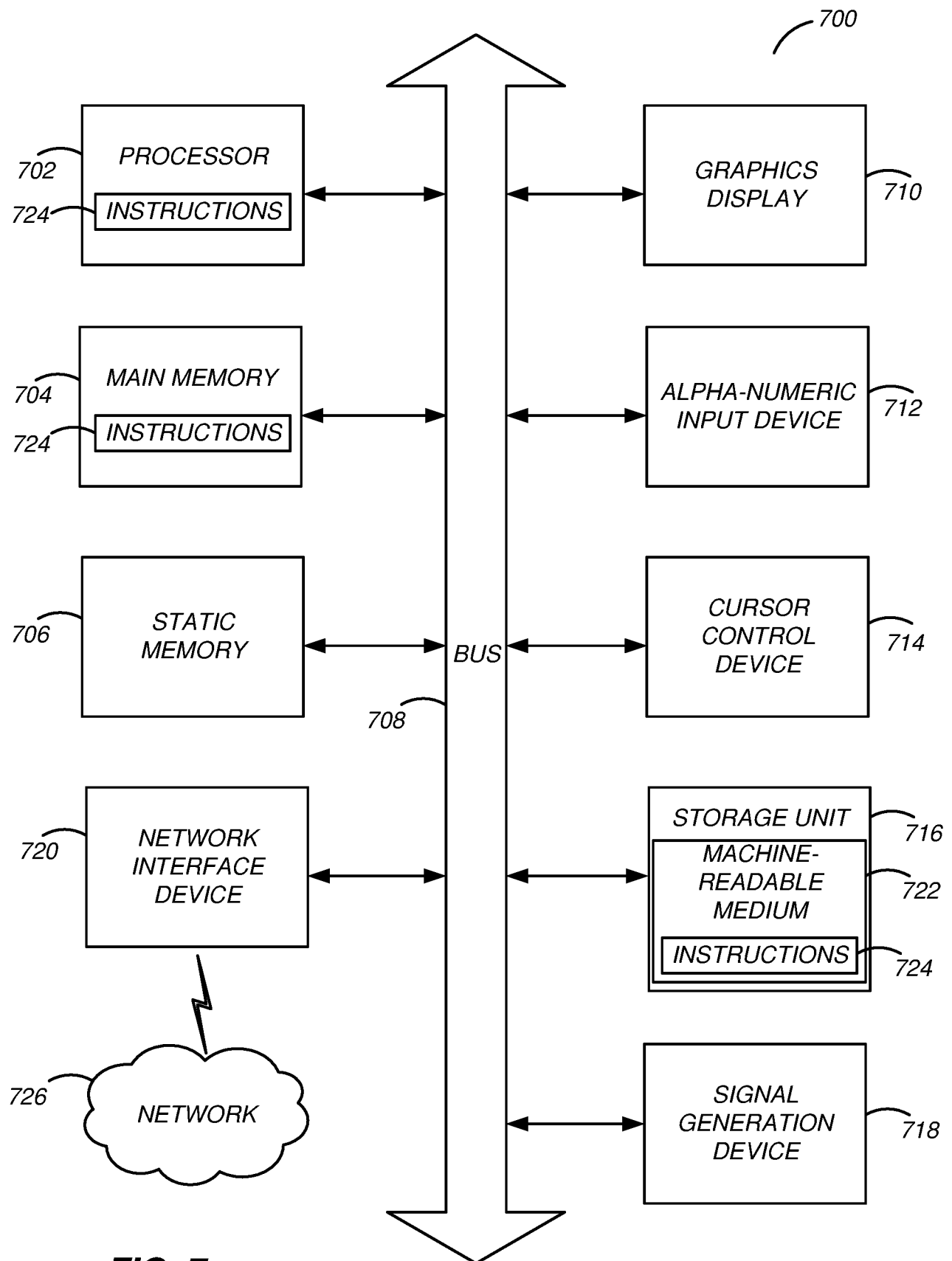


**FIG. 7**

## Electronic Patent Application Fee Transmittal

|                                             |                                                                                                                                              |                 |               |                             |
|---------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------|-----------------|---------------|-----------------------------|
| <b>Application Number:</b>                  |                                                                                                                                              |                 |               |                             |
| <b>Filing Date:</b>                         |                                                                                                                                              |                 |               |                             |
| <b>Title of Invention:</b>                  | REDUCING FALSE POSITIVES FOR AUTOMATIC BRAKING OF AUTONOMOUS VEHICLES BASED ON PREDICTION OF HIDDEN CONTEXT ASSOCIATED WITH TRAFFIC ENTITIES |                 |               |                             |
| <b>First Named Inventor/Applicant Name:</b> | Samuel English Anthony                                                                                                                       |                 |               |                             |
| <b>Filer:</b>                               | Rajendra Bhagwatisingh Panwar                                                                                                                |                 |               |                             |
| <b>Attorney Docket Number:</b>              | 35447-42480/US                                                                                                                               |                 |               |                             |
| Filed as Small Entity                       |                                                                                                                                              |                 |               |                             |
| <b>Filing Fees for Provisional</b>          |                                                                                                                                              |                 |               |                             |
| <b>Description</b>                          | <b>Fee Code</b>                                                                                                                              | <b>Quantity</b> | <b>Amount</b> | <b>Sub-Total in USD(\$)</b> |
| <b>Basic Filing:</b>                        |                                                                                                                                              |                 |               |                             |
| PROVISIONAL APPLICATION FILING FEE          | 2005                                                                                                                                         | 1               | 140           | 140                         |
| <b>Pages:</b>                               |                                                                                                                                              |                 |               |                             |
| <b>Claims:</b>                              |                                                                                                                                              |                 |               |                             |
| <b>Miscellaneous-Filing:</b>                |                                                                                                                                              |                 |               |                             |
| <b>Petition:</b>                            |                                                                                                                                              |                 |               |                             |
| <b>Patent-Appeals-and-Interference:</b>     |                                                                                                                                              |                 |               |                             |
| <b>Post-Allowance-and-Post-Issuance:</b>    |                                                                                                                                              |                 |               |                             |

| Description        | Fee Code | Quantity | Amount | Sub-Total in USD(\$) |
|--------------------|----------|----------|--------|----------------------|
| Extension-of-Time: |          |          |        |                      |
| Miscellaneous:     |          |          |        |                      |
| Total in USD (\$)  |          |          |        | 140                  |

## Electronic Acknowledgement Receipt

|                                             |                                                                                                                                              |
|---------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------|
| <b>EFS ID:</b>                              | 35503185                                                                                                                                     |
| <b>Application Number:</b>                  | 62822269                                                                                                                                     |
| <b>International Application Number:</b>    |                                                                                                                                              |
| <b>Confirmation Number:</b>                 | 3935                                                                                                                                         |
| <b>Title of Invention:</b>                  | REDUCING FALSE POSITIVES FOR AUTOMATIC BRAKING OF AUTONOMOUS VEHICLES BASED ON PREDICTION OF HIDDEN CONTEXT ASSOCIATED WITH TRAFFIC ENTITIES |
| <b>First Named Inventor/Applicant Name:</b> | Samuel English Anthony                                                                                                                       |
| <b>Customer Number:</b>                     | 758                                                                                                                                          |
| <b>Filer:</b>                               | Rajendra Bhagwatisingh Panwar                                                                                                                |
| <b>Filer Authorized By:</b>                 |                                                                                                                                              |
| <b>Attorney Docket Number:</b>              | 35447-42480/US                                                                                                                               |
| <b>Receipt Date:</b>                        | 22-MAR-2019                                                                                                                                  |
| <b>Filing Date:</b>                         |                                                                                                                                              |
| <b>Time Stamp:</b>                          | 14:05:40                                                                                                                                     |
| <b>Application Type:</b>                    | Provisional                                                                                                                                  |

### Payment information:

|                                          |                             |
|------------------------------------------|-----------------------------|
| Submitted with Payment                   | yes                         |
| Payment Type                             | DA                          |
| Payment was successfully received in RAM | \$ 140                      |
| RAM confirmation Number                  | 032519INTEFSW00000271192555 |
| Deposit Account                          | 192555                      |
| Authorized User                          | Rajendra Panwar             |

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

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

37 CFR 1.17 (Patent application and reexamination processing fees)

37 CFR 1.19 (Document supply fees)  
37 CFR 1.20 (Post Issuance fees)  
37 CFR 1.21 (Miscellaneous fees and charges)

## File Listing:

| Document Number              | Document Description                        | File Name      | File Size(Bytes)/ Message Digest          | Multi Part /.zip | Pages (if appl.) |
|------------------------------|---------------------------------------------|----------------|-------------------------------------------|------------------|------------------|
| 1                            | Application Data Sheet                      | 42480_ADS.pdf  | 1255897                                   | no               | 8                |
|                              |                                             |                | 40afea3547f299ed4b38aae15da8b667f877549d  |                  |                  |
| Warnings:                    |                                             |                |                                           |                  |                  |
| Information:                 |                                             |                |                                           |                  |                  |
| 2                            | Power of Attorney                           | 42480_POA.PDF  | 784234                                    | no               | 2                |
|                              |                                             |                | 6f8d7b3e102412e593d559cbdd6b478979dd5733  |                  |                  |
| Warnings:                    |                                             |                |                                           |                  |                  |
| Information:                 |                                             |                |                                           |                  |                  |
| 3                            | Specification                               | 42480_SPEC.pdf | 175852                                    | no               | 36               |
|                              |                                             |                | 69bd37de074ee5a195feff4fde245a4b60bea352  |                  |                  |
| Warnings:                    |                                             |                |                                           |                  |                  |
| Information:                 |                                             |                |                                           |                  |                  |
| 4                            | Drawings-only black and white line drawings | 42480_FIGS.pdf | 646886                                    | no               | 10               |
|                              |                                             |                | b5b837ffd58f68dfcf4e3cc35941cee02bb93651  |                  |                  |
| Warnings:                    |                                             |                |                                           |                  |                  |
| Information:                 |                                             |                |                                           |                  |                  |
| 5                            | Fee Worksheet (SB06)                        | fee-info.pdf   | 30222                                     | no               | 2                |
|                              |                                             |                | bb2b9a17c13f8bc27ecb16ae75b57d38b9bb2a2ba |                  |                  |
| Warnings:                    |                                             |                |                                           |                  |                  |
| Information:                 |                                             |                |                                           |                  |                  |
| Total Files Size (in bytes): |                                             |                | 2893091                                   |                  |                  |

**This Acknowledgement Receipt evidences receipt on the noted date by the USPTO of the indicated documents, characterized by the applicant, and including page counts, where applicable. It serves as evidence of receipt similar to a Post Card, as described in MPEP 503.**

**New Applications Under 35 U.S.C. 111**

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

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

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

**New International Application Filed with the USPTO as a Receiving Office**

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

Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it contains a valid OMB control number.

|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                                                                                                                              |                        |                |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------|------------------------|----------------|
| <b>Application Data Sheet 37 CFR 1.76</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                                                                                                                                              | Attorney Docket Number | 35447-42480/US |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                                                                                                                              | Application Number     |                |
| Title of Invention                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | REDUCING FALSE POSITIVES FOR AUTOMATIC BRAKING OF AUTONOMOUS VEHICLES BASED ON PREDICTION OF HIDDEN CONTEXT ASSOCIATED WITH TRAFFIC ENTITIES |                        |                |
| <p>The application data sheet is part of the provisional or nonprovisional application for which it is being submitted. The following form contains the bibliographic data arranged in a format specified by the United States Patent and Trademark Office as outlined in 37 CFR 1.76.</p> <p>This document may be completed electronically and submitted to the Office in electronic format using the Electronic Filing System (EFS) or the document may be printed and included in a paper filed application.</p> |                                                                                                                                              |                        |                |

## Secrecy Order 37 CFR 5.2:

|                          |                                                                                                                                                                                                                                       |
|--------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <input type="checkbox"/> | Portions or all of the application associated with this Application Data Sheet may fall under a Secrecy Order pursuant to 37 CFR 5.2 (Paper filers only. Applications that fall under Secrecy Order may not be filed electronically.) |
|--------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

## Inventor Information:

|                                                                                                                                             |            |                           |             |                      |                        |  |
|---------------------------------------------------------------------------------------------------------------------------------------------|------------|---------------------------|-------------|----------------------|------------------------|--|
| Inventor                                                                                                                                    | 1          |                           |             |                      | <a href="#">Remove</a> |  |
| Legal Name                                                                                                                                  |            |                           |             |                      |                        |  |
| Prefix                                                                                                                                      | Given Name | Middle Name               | Family Name | Suffix               |                        |  |
|                                                                                                                                             | Samuel     | English                   | Anthony     |                      |                        |  |
| Residence Information (Select One) • US Residency Non US Residency Active US Military Service                                               |            |                           |             |                      |                        |  |
| City                                                                                                                                        | Cambridge  | State/Province            | MA          | Country of Residence | US                     |  |
| Mailing Address of Inventor:                                                                                                                |            |                           |             |                      |                        |  |
| Address 1                                                                                                                                   |            | Perceptive Automata, Inc. |             |                      |                        |  |
| Address 2                                                                                                                                   |            | 10 Ware Street            |             |                      |                        |  |
| City                                                                                                                                        | Cambridge  | State/Province            | MA          |                      |                        |  |
| Postal Code                                                                                                                                 | 02138      | Country                   | US          |                      |                        |  |
| All Inventors Must Be Listed - Additional Inventor Information blocks may be generated within this form by selecting the <b>Add</b> button. |            |                           |             |                      |                        |  |

## Correspondence Information:

|                                                                                                                                       |                  |                           |                              |
|---------------------------------------------------------------------------------------------------------------------------------------|------------------|---------------------------|------------------------------|
| Enter either Customer Number or complete the Correspondence Information section below.<br>For further information see 37 CFR 1.33(a). |                  |                           |                              |
| <input type="checkbox"/> An Address is being provided for the correspondence information of this application.                         |                  |                           |                              |
| Customer Number                                                                                                                       | 00758            |                           |                              |
| Email Address                                                                                                                         | ptoc@fenwick.com | <a href="#">Add Email</a> | <a href="#">Remove Email</a> |

## Application Information:

|                                         |                                                                                                                                              |                                           |                                     |
|-----------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------|-------------------------------------|
| Title of the Invention                  | REDUCING FALSE POSITIVES FOR AUTOMATIC BRAKING OF AUTONOMOUS VEHICLES BASED ON PREDICTION OF HIDDEN CONTEXT ASSOCIATED WITH TRAFFIC ENTITIES |                                           |                                     |
| Attorney Docket Number                  | 35447-42480/US                                                                                                                               | Small Entity Status Claimed               | <input checked="" type="checkbox"/> |
| Application Type                        | Provisional                                                                                                                                  |                                           |                                     |
| Subject Matter                          | Utility                                                                                                                                      |                                           |                                     |
| Total Number of Drawing Sheets (if any) | 10                                                                                                                                           | Suggested Figure for Publication (if any) |                                     |

|                                           |                                                                                                                                              |                        |                |
|-------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------|------------------------|----------------|
| <b>Application Data Sheet 37 CFR 1.76</b> |                                                                                                                                              | Attorney Docket Number | 35447-42480/US |
|                                           |                                                                                                                                              | Application Number     |                |
| Title of Invention                        | REDUCING FALSE POSITIVES FOR AUTOMATIC BRAKING OF AUTONOMOUS VEHICLES BASED ON PREDICTION OF HIDDEN CONTEXT ASSOCIATED WITH TRAFFIC ENTITIES |                        |                |

**Filing By Reference:**

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

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

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

**Publication Information:**

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

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

**Representative Information:**

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

|                    |                                                  |                                              |                                                         |
|--------------------|--------------------------------------------------|----------------------------------------------|---------------------------------------------------------|
| Please Select One: | <input checked="" type="radio"/> Customer Number | <input type="radio"/> US Patent Practitioner | <input type="radio"/> Limited Recognition (37 CFR 11.9) |
| Customer Number    | 00758                                            |                                              |                                                         |

**Domestic Benefit/National Stage Information:**

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

When referring to the current application, please leave the "Application Number" field blank.

|                                                                                                                       |                      |                                       |
|-----------------------------------------------------------------------------------------------------------------------|----------------------|---------------------------------------|
| Prior Application Status                                                                                              | <input type="text"/> | <input type="button" value="Remove"/> |
| Application Number                                                                                                    | Continuity Type      | Prior Application Number              |
| <input type="text"/>                                                                                                  | <input type="text"/> | <input type="text"/>                  |
| Additional Domestic Benefit/National Stage Data may be generated within this form by selecting the <b>Add</b> button. |                      |                                       |

|                                           |                                                                                                                                              |                        |                |
|-------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------|------------------------|----------------|
| <b>Application Data Sheet 37 CFR 1.76</b> |                                                                                                                                              | Attorney Docket Number | 35447-42480/US |
|                                           |                                                                                                                                              | Application Number     |                |
| Title of Invention                        | REDUCING FALSE POSITIVES FOR AUTOMATIC BRAKING OF AUTONOMOUS VEHICLES BASED ON PREDICTION OF HIDDEN CONTEXT ASSOCIATED WITH TRAFFIC ENTITIES |                        |                |

## Foreign Priority Information:

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

| Application Number | Country <sup>i</sup> | Filing Date (YYYY-MM-DD) | Access Code <sup>i</sup> (if applicable) |
|--------------------|----------------------|--------------------------|------------------------------------------|
|                    |                      |                          |                                          |

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

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

☐ This application (1) claims priority to or the benefit of an application filed before March 16, 2013 and (2) also contains, or contained at any time, a claim to a claimed invention that has an effective filing date on or after March 16, 2013.

NOTE: By providing this statement under 37 CFR 1.55 or 1.78, this application, with a filing date on or after March 16, 2013, will be examined under the first inventor to file provisions of the AIA.

|                                           |                                                                                                                                              |                        |                |
|-------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------|------------------------|----------------|
| <b>Application Data Sheet 37 CFR 1.76</b> |                                                                                                                                              | Attorney Docket Number | 35447-42480/US |
|                                           |                                                                                                                                              | Application Number     |                |
| Title of Invention                        | REDUCING FALSE POSITIVES FOR AUTOMATIC BRAKING OF AUTONOMOUS VEHICLES BASED ON PREDICTION OF HIDDEN CONTEXT ASSOCIATED WITH TRAFFIC ENTITIES |                        |                |

## Authorization or Opt-Out of Authorization to Permit Access:

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

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

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

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

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

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

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

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

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

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

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

|                                           |                                                                                                                                              |                        |                |
|-------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------|------------------------|----------------|
| <b>Application Data Sheet 37 CFR 1.76</b> |                                                                                                                                              | Attorney Docket Number | 35447-42480/US |
|                                           |                                                                                                                                              | Application Number     |                |
| Title of Invention                        | REDUCING FALSE POSITIVES FOR AUTOMATIC BRAKING OF AUTONOMOUS VEHICLES BASED ON PREDICTION OF HIDDEN CONTEXT ASSOCIATED WITH TRAFFIC ENTITIES |                        |                |

## Applicant Information:

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

|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                                          |                                                  |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------|--------------------------------------------------|
| <b>Applicant</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | 1                                        | <a href="#">Remove</a>                           |
| <p>If the applicant is the inventor (or the remaining joint inventor or inventors under 37 CFR 1.45), this section should not be completed. The information to be provided in this section is the name and address of the legal representative who is the applicant under 37 CFR 1.43; or the name and address of the assignee, person to whom the inventor is under an obligation to assign the invention, or person who otherwise shows sufficient proprietary interest in the matter who is the applicant under 37 CFR 1.46. If the applicant is an applicant under 37 CFR 1.46 (assignee, person to whom the inventor is obligated to assign, or person who otherwise shows sufficient proprietary interest) together with one or more joint inventors, then the joint inventor or inventors who are also the applicant should be identified in this section.</p> <p style="text-align: right;"><a href="#">Clear</a></p> |                                          |                                                  |
| <input checked="" type="radio"/> Assignee                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | Legal Representative under 35 U.S.C. 117 | Joint Inventor                                   |
| Person to whom the inventor is obligated to assign.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                                          | Person who shows sufficient proprietary interest |
| If applicant is the legal representative, indicate the authority to file the patent application, the inventor is:                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                                          |                                                  |
| <div style="border: 1px solid black; height: 20px; width: 100%;"></div>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |                                          |                                                  |
| Name of the Deceased or Legally Incapacitated Inventor: <div style="border: 1px solid black; height: 20px; width: 100%;"></div>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                                          |                                                  |
| If the Applicant is an Organization check here. <input checked="" type="checkbox"/>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                                          |                                                  |
| Organization Name                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | Perceptive Automata, Inc.                |                                                  |
| <b>Mailing Address Information For Applicant:</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                                          |                                                  |
| Address 1                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | 10 Ware Street                           |                                                  |
| Address 2                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                          |                                                  |
| City                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | Cambridge                                | State/Province MA                                |
| Country                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | US                                       | Postal Code 02138                                |
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| Email Address                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                                          |                                                  |
| Additional Applicant Data may be generated within this form by selecting the Add button. <a href="#">Add</a>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                                          |                                                  |

## Assignee Information including Non-Applicant Assignee Information:

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|                                           |                                                                                                                                              |                        |                |
|-------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------|------------------------|----------------|
| <b>Application Data Sheet 37 CFR 1.76</b> |                                                                                                                                              | Attorney Docket Number | 35447-42480/US |
|                                           |                                                                                                                                              | Application Number     |                |
| Title of Invention                        | REDUCING FALSE POSITIVES FOR AUTOMATIC BRAKING OF AUTONOMOUS VEHICLES BASED ON PREDICTION OF HIDDEN CONTEXT ASSOCIATED WITH TRAFFIC ENTITIES |                        |                |

|                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                      |                      |                      |                      |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------|----------------------|----------------------|----------------------|
| <b>Assignee</b>   1                                                                                                                                                                                                                                                                                                                                                                                                                                    |                      |                      |                      |                      |
| Complete this section if assignee information, including non-applicant assignee information, is desired to be included on the patent application publication. An assignee-applicant identified in the "Applicant Information" section will appear on the patent application publication as an applicant. For an assignee-applicant, complete this section only if identification as an assignee is also desired on the patent application publication. |                      |                      |                      |                      |
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| Address 2                                                                                                                                                                                                                                                                                                                                                                                                                                              |                      | <input type="text"/> |                      |                      |
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| Country <sup>i</sup>                                                                                                                                                                                                                                                                                                                                                                                                                                   | <input type="text"/> | Postal Code          | <input type="text"/> |                      |
| Phone Number                                                                                                                                                                                                                                                                                                                                                                                                                                           | <input type="text"/> | Fax Number           | <input type="text"/> |                      |
| Email Address                                                                                                                                                                                                                                                                                                                                                                                                                                          | <input type="text"/> |                      |                      |                      |
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**Signature:**

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

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

|                                                                                                                        |                   |           |                   |                     |
|------------------------------------------------------------------------------------------------------------------------|-------------------|-----------|-------------------|---------------------|
| Signature                                                                                                              | /Rajendra Panwar/ |           | Date (YYYY-MM-DD) | 2019-03-22          |
| First Name                                                                                                             | Rajendra B.       | Last Name | Panwar            | Registration Number |
|                                                                                                                        |                   |           |                   | 63,165              |
| Additional Signature may be generated within this form by selecting the Add button. <input type="button" value="Add"/> |                   |           |                   |                     |

|                                           |                                                                                                                                              |                        |                |
|-------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------|------------------------|----------------|
| <b>Application Data Sheet 37 CFR 1.76</b> |                                                                                                                                              | Attorney Docket Number | 35447-42480/US |
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This collection of information is required by 37 CFR 1.76. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.14. This collection is estimated to take 23 minutes to complete, including gathering, preparing, and submitting the completed application data sheet form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. **SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.**

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

**REDUCING FALSE POSITIVES FOR AUTOMATIC BRAKING OF  
AUTONOMOUS VEHICLES BASED ON PREDICTION OF HIDDEN CONTEXT  
ASSOCIATED WITH TRAFFIC ENTITIES**

**TECHNICAL FIELD**

**[0001]** The present disclosure relates generally to navigating an autonomous vehicle through traffic and more specifically to reducing false positives for automatic braking of autonomous vehicles based on prediction of hidden context associated with traffic entities.

**BACKGROUND**

**[0002]** An autonomous vehicle uses different types of sensors to receive input describing the surroundings (or environment) of the autonomous vehicle while driving through traffic. For example, an autonomous vehicle may perceive the surroundings using camera images and lidar scans. The autonomous vehicle determines whether an object in the surroundings is stationary, for example, buildings or trees or the object is non-stationary, for example, a pedestrian, a vehicle, and so on. The autonomous vehicle system predicts the motion of non-stationary objects to make sure that the autonomous vehicle is able to navigate through non-stationary obstacles in the traffic.

**[0003]** Conventional systems predict motion of non-stationary objects using kinematics. For example, an autonomous vehicle may send signals to controls of the autonomous vehicle by predicting “motion vectors” of traffic entities such as pedestrians, bicyclists, and other vehicles near the autonomous vehicle. This is accomplished by collecting data of a traffic entity’s current and past movements, determining a motion vector of the traffic entity at a current time based on these movements, and extrapolating a future motion vector representing the traffic entity’s predicted motion at a future time based on the current motion vector. However, these techniques fail to predict motion of certain non-stationary objects for

example, pedestrians, bicyclists, and so on. For example, if the autonomous vehicle detects a pedestrian standing in a street corner, the motion of the pedestrian does not help predict whether the pedestrian will cross the street or whether the pedestrian will remain standing on a street corner. Similarly, if the autonomous vehicle detects a bicyclist in a lane, the current motion of the bicycle does not help the autonomous vehicle predict whether the bicycle will change lanes.

**[0004]** Autonomous vehicles use automatic braking systems to stop the vehicle or slow down the vehicle to avoid sudden changes in movements of traffic entities, for example, pedestrians or bicyclists. For example, the autonomous vehicle may predict based on a motion vector of a bicyclist that the bicyclists will reach a certain position at the end of a given time interval. Accordingly, the autonomous vehicle may predict that it is safe to continue along a particular trajectory. However, the bicyclists may not be aware of the autonomous vehicle that may be behind the bicyclists and as a result, may suddenly decide to change the direction of travel. Conventional systems that predict based on motion vectors of traffic entities are likely to suddenly determine a change in the environment indicating a high likelihood of collision with the bicyclist, thereby invoking automatic braking system to stop or slow down the autonomous vehicle.

**[0005]** As another example, an autonomous vehicle may detect a pedestrian is standing by the side of the road and therefore unlikely to come in the way of the autonomous vehicle. As a result, the autonomous vehicle may continue driving at a particular speed on the road. However, the pedestrian may suddenly decide to cross the street. Conventional system detect a sudden change in environment indicating a likelihood of the collision with the pedestrian thereby triggering the automatic braking system causing the autonomous vehicle to stop or suddenly slow down.

[0006] Some autonomous vehicles may overcompensate for the likelihood of a traffic entity making a sudden movement. For example, the autonomous vehicle may drive very far behind a bicyclist assuming that the bicyclist may change direction and come in the way of the autonomous vehicle or the autonomous vehicle may change direction to avoid a pedestrian standing by the side of the road with no intention to cross the street. This causes such systems to drive the autonomous vehicle either slower than necessary or take unnecessary detours.

[0007] Failure of autonomous vehicles fail to accurately predict motion of non-stationary traffic objects results in unnatural movement of the autonomous vehicle, for example, as a result of the autonomous vehicle suddenly stopping due to a pedestrian moving in the road or the autonomous vehicle continuing to wait for a person to cross a street even if the person never intends to cross the street. As a result, the autonomous vehicle is likely to drive in a manner that is very different from a human driver. This results in a poor experience for people present in the autonomous vehicle. This also results in low confidence of people in the driving capabilities of an autonomous vehicle.

### **BRIEF DESCRIPTION OF FIGURES**

[0008] Various objectives, features, and advantages of the disclosed subject matter can be more fully appreciated with reference to the following detailed description of the disclosed subject matter when considered in connection with the following drawings, in which like reference numerals identify like elements.

[0009] FIG. 1A is a system diagram of a networked system for predicting human behavior according to some embodiments of the invention.

[0010] FIG. 1B is the system architecture of a vehicle computing system that routes an autonomous vehicle based on prediction of hidden context associated with traffic objects according to an embodiment of the invention.

**[0011]** FIG. 1C is the system architecture of a vehicle computing system that routes an autonomous vehicle based on prediction of hidden context associated with traffic objects according to another embodiment of the invention.

**[0012]** FIG. 2A is a flow chart showing a process of predicting human behavior, according to some embodiments of the invention.

**[0013]** FIG. 2B shows an example of a derived stimulus, according to some embodiments of the invention.

**[0014]** FIG. 3 is a system diagram showing a sensor system associated with a vehicle, according to some embodiments of the invention.

**[0015]** FIG. 4 shows a process of generating derived stimuli from raw camera or sensor data in the vehicle, according to some embodiments of the invention.

**[0016]** FIG. 5 is a flowchart showing a process of collecting predictions and other information from human observers based on derived stimuli, according to some embodiments of the invention.

**[0017]** FIG. 6 shows a data structure associated with tracking video frame data, according to some embodiments of the invention.

**[0018]** FIG. 7 is a flowchart showing a process for producing summary statistics of a video frame or derived stimulus according to some embodiments of the invention.

**[0019]** FIG. 8 is a flowchart showing a process of training a learning algorithm using summary statistics, according to some embodiments of the invention.

**[0020]** FIG. 9 is a flowchart showing a process of predicting the state of mind of road users using a trained learning algorithm, according to some embodiments of the invention.

**[0021]** FIG. 10 is a diagram showing an example of an application of a context user prediction process in an automobile context, according to some embodiments of the invention.

**[0022]** FIG. 11 represents a flowchart illustrating the process of navigating the autonomous vehicle based on hidden context, according to an embodiment.

**[0023]** FIG. 12 represents a flowchart illustrating the process of using the modulatory signals to reduce false positives while navigating the autonomous vehicle, according to an embodiment.

**[0024]** FIG. 13 is a block diagram illustrating components of an example machine able to read instructions from a machine-readable medium and execute them in a processor (or controller).

### **DETAILED DESCRIPTION**

**[0025]** Embodiments of the invention predict hidden context associated with traffic entities that determines behavior of these traffic entities in the traffic. A traffic entity represents an object in traffic, for example, a pedestrian, a bicycle, a vehicle, a delivery robot, and so on. Hidden context includes factors that affect the behavior of such traffic entities, for example, a state of mind of a pedestrian, a degree of awareness of the existence of the autonomous vehicle in the vicinity (for example, whether a bicyclist is aware of the existence of the autonomous vehicle in the proximity of the bicyclist), and so on. The system uses the hidden context to predict behavior of people near a vehicle in a way that more closely resembles how human drivers would judge the behavior.

**[0026]** In one embodiment, a group of users (or human observers) view sample images of people (such as pedestrians) near streets and/or vehicles and indicate or are measured for their understanding of how they believe the people will behave. These indicators or measurements are then used as a component for training a machine learning based model that predicts how people will behave in a real-world context. In other words, after being trained based on the reactions of human observers to sample images in a training environment, the machine

learning based model predicts behavior of traffic entities in a real-world environment, for example, actual pedestrian behavior in a real-world environment.

**[0027]** A non-stationary object may also be referred to as a movable object. An object in the traffic may also be referred to as an entity, for example, a traffic entity. Systems for predicting human interactions with vehicles are disclosed in U.S. Patent Application Number 15/830,549, filed on December 4, 2017 which is incorporated herein by reference in its entirety.

#### System Environment

**[0028]** FIG. 1 is a system diagram of a networked system for predicting human behavior according to some embodiments of the invention. FIG. 1 shows a vehicle 102, a network 104, a server 106, a user response database 110, a user terminal 108, a model training system 112 and a prediction engine 114.

**[0029]** The vehicle 102 can be any type of manual or motorized vehicle such as a car, bus, train, scooter, or bicycle. As described in more detail below, the vehicle 102 can include sensors for monitoring the environment surrounding the vehicle. In one implementation, the sensors can include a camera affixed to any portion of the vehicle for capturing a video of people near the vehicle.

**[0030]** The network 104 can be any wired and/or wireless network capable of receiving sensor data collected by the vehicle 102 and distributing it to the server 106, the model training system 112, and, through the model training system 112, the prediction engine 114.

**[0031]** The server 106 can be any type of computer system capable of (1) hosting information (such as image, video and text information) and delivering it to a user terminal (such as client device 108), (2) recording responses of multiple users (or human observers) to the information, and (3) delivering such information and accompanying responses (such as responses input via client device 108) back to the network 104.

**[0032]** The user response database 110 can be any type of database or data storage system capable of storing the image, video, and text information and associated user responses and subsequently recalling them in response to a query.

**[0033]** The model training system 112 can be implemented in any type of computing system. In one embodiment, the system 112 receives the image, video, and/or text information and accompanying, or linked, user responses from the database 110 over the network 104. In some embodiments, the text segments are discrete values or free text responses. The model training system 112 can use images, video segments and text segments as training examples to train an algorithm, and can create labels from the accompanying user responses based on the trained algorithm. These labels indicate how the algorithm predicts the behavior of the people in the associated image, video, and/or text segments. After the labels are created, the model training system 112 can transmit them to the prediction engine 144.

**[0034]** The prediction engine 114 can be implemented in any computing system. In an illustrative example, the prediction engine 114 includes process that executes a model that has been trained by the model training system 112. This process estimates a label for a new (*e.g.*, an actual “real-world”) image, video, and/or text segment based on the labels and associated image, video, and/or text segments that it received from the model training system 112. In some embodiments, this label comprises aggregate or summary information about the responses of a large number of users (or human observers) presented with similar image, video, or text segments while the algorithm was being trained.

**[0035]** FIG. 1B is the system architecture of a vehicle computing system that routes an autonomous vehicle based on prediction of hidden context associated with traffic objects according to an embodiment of the invention. The vehicle computing system 120A comprises the prediction engine 102, a future position estimator 125, a motion planner 130, a

vehicle control module 135, a Kalman filter modulation module 140, a world model modulation module 145, and a false positive reduction module 155. Other embodiments may include more or fewer modules than those shown in FIG. 1B. Actions performed by a particular module as indicated herein may be performed by other modules than those indicated herein.

**[0036]** The sensors of an autonomous vehicle capture sensor data 160 representing a scene describing the traffic surrounding the autonomous vehicle. Examples of sensors used by an autonomous vehicle include cameras, lidars, GNSS (global navigation satellite system such as a global positioning system, or GPS), IMU (inertial measurement unit), and so on. Examples of sensor data includes camera images and lidar scans.

**[0037]** The traffic includes one or more traffic entities, for example, a pedestrian 162. The vehicle computing system 120 analyzes the sensor data 160 and identifies various traffic entities in the scene, for example, pedestrians, bicyclists, other vehicles, and so on. The vehicle computing system 120 determines various parameters associated with the traffic entity, for example, the location (represented as x and y coordinates), a motion vector describing the movement of the traffic entity, and so on.

**[0038]** The future position estimator 125 estimates the future position of a traffic entity. The motion planner 130 determines a plan for the motion of the autonomous vehicle. The vehicle control module 135 sends signals to the vehicle controls (for example, accelerator, brakes, steering, emergency braking system, and so on) to control the movement of the autonomous vehicle. In an embodiment, the future position estimates for a traffic entity determined by the future position estimator 125 based on sensor data 160 are provided as input to the motion planner 130. The motion planner 130 determines a plan for navigating the autonomous vehicle through traffic, and provides a description of the plan to the vehicle control module 135. The vehicle control module 135 generates signals for providing to the

vehicle controls. For example, the vehicle control module 135 may send control signals to an emergency braking system to stop the vehicle suddenly while driving, the vehicle control module 135 may send control signals to the accelerator to increase or decrease the speed of the vehicle, or the vehicle control module 135 may send control signals to the steering of the autonomous vehicle to change the direction in which the autonomous vehicle is moving.

**[0039]** FIG. 1C is the system architecture of a vehicle computing system that routes an autonomous vehicle based on prediction of hidden context associated with traffic objects according to an embodiment of the invention. The vehicle computing system 120 comprises the prediction engine 102, a motion planner 130, a vehicle control module 135, and a POMDP (partially observable Markov decision process) prior biasing module 150. The output of the POMDP prior biasing module 150 is provided to the motion planner 130. The motion planner 130 provides input to the vehicle control module 135. Other embodiments may include more or fewer modules than those shown in FIG. 1B. Actions performed by a particular module as indicated herein may be performed by other modules than those indicated herein.

**[0040]** The POMDP prior biasing module 150 performs path planning to pick the optimal route to get to a destination. The system determines an estimation at each time step based on an observation vector which is assumed to comprise a functionally sufficient set of information to estimate the underlying state of the world. The POMDP prior biasing module 150 is trained including hidden context in its observation vector. Accordingly, the motion paths selected by the estimator are sensitive to the best guess information about the hidden context, for example, state of mind of human road users. This best guess information includes a representation of the level of human uncertainty in judgment.

**[0041]** FIG. 2A is a flow chart showing a process of predicting human behavior, according to some embodiments of the invention. In one implementation, video or other data

is captured by a camera or sensor mounted on the vehicle 102. The camera or other sensor can be mounted in a fixed or temporary manner to the vehicle 102. Of course, the camera does not need to be mounted to an automobile, and could be mounted to another type of vehicle, such as a bicycle. As the vehicle travels along various streets, the camera or sensor captures still and/or moving images (or other sensor data) of pedestrians, bicycles, automobiles, *etc.* moving or being stationary on or near the streets. In step 202, this video or other data captured by the camera or other sensor is transmitted from the vehicle 102, over the network 104, and to the server 106 where it is stored.

**[0042]** Then, in step 204, video frames or segments are extracted from the stored video or other data and are used to create stimulus data including derived stimulus (or stimuli). In one implementation, the derived stimulus corresponds to a scene in which one or more humans are conducting activities (*e.g.*, standing, walking, driving, riding a bicycle, *etc.*) beside or on a street and/or near a vehicle. As explained in more detail below for example in step 214 and in the text accompanying FIG. 9, as part of the training process for the prediction algorithm, human observers view the derived stimulus and predict how they believe the humans shown in the derived stimulus will act. In yet a further implementation, after the video frames or segments are extracted from the stored data, the derived stimulus is generated by manipulating the pixels or equivalent array data acquired from the camera or other sensor in step 204, producing a new data file that conveys a portion of the information from the original video with certain aspects highlighted or obscured, as described below in FIG 4.

**[0043]** FIG. 2B shows an example of a derived stimulus, according to some embodiments of the invention. As shown, three non-consecutive frames 220, 222, 223, and 224, are extracted from a short segment of video. A copy of the first frame is made 220. On the copy of the first frame 220, a box 221 is drawn around the figure of interest, highlighting that figure. The copy of the first frame 220 and the three extracted frames 222, 223, and 224 are

then recombined into a short video segment that loops. This encourages human observers to focus on a figure of interest in the video segment.

**[0044]** In step 206, the derived stimulus is transmitted from the server 106 and displayed to a large number of users (or human observers) on the user terminal 108 (or multiple terminals 108). The terminal(s) 108 prompt the human observers to predict how the people shown in the derived stimulus will act, and upon viewing the displayed stimulus, the observers input their responses corresponding to their predictions. For example, in the derived stimulus shown in FIG. 2B, the human observers may predict that the bicyclist will continue riding to the left in the figure. In other derived stimuli, the responses may predict whether a first person in the stimulus will cross the street, another person will remain standing on a street corner, and yet another person will change lanes on his or her bicycle. In an illustrative embodiment, the human observers may make a continuous or ordinal judgment about the state of mind or the predicted behavior of the people shown in the derived stimulus and record that judgment. For example, the human observers may select an appropriate icon displayed on the terminal(s) 108 by clicking a mouse or by pressing a key to indicate their judgment or prediction. The judgment or prediction may correspond to the human observers' assessment of the state of mind of the person in the derived stimulus or other awareness or intention that would be relevant to a hypothetical driver who sees the person in the derived stimulus while driving. In step 208, the derived stimulus and associated human observer responses are transmitted from the terminal(s) 108 to the server 106 and recorded in the user response database 110.

**[0045]** In step 210, summary statistics are generated based on the user responses. For example, the statistics may characterize the aggregate responses of multiple human observers to a particular derived stimulus. For instance, if the derived stimulus shows a pedestrian walking on a sidewalk towards an intersection, the response can be categorized in terms of

how many human observers believe that the pedestrian will stop upon reaching the intersection, continue walking straight across the intersection, turn a corner and continue walking along the sidewalk without crossing the intersection, *etc.* These summary statistics can characterize the human observer responses in terms of certain parameters associated with the statistics, such as a content of a response, a time associated with entering a response, and a position of an eye of a human observer associated with the response. The parameters can also be associated with a (1) central tendency, variance, skew, kurtosis, scale, or histogram. For example, the amount of time users took to input their responses can be characterized in terms of central tendency, variance, skew, kurtosis, scale, histogram. Also, the statistics can include a parameter that additionally or alternatively characterizes the movement of the human observers' eyes relative to a display when making the judgments in terms of central tendency, variance, skew, kurtosis, scale, histogram or two-dimensional distribution. In one embodiment, the statistics are stored in the user response database 110 with an index that identifies the raw video or sensor data from which the derived stimulus was generated. In a further embodiment, the statistics stored in the database 110 cover a large set of images of people on or near roads and are categorized in a number of different categories, such as pedestrian, driver, motorcyclist, bicyclist, scooter driver, self-balancing scooter rider, unicyclist, motorized wheelchair user, skateboarder, or others. Moreover, the statistics are respectively stored along with, or linked to, the images of the derived stimuli corresponding to the statistics.

**[0046]** In step 212, the stored statistics and corresponding images (*e.g.*, the video frames or segments that were extracted from the video or other data (captured from the camera or sensor of the vehicle 202)) are sent over the network 104 to the model training system 112 and used to train a prediction algorithm. For example, the collection of images and statistics can be used to train a supervised learning algorithm, which can comprise a random forest

regressor, a support vector regressor, a simple neural network, a deep convolutional neural network, a recurrent neural network, a long-short-term memory (**LSTM**) neural network with linear or nonlinear kernels that are two dimensional or three dimensional, or any other supervised learning algorithm which is able to take a collection of data labeled with continuous values and adapt its architecture in terms of weights, structure or other characteristics to minimize the deviation between its predicted label on a novel stimulus and the actual label collected on that stimulus using the same method as was used on the set of stimuli used to train that network. The model is given data which comprises some subset of the pixel data from the video frames that the summary statistics were generated from. In one implementation, this subset includes the pixel data contained in a box (such as the box 221 shown in FIG. 2B) drawn to contain the boundaries of the person, cyclist, motorist and vehicle, or other road user, including their mode of conveyance. In some other implementations, it also includes the entire pixel data from the rest of the image. In one of those implementations, that pixel data is selected according to criteria such as the salience of those features in terms of contrast, lighting, presence of edges, or color. In an additional implementation, the features can include descriptive meta-data about the images such as the dimensions and location of the bounding box, the shape of the bounding box or the change in size or position of the bounding box from one frame to the next.

**[0047]** In step 214, the prediction engine 114 uses the trained model from the model training system 112 to predict the actual, “real-world” or “live data” behavior of people on or near a road. In one embodiment, the prediction engine 114 receives “live data” that matches the format of the data used to train the trained model. For example, if the trained model was trained based on video data received from a camera on the vehicle 102, the “live data” that is input to the algorithm likewise is video data from the same or similar type camera. On the other hand, if the model was trained based on another type of sensor data received from

another type of sensor on the vehicle 102, the “live data” that is input to the prediction engine 114 likewise is the other type of data from the same or similar sensor.

**[0048]** The trained model or algorithm makes a prediction of what a pedestrian or other person shown in the “live data” would do based on the summary statistics and/or training labels of one or more derived stimulus. The accuracy of the model is determined by having it make predictions of novel derived stimuli that were not part of the training images previously mentioned but which do have human ratings attached to them, such that the summary statistics on the novel images can be generated using the same method as was used to generate the summary statistics for the training data, but where the correlation between summary statistics and image data was not part of the model training process. The predictions produced by the trained model comprise a set of predictions of the state of mind of road users that can then be used to improve the performance of autonomous vehicles, robots, virtual agents, trucks, bicycles, or other systems that operate on roadways by allowing them to make judgments about the future behavior of road users based on their state of mind.

**[0049]** FIG. 3 is a system diagram showing a sensor system associated with a vehicle, according to some embodiments of the invention. FIG. 3 shows a vehicle 306 with arrows pointing to the locations of its sensors 300, a local processor and storage 302, and remote storage 304.

**[0050]** Data is collected from cameras or other sensors 300 including solid state Lidar, rotating Lidar, medium range radar, or others mounted on the car in either a fixed or temporary capacity and oriented such that they capture images of the road ahead, behind, and/or to the side of the car. In some embodiments, the sensor data is recorded on a physical storage medium (not shown) such as a compact flash drive, hard drive, solid state drive or dedicated data logger. In some embodiments, the sensors 300 and storage media are managed by the processor 302.

**[0051]** The sensor data can be transferred from the in-car data storage medium and processor 302 to another storage medium 304 which could include cloud-based, desktop, or hosted server storage products. In some embodiments, the sensor data can be stored as video, video segments, or video frames.

**[0052]** In some embodiments, data in the remote storage 304 also includes database tables associated with the sensor data. When sensor data is received, a row can be added to a database table that records information about the sensor data that was recorded, including where it was recorded, by whom, on what date, how long the segment is, where the physical files can be found either on the internet or on local storage, what the resolution of the sensor data is, what type of sensor it was recorded on, the position of the sensor, and other characteristics.

**[0053]** In an embodiment, video or data frames are selected according to a method which selects either random or specific frames from video or sensor data segments. As described above, sensor data can include video segments or specific frames. These frames can either be contiguous or non-contiguous, and can be in the original order, in a permuted order, in reverse order, or in random order. Some of the frames can be repeated once or more than once. The frames are selected so that when human observers are later presented with reordered versions of the sequences of frames, they perceive either the actual motion of humans in the scene that was captured in the original video, or motion that is a product of the ordering of the frames but which diverges via reordering from the motion that was originally captured. The temporal information that the human observers looking at the sets of images or derived stimulus are able to use to answer questions about the sets of images may be therefore limited or expanded to include specific temporal cues that were or were not in the original sequence.

**[0054]** In some embodiments, some of the frames are manipulated. The frames can be manipulated by adjusting pixel values. These manipulations can include blurring, the addition or one or more occluding bars, bands, or shapes, sharpening, the removal of color information, the manipulation of color information, the drawing of non-occluding or highlighting shapes on the image, other manipulations, or a combination of the manipulations listed here, or a combination of the manipulations listed here with other manipulations, or other manipulations of the pixels not listed combined with each other. The manipulations serve the purpose of highlighting, occluding or degrading portions of the image, so that when the images are shown to the human observers, they are directed to people or specific portions of the image when predicting what the people in the images will do. For example, using the highlighting described above, a certain pedestrian in a scene can be isolated such that a human observer's feedback can be more reliably associated with the pedestrian.

**[0055]** In some embodiments, frames are recombined to form a derived stimulus. In some embodiments, if there is only one frame that frame comprises the derived stimulus. If there is more than one frame those frames may then be recombined. The recombination into a temporal segment can involve the frames having the same display time and interval as in the original video clip or could involve faster, slower or variable display times. The timing of the recombination is chosen in order to shape the perceived temporal duration of the activities visible in the original video segment so the judgments the observers make will rely on temporal information that is or is not identical to that featured in the original image.

**[0056]** According to an embodiment, human observers are given detailed instructions about how to answer questions about derived stimuli. The human observers are presented with derived stimuli and asked to answer questions about them. The observers respond to the stimuli and those responses are recorded. The recorded responses are aggregated and logged in a database, for example, in the user response database 110.

**[0057]** The human observers may be shown a display which includes the derived stimulus. The display also includes a mechanism for making a judgment about the stimulus. The mechanism for making the judgment can be a continuous indicator such as a ribbon on which the observer could drag a control to a certain point. The mechanism can also be an ordinal measure such as a Likert scale where the observer can make a judgment about a degree of certainty of the judgment. The mechanism can also be a control that the human observer drags with their mouse to draw a trajectory onscreen indicating a judgment. The mechanism can also be a text entry field where the observer types a description of their judgment. The judgment that the human observer makes is an evaluation of the state of mind of a road user depicted in the derived stimulus. The evaluation can be of the intention, awareness, personality, state of consciousness, level of tiredness, aggressiveness, enthusiasm, thoughtfulness or another characteristic of the internal mental state of the pictured road user. If the ratings collected are on an ordinal scale they can describe the characteristic using language of probability, such as “the other driver may be attentive” or “the other driver” is definitely attentive” or “the other driver is definitely not attentive”. The ratings of large numbers of human observers are collected. Summary statistics are generated based on the responses of all of the observers who looked at an image. Individual variability in responses to a given stimulus can be characterized in the information given by the observers to the learning algorithm. The summary statistics might include unweighted information from all observers, or might exclude observers based on extrinsic or intrinsic criteria such as the time it took an observer to respond, the geographical location of an observer, the observer’s self-reported driving experience, or the observer’s reliability in making ratings of a set of other images.

**[0058]** The explicit response of the observer is recorded as well as implicit data. The implicit data can include how long the subject took to respond, if they hesitated in their

motions, if they deleted keystrokes, if they moved the mouse anywhere other than the location corresponding to the response they eventually chose, where their eyes moved, or other implicit measures.

**[0059]** The summary statistics could include measurements of the central tendency of the distribution of scores like the mean, median, or mode. They could include measurements of the heterogeneity of the scores like variance, standard deviation, skew, kurtosis, heteroskedasticity, multimodality, or uniformness. They could also include summary statistics like those above calculated from the implicit measurements of the responses listed above.

**[0060]** The system trains a learning algorithm using summary statistics. For example, in one embodiment, the process may train an algorithm used in the model training system 112. The system extracts summary statistics linked to a given video or sensor frame from the database 110. Subsequently, the video or sensor frame may be collated with the statistics label for the frame. The collated frame is provided to the learning algorithm in the model training system 112, and this process yields a trained model configured to execute a learning algorithm.

**[0061]** The learning algorithm may be any type of supervised learning algorithm capable of predicting a continuous label for a two or three dimensional input, including but not limited to a random forest regressor, a support vector regressor, a simple neural network, a deep convolutional neural network, a recurrent neural network, a long-short-term memory (LSTM) neural network with linear or nonlinear kernels that are two dimensional or three dimensional.

**[0062]** In one embodiment of the model training system 112, the algorithm is a deep neural network. In this embodiment the parameters are the weights attached to the connections between the artificial neurons comprising the network. Pixel data from an image

in a training set collated with human observer summary statistics serves as an input to the network. This input is transformed according to a mathematical function by each of the artificial neurons, and the transformed information transmitted from that artificial neuron to other artificial neurons in the neural network. The neural network model is trained by minimizing the difference between the summary statistics output by the neural network and the summary statistics calculated from the responses of the human observers.

**[0063]** The trained model is used for predicting the state of mind of traffic entities. The trained model receives a “real world” or “live data” video or sensor frame. The trained model analyzes the frame and outputs a prediction of summary statistics on the frame. The model outputs a number or set of numbers that comprise the predicted summary statistics for the “real world” or “live data” image. The predicted summary statistics are the model’s best estimation of what the summary statistics would be on the image if the image had human annotations collected. The prediction is generated automatically by passing the sensor data through the model.

**[0064]** FIG. 4 is a diagram showing an example of an application of a context user prediction process in an automobile context, according to some embodiments of the invention. In this example intention 406 418 means that the road user 402 414 has the goal of moving into the path of the vehicle 400 before the vehicle 400 (on which the system is mounted) reaches their position. Awareness 404 416 in this example means that the road user 402 414 understands that the vehicle on which the system is mounted 400 is present in their vicinity. In this example, when cyclist 402 rides into the field of view of a camera mounted on vehicle 400, the pixel data of the camera image of the cyclist is fed to a trained algorithm as described above in step 900. The trained algorithm analyzes the image as described above in step 902. The trained algorithm would predict summary statistics as in step 904. These summary statistics are an estimate of what the summary statistics would be for a collection of

human observers who were shown a derived stimulus of the camera data as in step 504. The estimates summary statistics are therefore the system's best answer to the question "does this cyclist intend to enter the path of the vehicle." The vehicle is therefore able to make a guess 406 about the intention of the cyclist that is closely matched to the guess that a human driver would make in that same situation. In this example, the intention of the cyclist 406 is relatively high, as indicated by the number of horizontal bars in the display. The system installed on an automobile 400 also makes predictions about the awareness 404 of cyclists of the vehicle 400, by the same method described for intention. It also makes predictions about the willingness of an automobile 408 to yield 410 or its desire to turn across the system-containing vehicle's path 412 by the same method described above. In the case of the automobile the questions that human subjects answered that would be predicted by the algorithm are "would the vehicle be willing to yield" 410 and "does the vehicle wish to turn across your path" 412. It also makes predictions about the desire of pedestrians 414 to cross in front of the vehicle 418, and whether those pedestrians are aware of the vehicle 416, by the same method described above.

**[0065]** The models described above can be implemented as a real-time module that makes predictions of road user behavior based on input from cameras or other sensors installed on a car 400. In the case of an autonomous car, these predictions can be used to make inferences about the intent of road users such as cyclists 402, other motorists 408, and pedestrians 414 to cross into the path of the car, as well as whether the road users are aware of the car and its future path. They can also be used to predict whether other road users would be surprised, welcoming, or aggressively unwelcoming if the car were to engage in maneuvers which would take it into the path of another road user (e.g., would an oncoming car yield if the car implementing the systems and methods described herein were to turn left).

### Determining a Stable Signal for Predicting Behavior of Traffic Entities

**[0066]** A pedestrian consumes information about the world that the pedestrian is walking in. The sensory apparatus of a traffic entity, for example, a pedestrian ingests many gigabytes of information about the world. This information is converted into a vast range of inferential judgments. Those judgments are used to update and execute moment-by-moment motion plans that propel the pedestrian through the traffic, and allow it to reach the pedestrian's target.

**[0067]** A human brain is able to negotiate complex situations with many contingent factors. This flexibility and capacity that makes human behavior very difficult to model using a computer. Even given a consistent goal structure the complexity of predicting human inference scales with the complexity of the inputs to the human perceptual system. In a complex environments, such as a pedestrian navigating a busy intersection, the number of perceptual inputs with high valence to moment-by-moment motion planning is extremely large. At any time the pedestrians actions at the next moment are influenced by many hundreds of different aspects of the scene. These can include moving agents, contextual cues, distractions, fixed obstacles, newly noticed scene aspects, and the internal process of reflection. Because of this, predicting the behavior of a pedestrian at any time that is not extremely close to the present is intractable. Even with a complete world model, the number of possible actions at, say, one second from the present moment are subject to a combinatorial explosion.

**[0068]** Embodiments of the invention extract a stable signal of potential behavior of a traffic entity, for example, pedestrian that is not subject to the combinatorial explosion of inputs. In one embodiment, this stable signal is used to modulate the performance envelope of a vehicle under full or partial automatic control. In another embodiment, this stable signal

is used to inform the human operator of a vehicle that the behavior of upcoming road users may require their attention.

**[0069]** In an embodiment, the stable signal is a computational model of the mental state of the pedestrian. Humans look at other humans and with a high degree of reliability and make estimates of their internal mental states as they apply to behavior. Embodiments of the invention train a model by leveraging indirect but highly reliable measurements of human theory of mind reasoning. This allows the model to make predictions about the internal mental states of others.

**[0070]** Embodiments of the invention predict an internal mental state of a pedestrian as a stable signal. The internal mental state of a pedestrian comprises a goal-oriented planning and evaluation system with short and long-term memory. A pedestrian on the sidewalk has come to occupy the sidewalk in pursuance of a specific goal (for example, to get to the other side). This goal has a duration that is (in general) far longer than the amount of time in which a computing system of an automatic vehicle would have to consider that pedestrian's state of mind. If a pedestrian has the goal of eventually reaching a destination on the other side of the street down which the vehicle in question is traveling, that goal will obtain until they have reached that destination. This goal will not generally be changed by transient conditions like the appearance of a "do not walk" sign. However, the likelihood that the pedestrian steps into the street at any given moment is very contingent on that transient condition. Embodiments of the invention predict estimates of state of mind, which aim to predict the internal goal and belief structure of the pedestrian, are therefore not subject to the combinatorial explosion of contingent factors.

#### Overall Process of Navigating an Autonomous Vehicle through Traffic

**[0071]** FIG. 5 represents a flowchart illustrating the process of navigating the autonomous vehicle based on hidden context, according to an embodiment. The steps

illustrated in the flowchart may be performed in an order different from that illustrated in FIG. 5. For example, certain steps may be performed in parallel. The steps may be performed by modules other than those indicated herein.

**[0072]** The vehicle computing system 120 receives 500 sensor data from sensors of the autonomous vehicle. For example, the vehicle computing system 120 may receive lidar scans from lidars and camera images from cameras mounted on the autonomous vehicle. In an embodiment, the vehicle computing system 120 builds a point cloud representation of the surroundings of the autonomous vehicle based on the sensor data. The point cloud representation includes coordinates of points surrounding the vehicle, for example, three dimensional points and parameters describing each point, for example, the color, intensity, and so on. The vehicle computing system 120 identifies 502 one or more traffic entities based on the sensor data, for example, pedestrians, bicyclists, or other vehicles driving in the traffic. The traffic entities represent non-stationary objects in the surroundings of the autonomous vehicle.

**[0073]** The vehicle computing system 120 repeats the following steps 504 and 506 for each identified traffic entity. The vehicle computing system 120 determines 504 motion parameters for the traffic entity, for example, speed and direction of movement of the traffic entity. The vehicle computing system 120 also determines 506 a hidden context associated with the traffic entity using the prediction engine 102. The hidden context may represent a state of mind of a person represented by the traffic entity. For example, the hidden context may represent a near term goal of the person represented by the traffic entity, for example, indicating that the person is likely to cross the street, or indicating that the person is likely to pick up an object (e.g., a wallet) dropped on the street but stay on that side of the street, or any other task that the person is likely to perform within a threshold time interval. The hidden context may represent a degree of awareness of the person about the autonomous

vehicle, for example, whether a bicyclist driving in front of the autonomous vehicle is likely to be aware that the autonomous vehicle is behind the bicycle.

**[0074]** In an embodiment, the vehicle computing system 120 represents the hidden context as a vector of values, each value representing a parameter, for example, a likelihood that a person represented by a traffic entity is going to cross the street in front of the autonomous vehicle, a degree of awareness of the presence of autonomous vehicle in the mind of a person represented by a traffic entity,

**[0075]** The vehicle computing system 120 navigates 508 the autonomous vehicle based on the motion parameters as well as the hidden context. For example, the vehicle computing system 120 may determine a safe distance from the traffic entity that the autonomous vehicle should maintain based on the motion parameters of the traffic entity. The vehicle computing system 120 modulates the safe distance based on the hidden context. The vehicle computing system 120 may adjust the safe distance based on whether the near-term goal of the person indicating that the person intends to reach a location in the direction of the movement of the traffic entity or in a different direction.

**[0076]** For example, based on the motion parameters, the vehicle computing system 120 may determine that the autonomous vehicle can drive within X meters of the traffic entity. However, the hidden context indicates that the person represented by the traffic entity intends to cross the street in a direction different from the direction indicated by the motion parameters. In this situation, the vehicle computing system 120 adjusts the safe distance such that the autonomous vehicle is able to drive closer to the traffic entity than the distance X. On the other hand, if the hidden context indicates that the person represented by the traffic entity intends to cross the street in a direction same as the direction indicated by the motion parameters, the vehicle computing system 120 adjusts the safe distance such that the autonomous vehicle maintains a distance greater than X from the traffic entity.

### False Positive Reduction

**[0077]** In autonomous vehicles and advance driver-assistance systems in which the driver is in control, the vehicle computing system 120 uses modulatory signals based on hidden context to reduce false positives. For instance, in the case of a braking system such as an automatic emergency braking (AEB) system, the vehicle computing system 120 modulates the activation threshold for the braking system based on a weighted linear combination of model outputs predicting estimates of values for hidden context attributes.

**[0078]** The vehicle computing system 120 determines the activation threshold for the emergency braking system based on the certainty of evidence required before brakes are applied. The vehicle computing system 120 determines the activation threshold for the emergency braking system to be higher in cases where the vehicle computing system 120 determines hidden context attributes with high certainty, e.g., hidden context attribute indicating whether the pedestrian in the roadway intended to cross the street or whether a bicyclist was aware of the vehicle. The vehicle computing system 120 adjusts the activation threshold to effectively remove or reduce false positive emergency braking scenarios, for example when a pedestrian enters the roadway for reasons other than intending to cross the road.

**[0079]** As an example, if the vehicle computing system 120 determines with a very high certainty that a pedestrian does not intend to cross the street, the vehicle computing system 120 adjusts the weightings and thresholds to decrease the likelihood of initiating the emergency breaking system when the pedestrian walks towards the street. On the other hand, if the vehicle computing system 120 determines with a very low certainty that the pedestrian does not intend to cross the street, the vehicle computing system 120 adjusts the weightings and thresholds to increase the likelihood of initiating the emergency breaking system if the pedestrian walks towards the street.

**[0080]** FIG. 6 represents a flowchart illustrating the process of using the modulatory signals to reduce false positives while navigating the autonomous vehicle, according to an embodiment. The vehicle computing system 120 performs the steps 622 and 624 for each traffic entity identified. The vehicle computing system 120 determines 622 a measure of statistical distribution of a hidden context for the traffic entity. In an embodiment, the prediction engine 102 executes a machine learning based model (e.g., a neural network) that predicts distribution associated with hidden context, for example, mean and variance of a likelihood that a person represented by a traffic entity wants to cross the street. The vehicle computing system 120 determines 624 an activation threshold value for the braking system of the autonomous vehicle based on the measure of statistical distribution of the hidden context. In an embodiment, the activation thresholds represents a threshold time to collision between the traffic entity and the vehicle. Accordingly, if the vehicle computing system 120 determines that the time to collision with a traffic entity is below the activation threshold, the vehicle computing system 120 activates emergency brakes of the autonomous vehicle.

**[0081]** The vehicle computing system 120 periodically predicts the time to collision for each traffic entity. If the vehicle computing system 120 determines 626 at any point in time that the time to collision of the autonomous vehicle within the activation threshold of a traffic entity, the vehicle computing system 120 activates the braking system.

**[0082]** The vehicle computing system 120 uses lower activation thresholds if the model outputs indicate higher uncertainty in values of hidden context attributes, for example, estimates of state of mind of a user represented by a traffic entity or estimates of degree of awareness of information such as the presence of the autonomous vehicle in the mind of a user represented by a traffic entity. Accordingly, in situations where the hidden context attribute indicates a high degree of uncertainty indicating a likelihood of a collision, the vehicle computing system 120 is more likely to initiate emergency maneuvers than in

situations where the hidden context attribute is determined with lower certainty indicating a likelihood of collision.

**[0083]** In an embodiment, the weightings and the amount of threshold modulation is set by a user. In other embodiments, the weightings and the amount of threshold modulation is adjusted based on simulation results. Accordingly, different weightings and threshold values are set and the results of navigation of an autonomous vehicle are determined based on simulation of traffic. The weightings and amounts of threshold values are adjusted, so as to minimize the likelihood of collision as well as provide a driving experience close to the driving experience when a human is driving the vehicle. In an embodiment, the results of simulation are provided to an expert for evaluation, for example, to rank the driving experience from the perspective of a human.

**[0084]** An additional tuning parameter that is used by the vehicle computing system 120 is the distributional nature of model outputs. The models of the prediction engine 102 predict the distributional characteristics of human responses to the presented human road user. In an embodiment, the vehicle computing system 120 uses the kurtosis of the output distribution as a tuning parameter that represents uncertainty for adjusting the activation thresholds of the AEB system. In cases where the kurtosis is very low, and the distribution approaches uniform, and vehicle computing system 120 uses low activation thresholds since the human uncertainty is determined to be high, and a measurement of central tendency is not useful for prediction. On the other hand, in cases with high kurtosis, the vehicle computing system 120 uses high activation thresholds since the central tendency is likely to represent substantial human agreement that the output intention or awareness value accurately reflects the internal mental state of the detected human road user.

## Navigating Autonomous Vehicle Based on Hidden Context

**[0085]** Embodiments of the vehicle computing system 120 predict hidden context representing intentions and future plans of an agent (e.g., a pedestrian or a bicyclist) and use the hidden context for navigating the autonomous vehicle, for example, by adjusting the path planning of the autonomous robot based on the hidden context. For example, the vehicle computing system 120 may improve the path planning by taking a machine learning based model that predicts the level of human uncertainty about the future actions of pedestrians and cyclists and uses that as an input into the autonomous vehicle's motion planner. The training vector further includes information about the ground truth of the world obtained from more computer vision models. The vehicle computing system 120 may use the output of the prediction engine 102 to generate a probabilistic map of the risk of encountering an obstacle given different possible motion vectors at the next time step. Alternatively, the vehicle computing system 120 may use the output of the prediction engine 102 to a motion plan which incorporates the probabilistic uncertainty of the human assessment.

**[0086]** In an embodiment, the prediction engine 102 determines a metric representing a degree of uncertainty in human assessment of the near-term goal of a pedestrian or any user representing a traffic entity. The specific form of the representation of uncertainty is a model output that comes in the form of a probability distribution, capturing the expected distributional characteristics of human assessments of the goal and awareness state of road users. The model output may comprise the central tendency, i.e., the mean likelihood that a person will act in a certain way and one or more parameters including the variance, kurtosis, skew, heteroskedasticity, and multimodality of the predicted human distribution. These summary statistics carry information about the level of human uncertainty.

## Computing Machine Architecture

**[0100]** FIG. 7 is a block diagram illustrating components of an example machine able to read instructions from a machine-readable medium and execute them in a processor (or controller). Specifically, FIG. 7 shows a diagrammatic representation of a machine in the example form of a computer system 700 within which instructions 724 (e.g., software) for causing the machine to perform any one or more of the methodologies discussed herein may be executed. In alternative embodiments, the machine operates as a standalone device or may be connected (e.g., networked) to other machines. In a networked deployment, the machine may operate in the capacity of a server machine or a client machine in a server-client network environment, or as a peer machine in a peer-to-peer (or distributed) network environment.

**[0101]** The machine may be a server computer, a client computer, a personal computer (PC), a tablet PC, a set-top box (STB), a personal digital assistant (PDA), a cellular telephone, a smartphone, a web appliance, a network router, switch or bridge, or any machine capable of executing instructions 724 (sequential or otherwise) that specify actions to be taken by that machine. Further, while only a single machine is illustrated, the term “machine” shall also be taken to include any collection of machines that individually or jointly execute instructions 724 to perform any one or more of the methodologies discussed herein.

**[0102]** The example computer system 700 includes a processor 702 (e.g., a central processing unit (CPU), a graphics processing unit (GPU), a digital signal processor (DSP), one or more application specific integrated circuits (ASICs), one or more radio-frequency integrated circuits (RFICs), or any combination of these), a main memory 704, and a static memory 706, which are configured to communicate with each other via a bus 708. The computer system 700 may further include graphics display unit 710 (e.g., a plasma display panel (PDP), a liquid crystal display (LCD), a projector, or a cathode ray tube (CRT)). The

computer system 700 may also include alphanumeric input device 712 (e.g., a keyboard), a cursor control device 714 (e.g., a mouse, a trackball, a joystick, a motion sensor, or other pointing instrument), a storage unit 716, a signal generation device 718 (e.g., a speaker), and a network interface device 720, which also are configured to communicate via the bus 708.

**[0103]** The storage unit 716 includes a machine-readable medium 722 on which is stored instructions 724 (e.g., software) embodying any one or more of the methodologies or functions described herein. The instructions 724 (e.g., software) may also reside, completely or at least partially, within the main memory 704 or within the processor 702 (e.g., within a processor's cache memory) during execution thereof by the computer system 700, the main memory 704 and the processor 702 also constituting machine-readable media. The instructions 724 (e.g., software) may be transmitted or received over a network 726 via the network interface device 720.

**[0104]** While machine-readable medium 722 is shown in an example embodiment to be a single medium, the term "machine-readable medium" should be taken to include a single medium or multiple media (e.g., a centralized or distributed database, or associated caches and servers) able to store instructions (e.g., instructions 724). The term "machine-readable medium" shall also be taken to include any medium that is capable of storing instructions (e.g., instructions 724) for execution by the machine and that cause the machine to perform any one or more of the methodologies disclosed herein. The term "machine-readable medium" includes, but not be limited to, data repositories in the form of solid-state memories, optical media, and magnetic media.

#### Additional Considerations

**[0087]** Although embodiments disclosed describe techniques for navigating autonomous vehicles, the techniques disclosed are applicable to any mobile apparatus, for example, a robot, a delivery vehicle, a drone, and so on.

**[0088]** The subject matter described herein can be implemented in digital electronic circuitry, or in computer software, firmware, or hardware, including the structural means disclosed in this specification and structural equivalents thereof, or in combinations of them. The subject matter described herein can be implemented as one or more computer program products, such as one or more computer programs tangibly embodied in an information carrier (e.g., in a machine readable storage device) or in a propagated signal, for execution by, or to control the operation of, data processing apparatus (e.g., a programmable processor, a computer, or multiple computers). A computer program (also known as a program, software, software application, or code) can be written in any form of programming language, including compiled or interpreted languages, and it can be deployed in any form, including as a stand-alone program or as a module, component, subroutine, or other unit suitable for use in a computing environment. A computer program does not necessarily correspond to a file. A program can be stored in a portion of a file that holds other programs or data, in a single file dedicated to the program in question, or in multiple coordinated files (e.g., files that store one or more modules, sub programs, or portions of code). A computer program can be deployed to be executed on one computer or on multiple computers at one site or distributed across multiple sites and interconnected by a communication network.

**[0089]** The processes and logic flows described in this specification, including the method steps of the subject matter described herein, can be performed by one or more programmable processors executing one or more computer programs to perform functions of the subject matter described herein by operating on input data and generating output. The processes and logic flows can also be performed by, and apparatus of the subject matter described herein can be implemented as, special purpose logic circuitry, e.g., an FPGA (field programmable gate array) or an ASIC (application specific integrated circuit).

**[0090]** Processors suitable for the execution of a computer program include, by way of example, both general and special purpose microprocessors, and any one or more processor of any kind of digital computer. Generally, a processor will receive instructions and data from a read only memory or a random access memory or both. The essential elements of a computer are a processor for executing instructions and one or more memory devices for storing instructions and data. Generally, a computer will also include, or be operatively coupled to receive data from or transfer data to, or both, one or more mass storage devices for storing data, e.g., magnetic, magneto optical disks, or optical disks. Information carriers suitable for embodying computer program instructions and data include all forms of nonvolatile memory, including by way of example semiconductor memory devices, (e.g., EPROM, EEPROM, and flash memory devices); magnetic disks, (e.g., internal hard disks or removable disks); magneto optical disks; and optical disks (e.g., CD and DVD disks). The processor and the memory can be supplemented by, or incorporated in, special purpose logic circuitry.

**[0091]** To provide for interaction with a user, the subject matter described herein can be implemented on a computer having a display device, e.g., a CRT (cathode ray tube) or LCD (liquid crystal display) monitor, for displaying information to the user and a keyboard and a pointing device, (e.g., a mouse or a trackball), by which the user can provide input to the computer. Other kinds of devices can be used to provide for interaction with a user as well. For example, feedback provided to the user can be any form of sensory feedback, (e.g., visual feedback, auditory feedback, or tactile feedback), and input from the user can be received in any form, including acoustic, speech, or tactile input.

**[0092]** The subject matter described herein can be implemented in a computing system that includes a back end component (e.g., a data server), a middleware component (e.g., an application server), or a front end component (e.g., a client computer having a graphical user

interface or a web browser through which a user can interact with an implementation of the subject matter described herein), or any combination of such back end, middleware, and front end components. The components of the system can be interconnected by any form or medium of digital data communication, e.g., a communication network. Examples of communication networks include a local area network (“LAN”) and a wide area network (“WAN”), e.g., the Internet.

**[0093]** It is to be understood that the disclosed subject matter is not limited in its application to the details of construction and to the arrangements of the components set forth in the following description or illustrated in the drawings. The disclosed subject matter is capable of other embodiments and of being practiced and carried out in various ways. Also, it is to be understood that the phraseology and terminology employed herein are for the purpose of description and should not be regarded as limiting.

**[0094]** As such, those skilled in the art will appreciate that the conception, upon which this disclosure is based, may readily be utilized as a basis for the designing of other structures, methods, and systems for carrying out the several purposes of the disclosed subject matter. It is important, therefore, that the claims be regarded as including such equivalent constructions insofar as they do not depart from the spirit and scope of the disclosed subject matter.

**[0095]** Although the disclosed subject matter has been described and illustrated in the foregoing exemplary embodiments, it is understood that the present disclosure has been made only by way of example, and that numerous changes in the details of implementation of the disclosed subject matter may be made without departing from the spirit and scope of the disclosed subject matter, which is limited only by the claims which follow.

Claimable material includes the following but is not limited to (automatic braking system):

1. A method comprising:

receiving, by an autonomous vehicle, sensor data from sensors mounted on the autonomous vehicle;

identifying, one or more traffic entities based on the sensor data, the traffic entities representing non-stationary objects in traffic in which the autonomous vehicle is driving;

for each of the one or more traffic entities:

determining a hidden context based on a machine learning based model, wherein the machine learning based model is trained based on feedback received from users responsive to presenting images or videos showing traffic scenarios to the users, wherein the output of the machine learning based model comprises a measure of statistical distribution of the hidden context; and

determining an activation threshold value for braking system of the autonomous vehicle based on the measure of statistical distribution of the hidden context;

predicting that the autonomous vehicle is likely to reach within the activation

threshold of a particular traffic entity within a threshold time interval; and

responsive to determining that the autonomous vehicle is likely to reach within the activation threshold of the particular traffic entity within the threshold time interval, activating the braking system of the autonomous vehicle.

2. The method as in any of the preceding claims, wherein the activation threshold value for the braking system of the autonomous vehicle has a value inversely proportionate to the degree of uncertainty in determining the hidden context.
3. The method as in any of the preceding claims, wherein determining the activation threshold value for braking system of the autonomous vehicle based on the distribution of the hidden context comprises:
  - determining a measure of kurtosis of the output distribution of the hidden context; and
  - wherein the activation threshold value for braking system of the autonomous vehicle has a value inversely proportionate to the measure of kurtosis of the output distribution of the hidden context.
4. The method as in any of the preceding claims, wherein the hidden context represents a state of mind of a user represented by the traffic entity.
5. The method as in any of the preceding claims, wherein the hidden context represents a task that a user represented by the traffic entity is planning on accomplishing.
6. The method as in any of the preceding claims, wherein the hidden context represents a degree of awareness of the autonomous vehicle by a user represented by the traffic entity.
7. The method as in any of the preceding claims, wherein the hidden context represents a goal of a user represented by the traffic entity, wherein the user expects to achieve the goal within a threshold time interval.

8. The method as in any of the preceding claims, wherein navigating the autonomous vehicle comprises:

generating signals for controlling the autonomous vehicle based on the motion parameters and the hidden context of each of the traffic entities; and  
sending the generated signals to controls of the autonomous vehicle.

9. The method as in any of the preceding claims, wherein the sensor data represents one or more images captured by a camera mounted on the autonomous vehicle.

10. The method as in any of the preceding claims, wherein the sensor data represents a lidar scan captured by a lidar mounted on the autonomous vehicle.

11. A non-transitory computer readable storage medium storing instructions for performing the steps of methods of claims 1-10.

12. A computer system comprising:  
one or more computer processors; and  
the non-transitory computer readable storage medium of claim 11.



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The country code and number of your priority application, to be used for filing abroad under the Paris Convention, is **US 62/822,269**

**Projected Publication Date:** None, application is not eligible for pre-grant publication

**Non-Publication Request:** No

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**\*\* SMALL ENTITY \*\***

**Title**

REDUCING FALSE POSITIVES FOR AUTOMATIC BRAKING OF AUTONOMOUS VEHICLES  
BASED ON PREDICTION OF HIDDEN CONTEXT ASSOCIATED WITH TRAFFIC ENTITIES

**Statement under 37 CFR 1.55 or 1.78 for AIA (First Inventor to File) Transition Applications: No**

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