US010818105B1

(12) **United States Patent**
Konrardy et al.

(10) **Patent No.: US 10,818,105 B1**
(45) **Date of Patent: Oct. 27, 2020**

(54) **SENSOR MALFUNCTION DETECTION**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 119 days.

(21) Appl. No.: **15/409,248**

(22) Filed: **Jan. 18, 2017**

Related U.S. Application Data

(60) Provisional application No. 62/434,359, filed on Dec. 14, 2016, provisional application No. 62/434,355,
(Continued)

(51) **Int. Cl.**
G07C 5/08 (2006.01)
H04L 29/08 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC ***G07C 5/0808*** (2013.01); ***G01B 21/00*** (2013.01); ***G06F 17/00*** (2013.01); ***G08B 21/00*** (2013.01); ***G08B 21/18*** (2013.01); ***H04L 67/12*** (2013.01)

(58) **Field of Classification Search**
CPC G07C 5/0808; G01B 21/00; G06F 17/00; G08B 21/00; G08B 21/18; H04L 67/12
See application file for complete search history.

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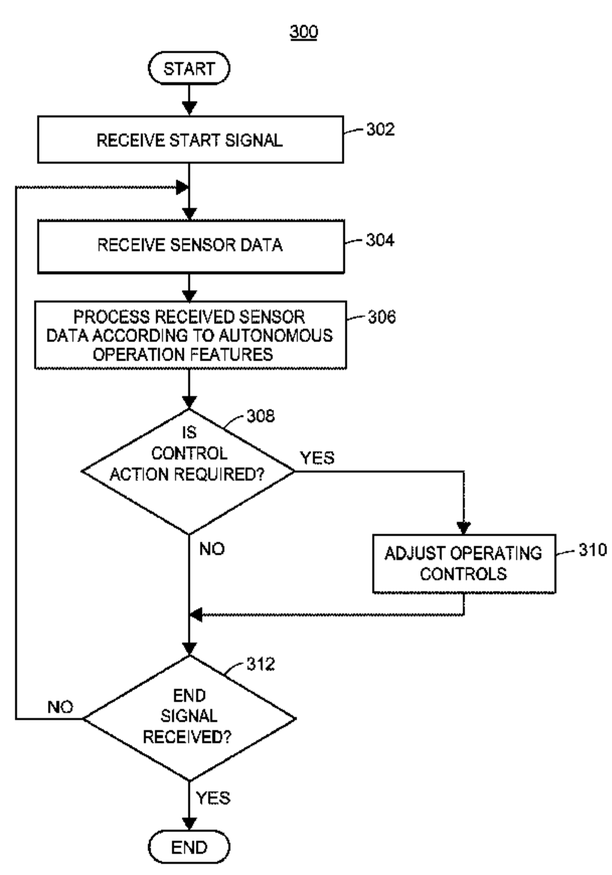
(57) **ABSTRACT**

Methods and systems for assessing, detecting, and responding to malfunctions involving components of autonomous vehicles and/or smart homes are described herein. Malfunctions may be detected by receiving sensor data from a plurality of sensors. One of these sensors may be selected for assessment. An electronic device may obtain from the selected sensor a set of signals. When the set of signals includes signals that are outside of a determined range of signals associated with proper functioning for the selected sensor, it may be determined that the selected sensor is malfunctioning. In response, an action may be performed to resolve the malfunction and/or mitigate consequences of the malfunction.

7 Claims, 12 Drawing Sheets



Related U.S. Application Data

filed on Dec. 14, 2016, provisional application No. 62/434,361, filed on Dec. 14, 2016, provisional application No. 62/434,370, filed on Dec. 14, 2016, provisional application No. 62/434,368, filed on Dec. 14, 2016, provisional application No. 62/434,365, filed on Dec. 14, 2016, provisional application No. 62/430,215, filed on Dec. 5, 2016, provisional application No. 62/428,843, filed on Dec. 1, 2016, provisional application No. 62/434,078, filed on Nov. 18, 2016, provisional application No. 62/434,093, filed on Nov. 18, 2016, provisional application No. 62/419,017, filed on Nov. 8, 2016, provisional application No. 62/418,999, filed on Nov. 8, 2016, provisional application No. 62/419,009, filed on Nov. 8, 2016, provisional application No. 62/418,988, filed on Nov. 8, 2016, provisional application No. 62/419,023, filed on Nov. 8, 2016, provisional application No. 62/419,002, filed on Nov. 8, 2016, provisional application No. 62/415,672, filed on Nov. 1, 2016, provisional application No. 62/415,668, filed on Nov. 1, 2016, provisional application No. 62/415,678, filed on Nov. 1, 2016, provisional application No. 62/415,673, filed on Nov. 1, 2016, provisional application No. 62/406,605, filed on Oct. 11, 2016, provisional application No. 62/406,600, filed on Oct. 11, 2016, provisional application No. 62/406,595, filed on Nov. 11, 2016, provisional application No. 62/406,611, filed on Oct. 11, 2016, provisional application No. 62/381,848, filed on Aug. 31, 2016, provisional application No. 62/380,686, filed on Aug. 29, 2016, provisional application No. 62/376,044, filed on Aug. 17, 2016, provisional application No. 62/373,084, filed on Aug. 10, 2016, provisional application No. 62/351,559, filed on Jun. 17, 2016, provisional application No. 62/349,884, filed on Jun. 14, 2016, provisional application No. 62/312,109, filed on Mar. 23, 2016, provisional application No. 62/303,500, filed on Mar. 4, 2016, provisional application No. 62/302,990, filed on Mar. 3, 2016, provisional application No. 62/287,659, filed on Jan. 27, 2016, provisional application No. 62/286,017, filed on Jan. 22, 2016.

(51) **Int. Cl.**

G01B 21/00	(2006.01)
G08B 21/18	(2006.01)
G08B 21/00	(2006.01)
G06F 17/00	(2019.01)

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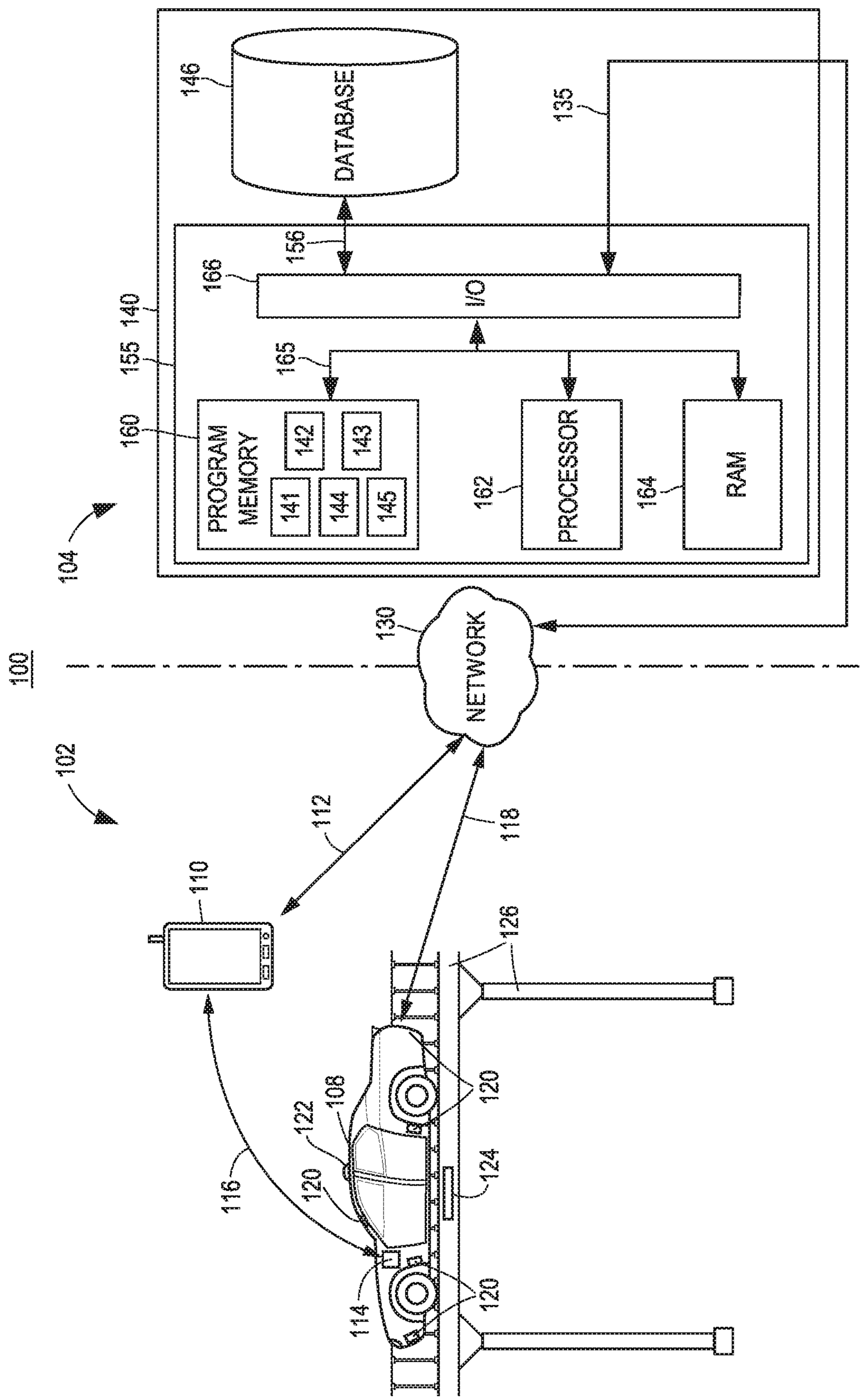
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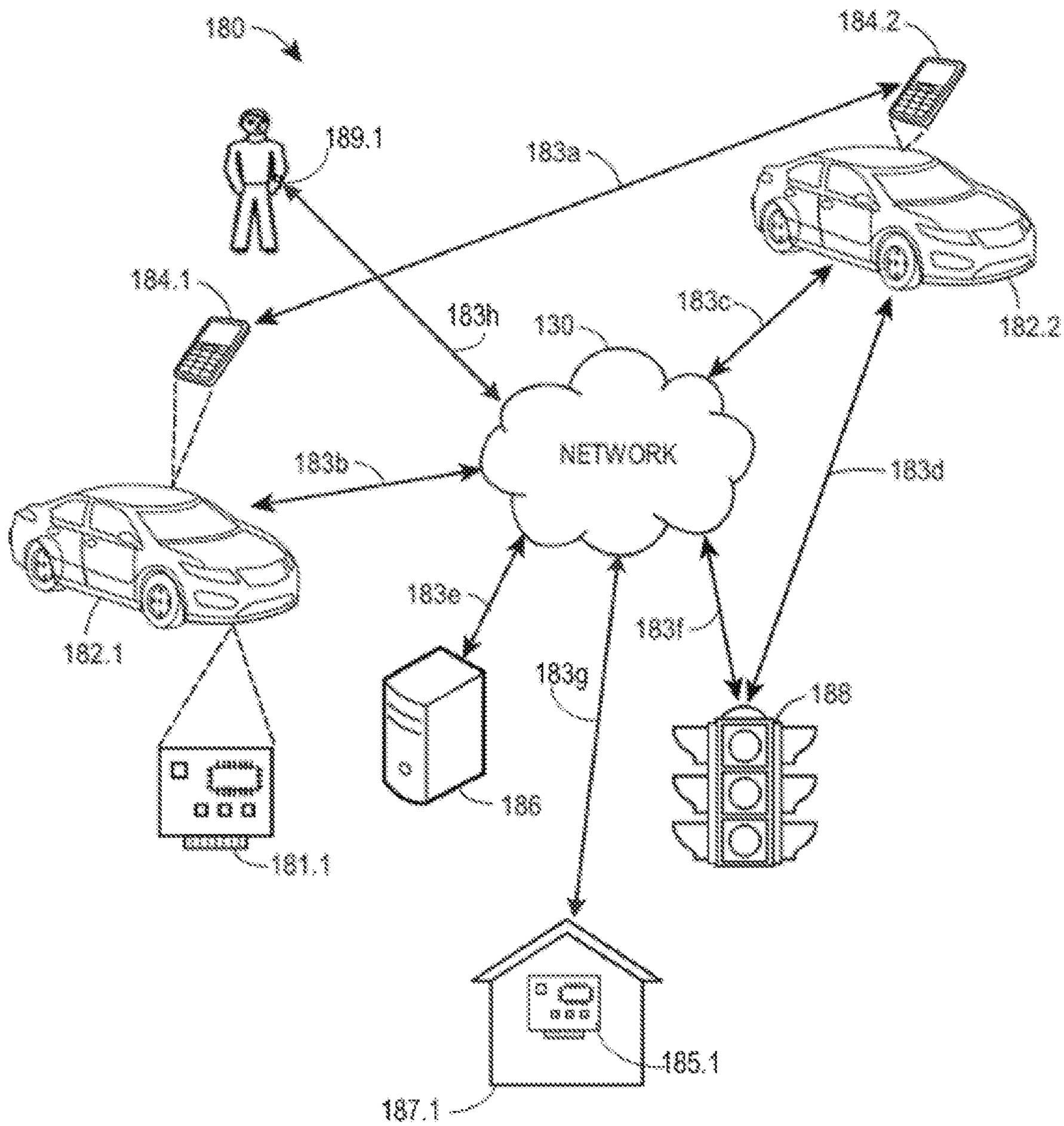
102
104
DATABASE
146
135
156
166
I/O
140
155
165
160
PROGRAM MEMORY
141
142
143
144
145
162
PROCESSOR
164
RAM
130
NETWORK
112
118
110
126
108
122
120
124
116
114

FIG. 1A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184.2
189.1
183a
184.1
183h
130
183c
182.2
NETWORK
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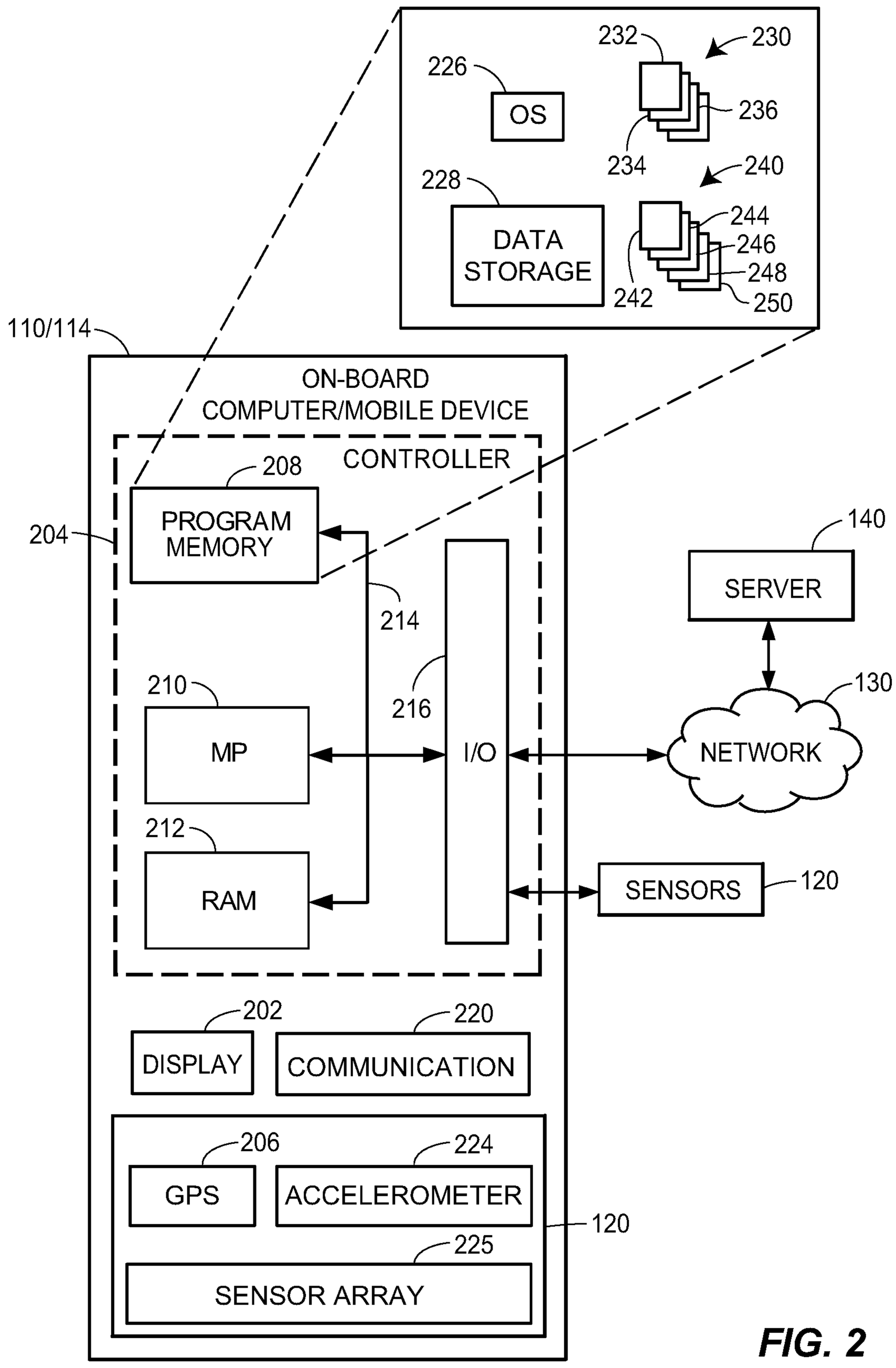
183d
182.1
183e
183f
183g
188
186
181.1
185.1
187.1

FIG. 1B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230
226
OS
236
234
240
228
DATA STORAGE
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246
248
242
250
110/114
ON-BOARD COMPUTER/MOBILE DEVICE
CONTROLLER
208
PROGRAM MEMORY
204
140
SERVER
214
130
210
216
MP
I/O
NETWORK
212
RAM
SENSORS
120
202
220
DISPLAY
COMMUNICATION
206
224
GPS
ACCELEROMETER
120
225
SENSOR ARRAY

FIG. 2

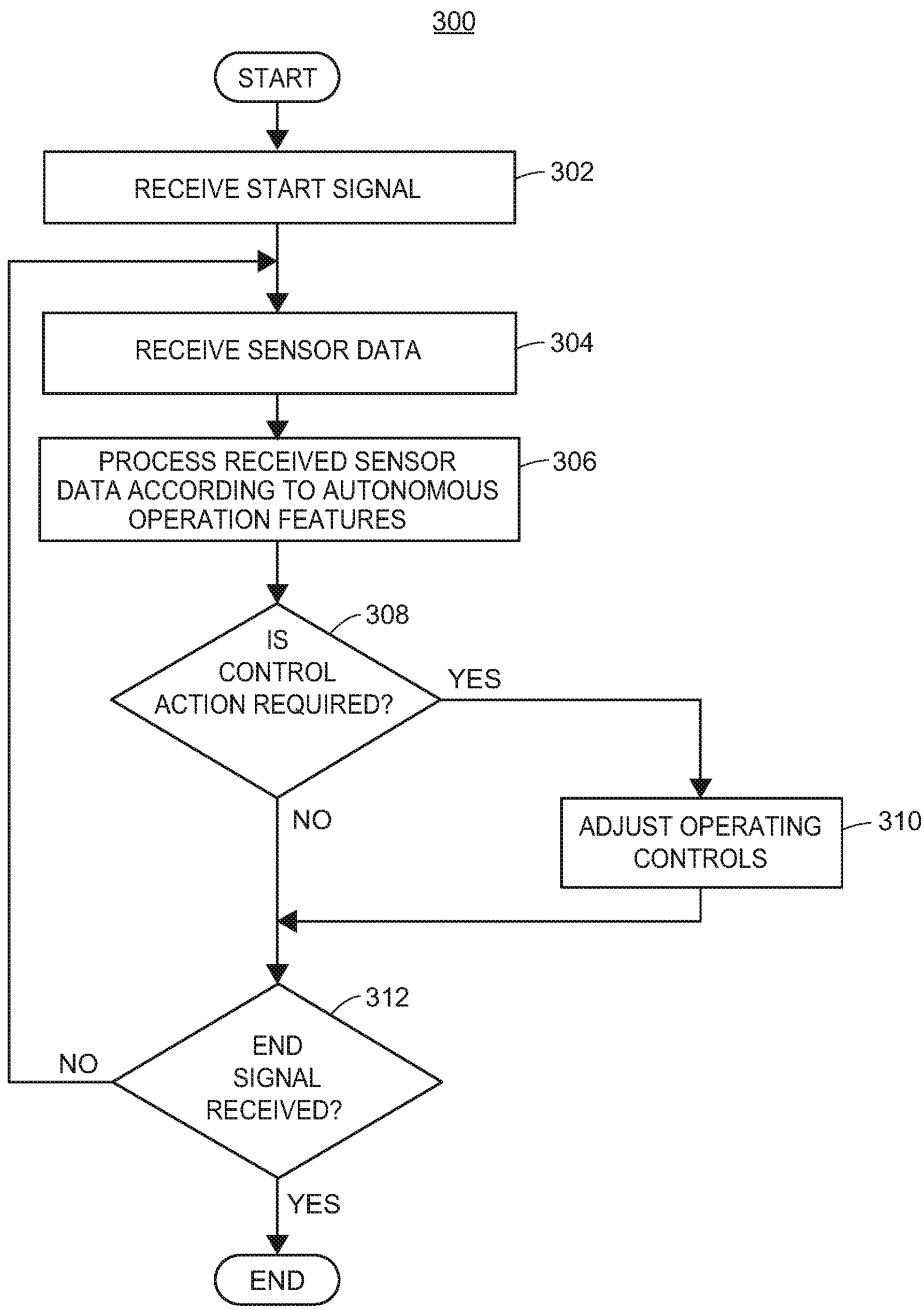
300
START
RECEIVE START SIGNAL
302
RECEIVE SENSOR DATA
304
PROCESS RECEIVED SENSOR DATA ACCORDING TO AUTONOMOUS OPERATION FEATURES
306
IS CONTROL ACTION REQUIRED?
308
YES
NO
ADJUST OPERATING CONTROLS
310
END SIGNAL RECEIVED?
312
NO
YES
END

FIG. 3

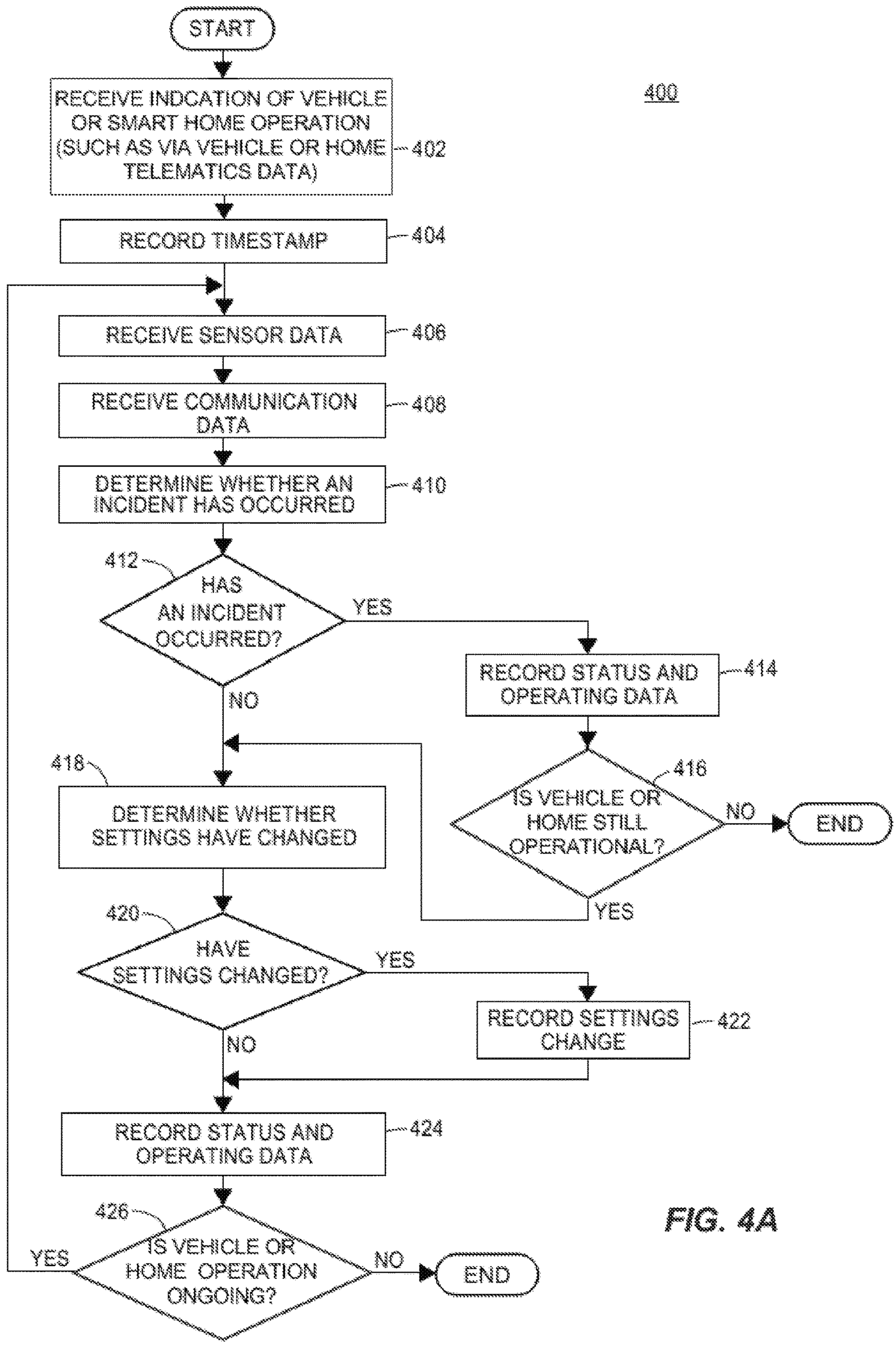
400
START
RECEIVE INDCATION OF VEHICLE OR SMART HOME OPERATION (SUCH AS VIA VEHICLE OR HOME TELEMATICS DATA)
402
RECORD TIMESTAMP
404
RECEIVE SENSOR DATA
406
RECEIVE COMMUNICATION DATA
408
DETERMINE WHETHER AN INCIDENT HAS OCCURRED
410
412
HAS AN INCIDENT OCCURRED?
YES
NO
RECORD STATUS AND OPERATING DATA
414
416
IS VEHICLE OR HOME STILL OPERATIONAL?
NO
END
YES
418
DETERMINE WHETHER SETTINGS HAVE CHANGED
420
HAVE SETTINGS CHANGED?
YES
NO
RECORD SETTINGS CHANGE
422
RECORD STATUS AND OPERATING DATA
424
426
IS VEHICLE OR HOME OPERATION ONGOING?
YES
NO
END

FIG. 4A

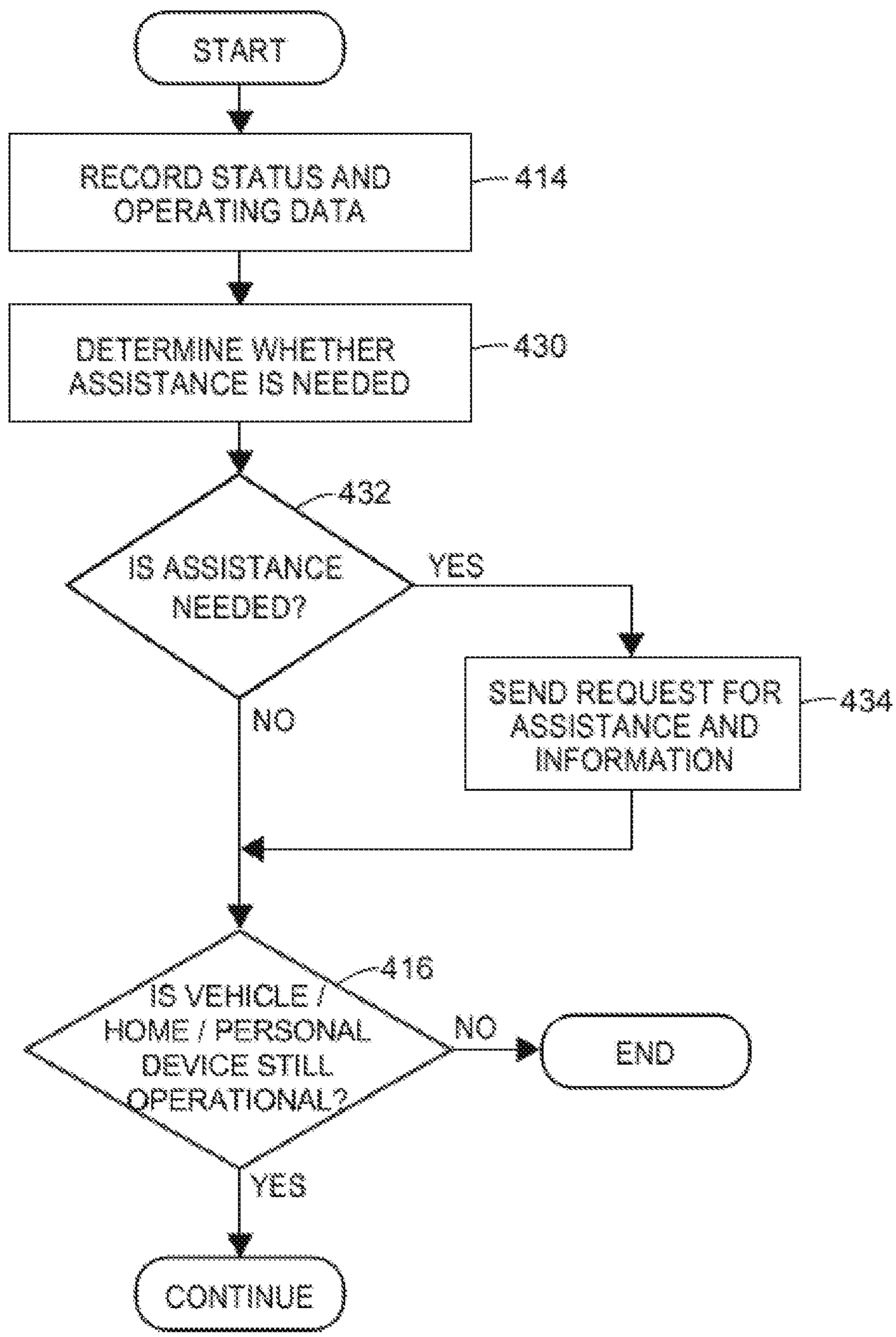
START
RECORD STATUS AND OPERATING DATA
414
DETERMINE WHETHER ASSISTANCE IS NEEDED
430
IS ASSISTANCE NEEDED?
432
YES
NO
SEND REQUEST FOR ASSISTANCE AND INFORMATION
434
IS VEHICLE / HOME / PERSONAL DEVICE STILL OPERATIONAL?
416
NO
END
YES
CONTINUE

FIG. 4B

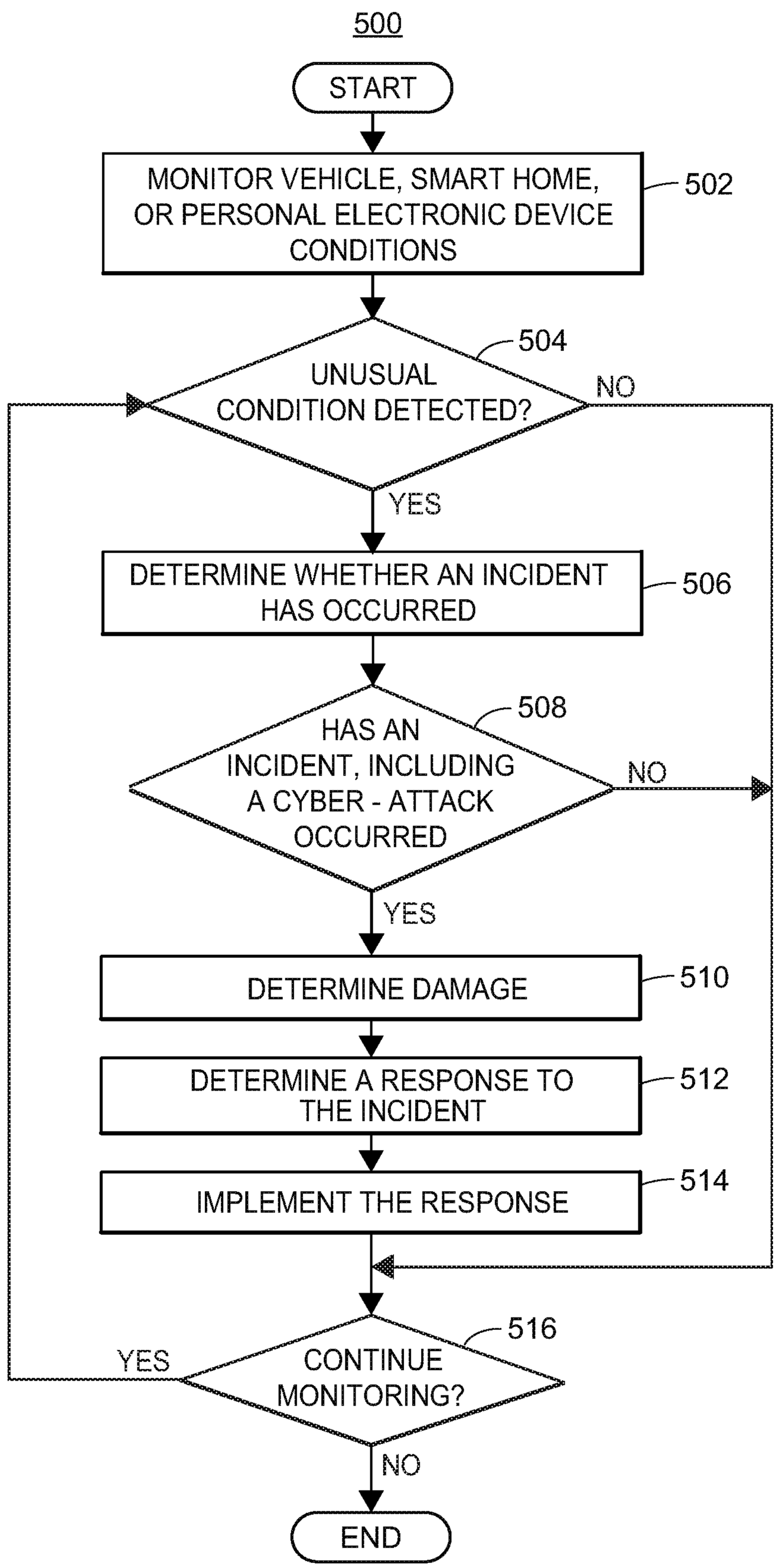
500
START
MONITOR VEHICLE, SMART HOME, OR PERSONAL ELECTRONIC DEVICE CONDITIONS
502
UNUSUAL CONDITION DETECTED?
504
NO
YES
DETERMINE WHETHER AN INCIDENT HAS OCCURRED
506
HAS AN INCIDENT, INCLUDING A CYBER - ATTACK OCCURRED
508
NO
YES
DETERMINE DAMAGE
510
DETERMINE A RESPONSE TO THE INCIDENT
512
IMPLEMENT THE RESPONSE
514
CONTINUE MONITORING?
516
YES
NO
END

FIG. 5

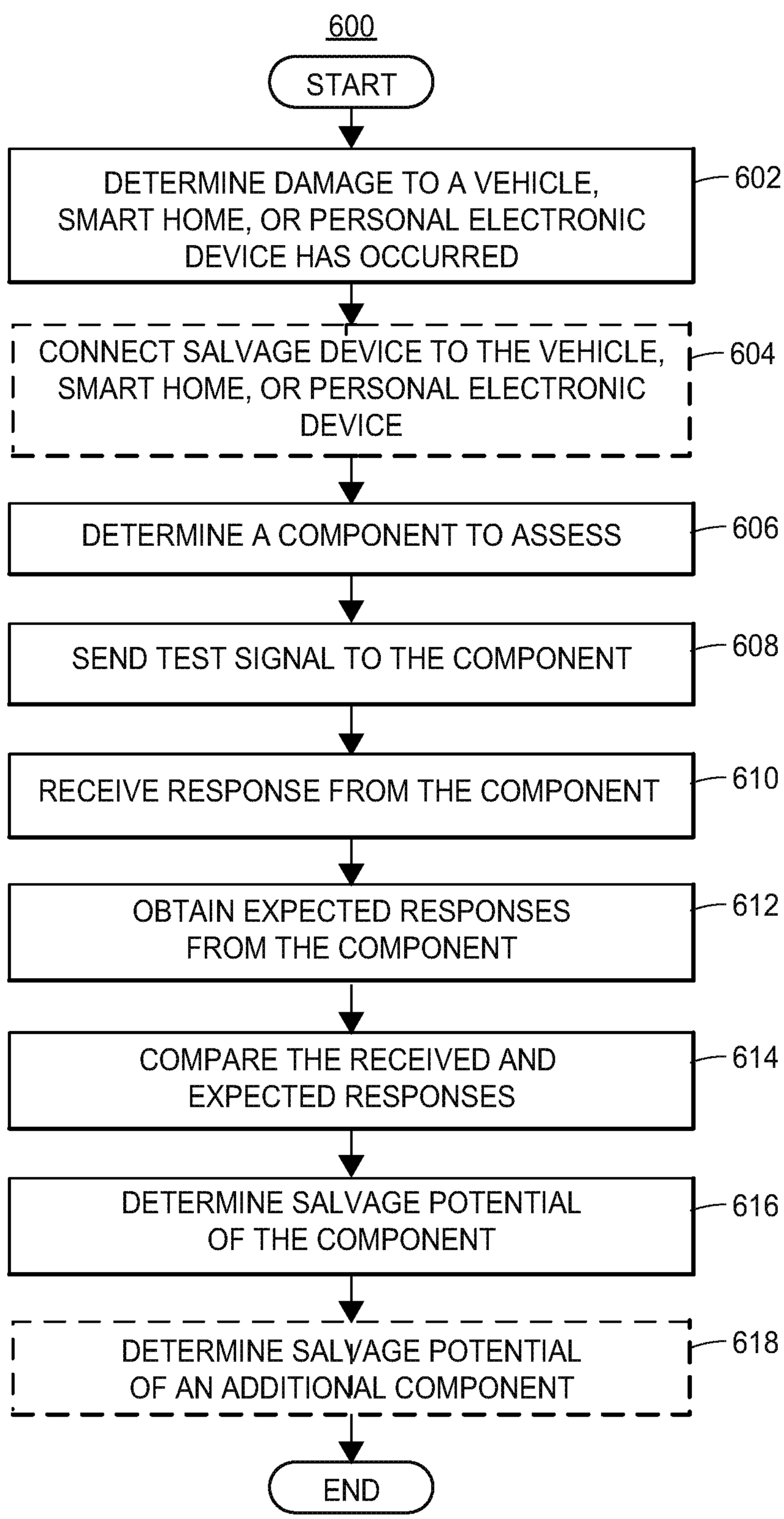
600
START
DETERMINE DAMAGE TO A VEHICLE, SMART HOME, OR PERSONAL ELECTRONIC DEVICE HAS OCCURRED
602
CONNECT SALVAGE DEVICE TO THE VEHICLE, SMART HOME, OR PERSONAL ELECTRONIC DEVICE
604
DETERMINE A COMPONENT TO ASSESS
606
SEND TEST SIGNAL TO THE COMPONENT
608
RECEIVE RESPONSE FROM THE COMPONENT
610
OBTAIN EXPECTED RESPONSES FROM THE COMPONENT
612
COMPARE THE RECEIVED AND EXPECTED RESPONSES
614
DETERMINE SALVAGE POTENTIAL OF THE COMPONENT
616
DETERMINE SALVAGE POTENTIAL OF AN ADDITIONAL COMPONENT
618
END

FIG. 6

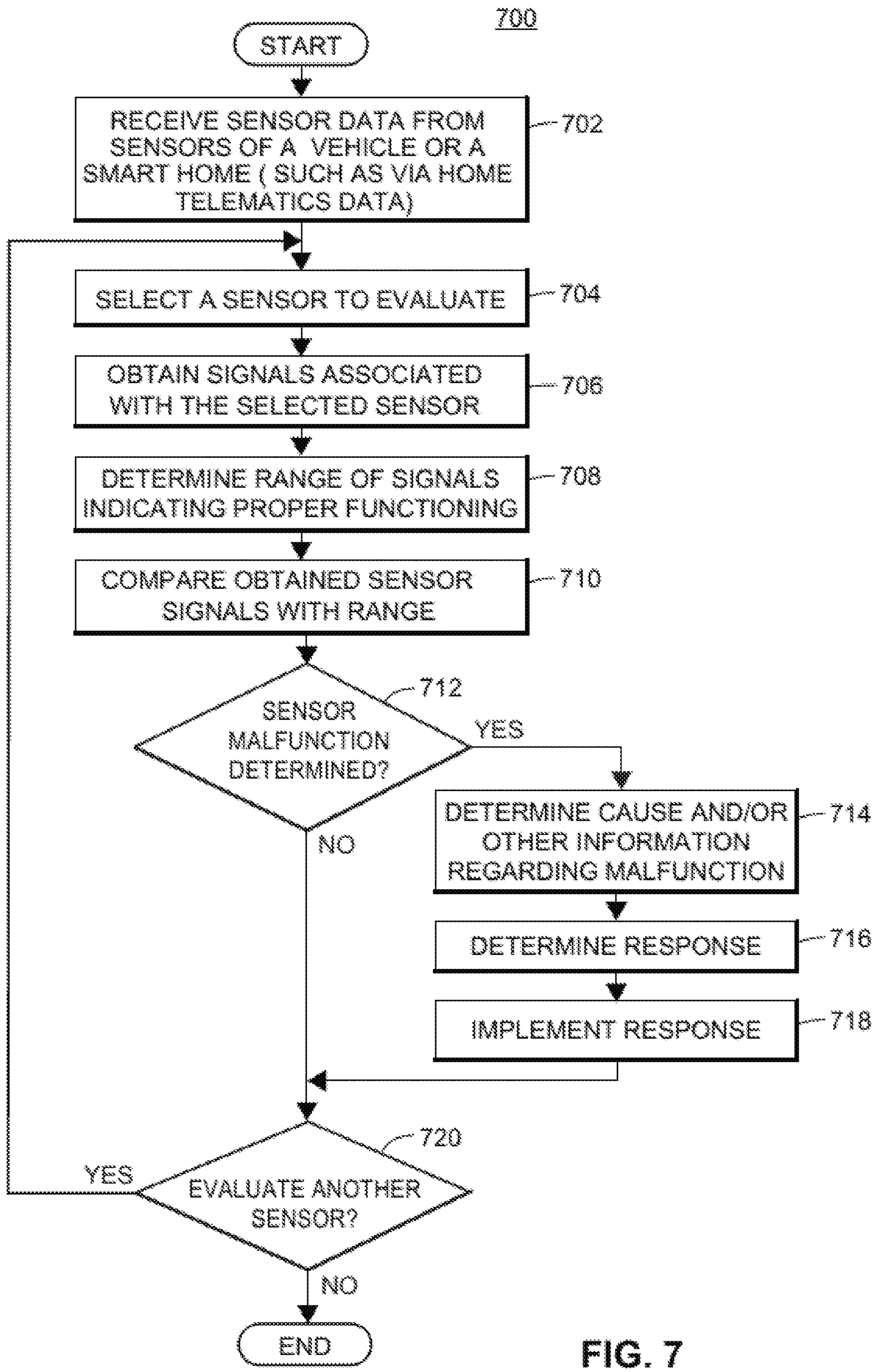
700
START
RECEIVE SENSOR DATA FROM SENSORS OF A VEHICLE OR A SMART HOME (SUCH AS VIA HOME TELEMATICS DATA)
702
SELECT A SENSOR TO EVALUATE
704
OBTAIN SIGNALS ASSOCIATED WITH THE SELECTED SENSOR
706
DETERMINE RANGE OF SIGNALS INDICATING PROPER FUNCTIONING
708
COMPARE OBTAINED SENSOR SIGNALS WITH RANGE
710
SENSOR MALFUNCTION DETERMINED?
712
YES
NO
DETERMINE CAUSE AND/OR OTHER INFORMATION REGARDING MALFUNCTION
714
DETERMINE RESPONSE
716
IMPLEMENT RESPONSE
718
EVALUATE ANOTHER SENSOR?
720
YES
NO
END

FIG. 7

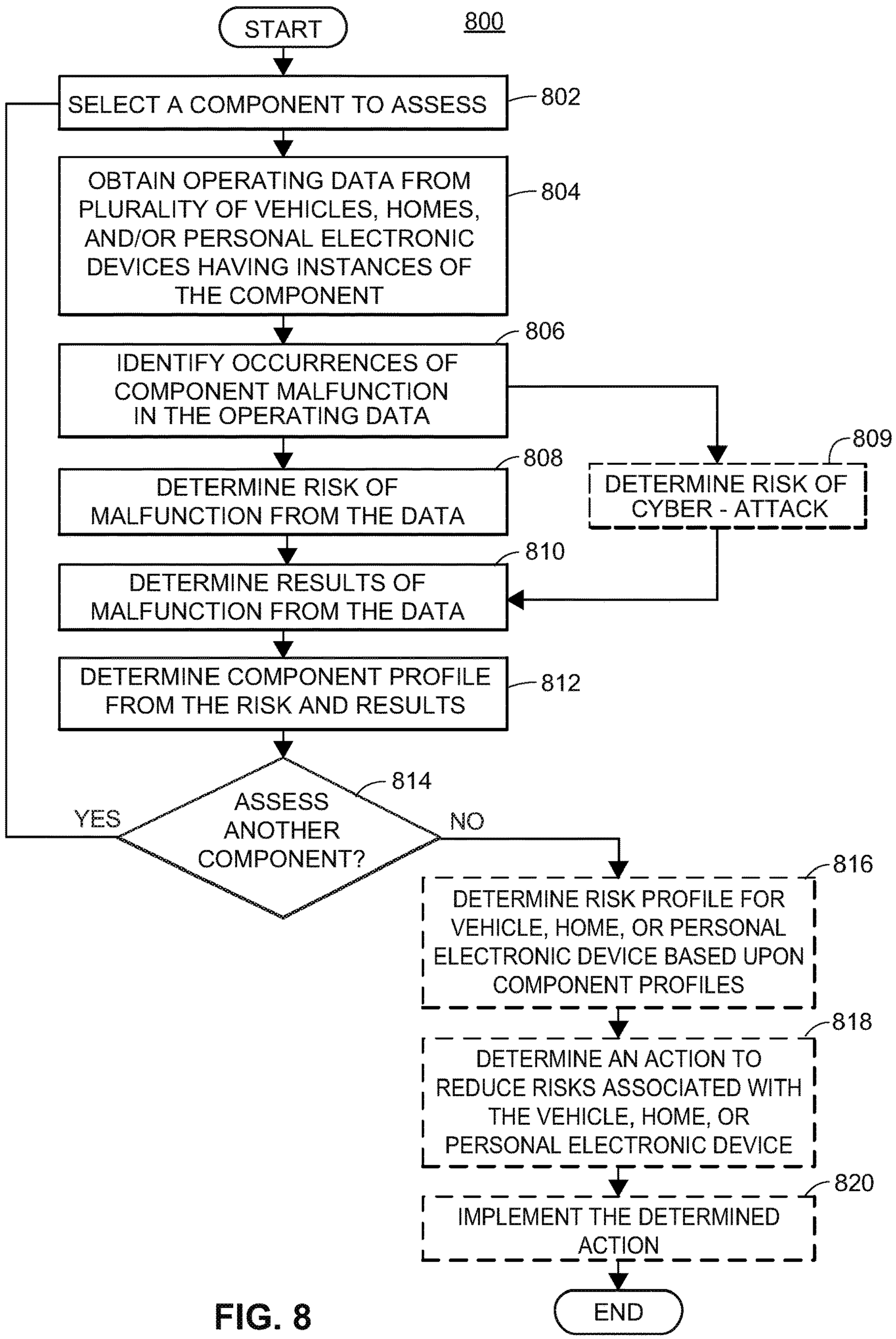
START
800
SELECT A COMPONENT TO ASSESS
802
OBTAIN OPERATING DATA FROM PLURALITY OF VEHICLES, HOMES, AND/OR PERSONAL ELECTRONIC DEVICES HAVING INSTANCES OF THE COMPONENT
804
IDENTIFY OCCURRENCES OF COMPONENT MALFUNCTION IN THE OPERATING DATA
806
DETERMINE RISK OF MALFUNCTION FROM THE DATA
808
DETERMINE RISK OF CYBER - ATTACK
809
DETERMINE RESULTS OF MALFUNCTION FROM THE DATA
810
DETERMINE COMPONENT PROFILE FROM THE RISK AND RESULTS
812
ASSESS ANOTHER COMPONENT?
814
YES
NO
DETERMINE RISK PROFILE FOR VEHICLE, HOME, OR PERSONAL ELECTRONIC DEVICE BASED UPON COMPONENT PROFILES
816
DETERMINE AN ACTION TO REDUCE RISKS ASSOCIATED WITH THE VEHICLE, HOME, OR PERSONAL ELECTRONIC DEVICE
818
IMPLEMENT THE DETERMINED ACTION
820
END

FIG. 8

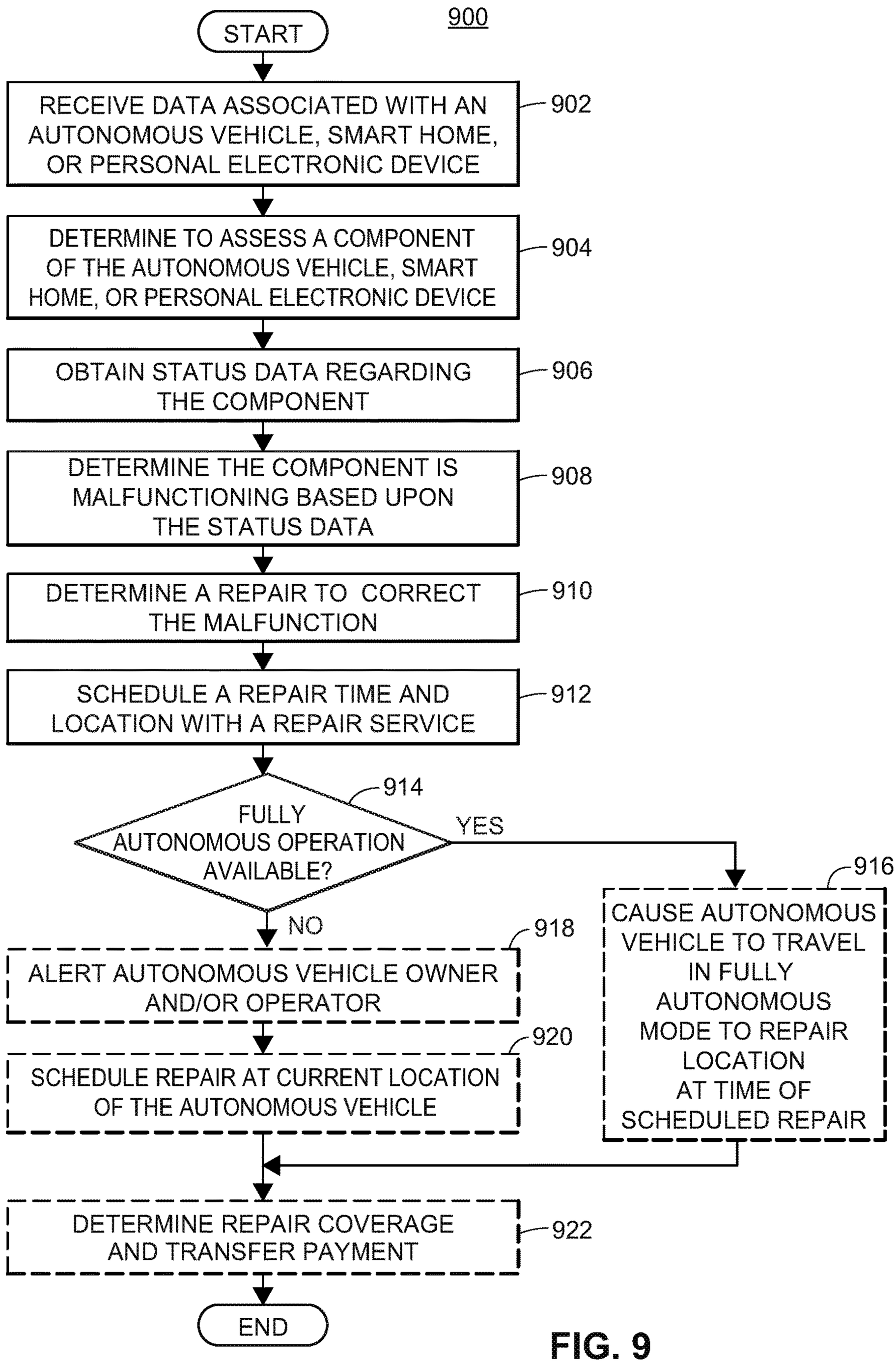
900
START
RECEIVE DATA ASSOCIATED WITH AN AUTONOMOUS VEHICLE, SMART HOME, OR PERSONAL ELECTRONIC DEVICE
902
DETERMINE TO ASSESS A COMPONENT OF THE AUTONOMOUS VEHICLE, SMART HOME, OR PERSONAL ELECTRONIC DEVICE
904
OBTAIN STATUS DATA REGARDING THE COMPONENT
906
DETERMINE THE COMPONENT IS MALFUNCTIONING BASED UPON THE STATUS DATA
908
DETERMINE A REPAIR TO CORRECT THE MALFUNCTION
910
SCHEDULE A REPAIR TIME AND LOCATION WITH A REPAIR SERVICE
912
FULLY AUTONOMOUS OPERATION AVAILABLE?
914
YES
NO
CAUSE AUTONOMOUS VEHICLE TO TRAVEL IN FULLY AUTONOMOUS MODE TO REPAIR LOCATION AT TIME OF SCHEDULED REPAIR
916
ALERT AUTONOMOUS VEHICLE OWNER AND/OR OPERATOR
918
SCHEDULE REPAIR AT CURRENT LOCATION OF THE AUTONOMOUS VEHICLE
920
DETERMINE REPAIR COVERAGE AND TRANSFER PAYMENT
922
END

FIG. 9

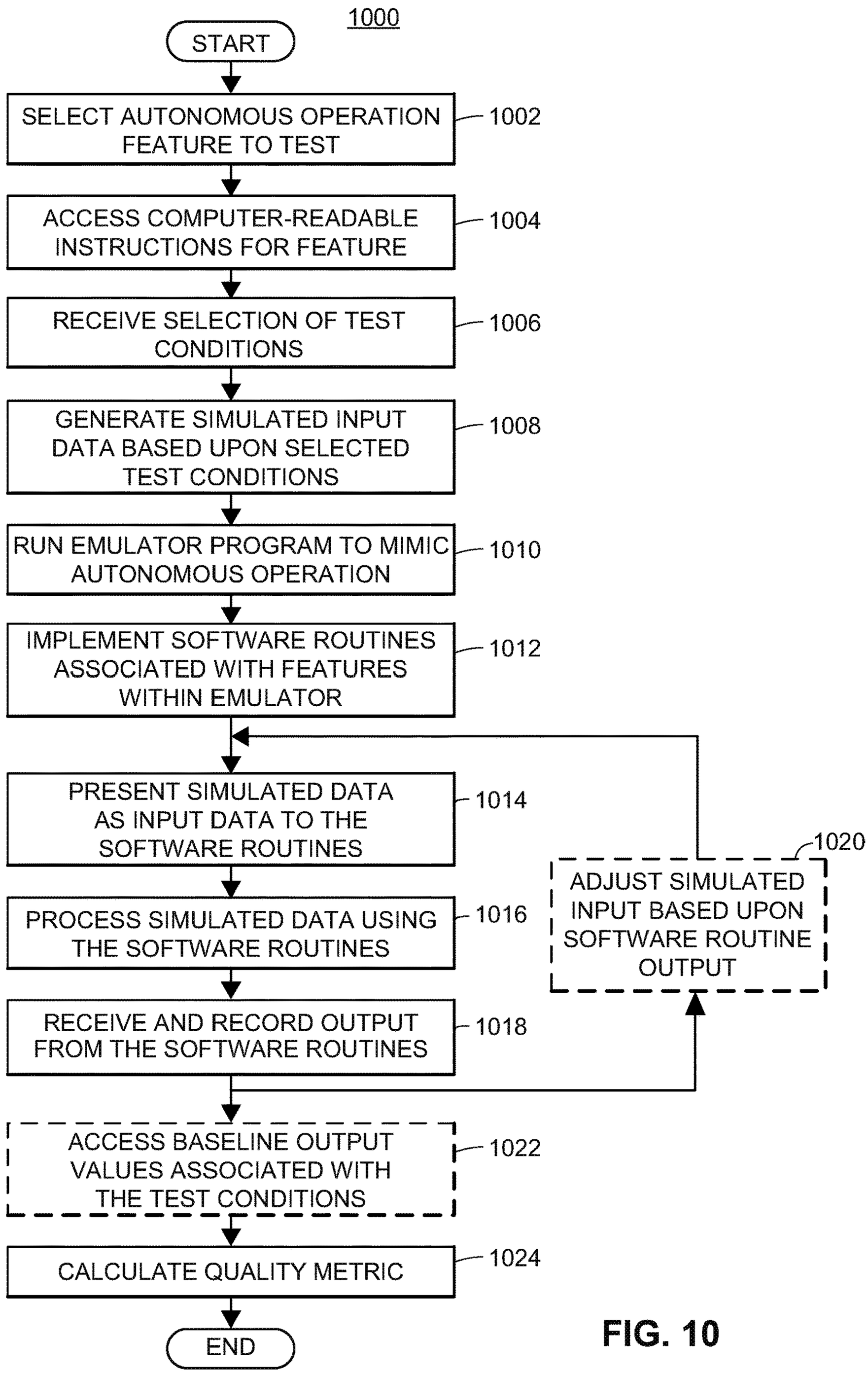
1000
START
SELECT AUTONOMOUS OPERATION FEATURE TO TEST
1002
ACCESS COMPUTER-READABLE INSTRUCTIONS FOR FEATURE
1004
RECEIVE SELECTION OF TEST CONDITIONS
1006
GENERATE SIMULATED INPUT DATA BASED UPON SELECTED TEST CONDITIONS
1008
RUN EMULATOR PROGRAM TO MIMIC AUTONOMOUS OPERATION
1010
IMPLEMENT SOFTWARE ROUTINES ASSOCIATED WITH FEATURES WITHIN EMULATOR
1012
PRESENT SIMULATED DATA AS INPUT DATA TO THE SOFTWARE ROUTINES
1014
PROCESS SIMULATED DATA USING THE SOFTWARE ROUTINES
1016
RECEIVE AND RECORD OUTPUT FROM THE SOFTWARE ROUTINES
1018
ADJUST SIMULATED INPUT BASED UPON SOFTWARE ROUTINE OUTPUT
1020
ACCESS BASELINE OUTPUT VALUES ASSOCIATED WITH THE TEST CONDITIONS
1022
CALCULATE QUALITY METRIC
1024
END

FIG. 10

SENSOR MALFUNCTION DETECTION

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims priority to and the benefit of the filing date of the following applications: (1) provisional U.S. Patent Application No. 62/286,017 entitled "Autonomous Vehicle Routing, Maintenance, & Fault Determination," filed on Jan. 22, 2016; (2) provisional U.S. Patent Application No. 62/287,659 entitled "Autonomous Vehicle Technology," filed on Jan. 27, 2016; (3) provisional U.S. Patent Application No. 62/302,990 entitled "Autonomous Vehicle Routing," filed on Mar. 3, 2016; (4) provisional U.S. Patent Application No. 62/303,500 entitled "Autonomous Vehicle Routing," filed on Mar. 4, 2016; (5) provisional U.S. Patent Application No. 62/312,109 entitled "Autonomous Vehicle Routing," filed on Mar. 23, 2016; (6) provisional U.S. Patent Application No. 62/349,884 entitled "Autonomous Vehicle Component and System Assessment," filed on Jun. 14, 2016; (7) provisional U.S. Patent Application No. 62/351,559 entitled "Autonomous Vehicle Component and System Assessment," filed on Jun. 17, 2016; (8) provisional U.S. Patent Application No. 62/373,084 entitled "Autonomous Vehicle Communications," filed on Aug. 10, 2016; (9) provisional U.S. Patent Application No. 62/376,044 entitled "Autonomous Operation Expansion through Caravans," filed on Aug. 17, 2016; (10) provisional U.S. Patent Application No. 62/380,686 entitled "Autonomous Operation Expansion through Caravans," filed on Aug. 29, 2016; (11) provisional U.S. Patent Application No. 62/381,848 entitled "System and Method for Autonomous Vehicle Sharing Using Facial Recognition," filed on Aug. 31, 2016; (12) provisional U.S. Patent Application No. 62/406,595 entitled "Autonomous Vehicle Action Communications," filed on Oct. 11, 2016; (13) provisional U.S. Patent Application No. 62/406,600 entitled "Autonomous Vehicle Path Coordination," filed on Oct. 11, 2016; (14) provisional U.S. Patent Application No. 62/406,605 entitled "Autonomous Vehicle Signal Control," filed on Oct. 11, 2016; (15) provisional U.S. Patent Application No. 62/406,611 entitled "Autonomous Vehicle Application," filed on Oct. 11, 2016; (16) provisional U.S. Patent Application No. 62/415,668 entitled "Method and System for Enhancing the Functionality of a Vehicle," filed on Nov. 1, 2016; (17) provisional U.S. Patent Application No. 62/415,672 entitled "Method and System for Repairing a Malfunctioning Autonomous Vehicle," filed on Nov. 1, 2016; (18) provisional U.S. Patent Application No. 62/415,673 entitled "System and Method for Autonomous Vehicle Sharing Using Facial Recognition," filed on Nov. 1, 2016; (19) provisional U.S. Patent Application No. 62/415,678 entitled "System and Method for Autonomous Vehicle Ride Sharing Using Facial Recognition," filed on Nov. 1, 2016; (20) provisional U.S. Patent Application No. 62/418,988 entitled "Virtual Testing of Autonomous Vehicle Control System," filed on Nov. 8, 2016; (21) provisional U.S. Patent Application No. 62/418,999 entitled "Detecting and Responding to Autonomous Vehicle Collisions," filed on Nov. 8, 2016; (22) provisional U.S. Patent Application No. 62/419,002 entitled "Automatic Repair on Autonomous Vehicles," filed on Nov. 8, 2016; (23) provisional U.S. Patent Application No. 62/419,009 entitled "Autonomous Vehicle Component Malfunction Impact Assessment," filed on Nov. 8, 2016; (24) provisional U.S. Patent Application No. 62/419,017 entitled "Autonomous Vehicle Sensor Malfunction Detection," filed on Nov. 8, 2016; (25) provisional U.S. Patent Application No. 62/419,023 entitled "Autonomous Vehicle Damage and Salvage Assessment," filed on Nov. 8, 2016; (26) provisional U.S. Patent Application No. 62/424,078 entitled "Systems and Methods for Sensor Monitoring," filed Nov. 18, 2016; (27) provisional U.S. Patent Application No. 62/424,093 entitled "Autonomous Vehicle Sensor Malfunction Detection," filed on Nov. 18, 2016; (28) provisional U.S. Patent Application No. 62/428,843 entitled "Autonomous Vehicle Control," filed on Dec. 1, 2016; (29) provisional U.S. Patent Application No. 62/430,215 entitled Autonomous Vehicle Environment and Component Monitoring," filed on Dec. 5, 2016; (30) provisional U.S. Patent Application No. 62/434,355 entitled "Virtual Testing of Autonomous Environment Control System," filed Dec. 14, 2016; (31) provisional U.S. Patent Application No. 62/434,359 entitled "Detecting and Responding to Autonomous Environment Incidents," filed Dec. 14, 2016; (32) provisional U.S. Patent Application No. 62/434,361 entitled "Component Damage and Salvage Assessment," filed Dec. 14, 2016; (33) provisional U.S. Patent Application No. 62/434,365 entitled "Sensor Malfunction Detection," filed Dec. 14, 2016; (34) provisional U.S. Patent Application No. 62/434,368 entitled "Component Malfunction Impact Assessment," filed Dec. 14, 2016; and (35) provisional U.S. Patent Application No. 62/434,370 entitled "Automatic Repair of Autonomous Components," filed Dec. 14, 2016. The entire contents of each of the preceding applications are hereby expressly incorporated herein by reference.

Additionally, the present application is related to the following co-pending U.S. patent applications: (1) U.S. patent application Ser. No. 15/409,143 entitled "Autonomous Operation Suitability Assessment and Mapping," filed Jan. 18, 2017; (2) U.S. patent application Ser. No. 15/409,146 entitled "Autonomous Vehicle Routing," filed Jan. 18, 2017; (3) U.S. patent application Ser. No. 15/409,149 entitled "Autonomous Vehicle Routing During Emergencies," filed Jan. 18, 2017; (4) U.S. patent application Ser. No. 15/409,159 entitled "Autonomous Vehicle Trip Routing," filed Jan. 18, 2017; (5) U.S. patent application Ser. No. 15/409,163 entitled "Autonomous Vehicle Parking," filed Jan. 18, 2017; (6) U.S. patent application Ser. No. 15/409,167 entitled "Autonomous Vehicle Retrieval," filed Jan. 18, 2017; (7) U.S. patent application Ser. No. 15/409,092 entitled "Autonomous Vehicle Action Communications," filed Jan. 18, 2017; (8) U.S. patent application Ser. No. 15/409,099 entitled "Autonomous Vehicle Path Coordination," filed Jan. 18, 2017; (9) U.S. patent application Ser. No. 15/409,107 entitled "Autonomous Vehicle Signal Control," filed Jan. 18, 2017; (10) U.S. patent application Ser. No. 15/409,115 entitled "Autonomous Vehicle Application," filed Jan. 18, 2017; (11) U.S. patent application Ser. No. 15/409,136 entitled "Method and System for Enhancing the Functionality of a Vehicle," filed Jan. 18, 2017; (12) U.S. patent application Ser. No. 15/409,180 entitled "Method and System for Repairing a Malfunctioning Autonomous Vehicle," filed Jan. 18, 2017; (13) U.S. patent application Ser. No. 15/409,148 entitled "System and Method for Autonomous Vehicle Sharing Using Facial Recognition," filed Jan. 18, 2017; (14) U.S. patent application Ser. No. 15/409,198 entitled "System and Method for Autonomous Vehicle Ride Sharing Using Facial Recognition," filed Jan. 18, 2017; (15) U.S. patent application Ser. No. 15/409,215 entitled "Autonomous Vehicle Sensor Malfunction Detection," filed Jan. 18, 2017; (16) U.S. patent application Ser. No. 15/409,271 entitled "Autonomous Vehicle Component Malfunction Impact Assessment," filed Jan. 18, 2017; (17) U.S. patent application Ser. No. 15/409,305 entitled "Component Malfunction Impact Assessment," filed Jan. 18,

2017; (18) U.S. patent application Ser. No. 15/409,318 entitled "Automatic Repair of Autonomous Vehicles," filed Jan. 18, 2017; (19) U.S. patent application Ser. No. 15/409,336 entitled "Automatic Repair of Autonomous Components," filed Jan. 18, 2017; (20) U.S. patent application Ser. No. 15/409,340 entitled "Autonomous Vehicle Damage and Salvage Assessment," filed Jan. 18, 2017; (21) U.S. patent application Ser. No. 15/409,349 entitled "Component Damage and Salvage Assessment," filed Jan. 18, 2017; (22) U.S. patent application Ser. No. 15/409,359 entitled "Detecting and Responding to Autonomous Vehicle Collisions," filed Jan. 18, 2017; (23) U.S. patent application Ser. No. 15/409,371 entitled "Detecting and Responding to Autonomous Environment Incidents," filed Jan. 18, 2017; (24) U.S. patent application Ser. No. 15/409,445 entitled "Virtual Testing of Autonomous Vehicle Control System," filed Jan. 18, 2017; (25) U.S. patent application Ser. No. 15/409,473 entitled "Virtual Testing of Autonomous Environment Control System," filed Jan. 18, 2017; (26) U.S. patent application Ser. No. 15/409,220 entitled "Autonomous Electric Vehicle Charging," filed Jan. 18, 2017; (27) U.S. patent application Ser. No. 15/409,213 entitled "Coordinated Autonomous Vehicle Automatic Area Scanning," filed Jan. 18, 2017; (28) U.S. patent application Ser. No. 15/409,228 entitled "Operator-Specific Configuration of Autonomous Vehicle Operation," filed Jan. 18, 2017; (29) U.S. patent application Ser. No. 15/409,236 entitled "Autonomous Vehicle Operation Adjustment Based Upon Route," filed Jan. 18, 2017; (30) U.S. patent application Ser. No. 15/409,239 entitled "Autonomous Vehicle Component Maintenance and Repair," filed Jan. 18, 2017; and (31) U.S. patent application Ser. No. 15/409,243 entitled "Anomalous Condition Detection and Response for Autonomous Vehicles," filed Jan. 18, 2017

FIELD

The present disclosure generally relates to systems and methods for component monitoring and assessment for damage or other malfunctions.

BACKGROUND

Vehicles are typically operated by a human vehicle operator who controls both steering and motive controls. Operator error, inattention, inexperience, misuse, or distraction leads to many vehicle collisions each year, resulting in injury and damage. Autonomous or semi-autonomous vehicles augment vehicle operators' information or replace vehicle operators' control commands to operate the vehicle, in whole or part, with computer systems based upon information from sensors within, or attached to, the vehicle. Such vehicles may be operated with or without passengers, thus requiring different means of control than traditional vehicles. Such vehicles also may include a plurality of advanced sensors, capable of providing significantly more data (both in type and quantity) than is available even from GPS navigation assistance systems installed in traditional vehicles.

Ensuring safe operation of such autonomous or semi-autonomous vehicles is of the utmost importance because the automated systems of these vehicles may not function properly in all environments. Although autonomous operation may be safer than manual operation under ordinary driving conditions, unusual or irregular environmental conditions may significantly impair the functioning of the autonomous operation features controlling the autonomous vehicle. Under some conditions, autonomous operation may become impractical or excessively dangerous. As an example, fog or heavy rain may greatly reduce the ability of autonomous operation features to safely control the vehicle. Additionally, damage or other impairment of sensors or other components of autonomous systems may significantly increase the risks associated with autonomous operation. Such conditions may change frequently, thereby changing the safety of autonomous vehicle operation. Similar risks associated with impaired sensors may also be present in a smart home environment.

BRIEF SUMMARY

The present embodiments may be related to autonomous or semi-autonomous vehicle operation, including driverless operation of fully autonomous vehicles. The embodiments described herein relate particularly to various aspects of autonomous operation feature, component, and software monitoring and/or assessment. When malfunctions or other problems are detected, remedial responses may be determined and implemented. Alternatively, some aspects relate to assessment of features, components, or software, either generally or in particular situations. Specific systems and methods are summarized below. The methods and systems summarized below may include additional, less, or alternate actions, including those discussed elsewhere herein.

In one aspect, a computer-implemented method for improving the functioning of a computer and/or detecting sensor malfunctions in an autonomous vehicle may be provided. The method may include, via one or more processors, transceivers, and/or sensors: (1) receiving sensor data including a plurality of signals from a plurality of sensors during operation of the autonomous vehicle; (2) selecting, by one or more processors, a first sensor from the plurality of sensors; (3) obtaining, by one or more processors, a first set of signals associated with the first sensor from the plurality of signals; (4) determining, by one or more processors, a first sensor range indicative of a range of signal values associated with proper functioning of the first sensor; (6) determining, by one or more processors, that the first sensor is malfunctioning when at least one signal in the first set of signals associated with the first sensors is outside the first sensor range and/or (7) performing, by one or more processors, an action in response to determining that the first sensor is malfunctioning. The method may include additional, less, or alternate actions, including those discussed elsewhere herein.

For instance, in some embodiments, the first sensor range may be determined based upon a baseline plurality of signals received from the first sensor during a plurality of previous operation sessions of the autonomous vehicle. In additional embodiments, the first sensor range may be determined by predicting values of signals associated with the first sensor based upon a second set of signals from the plurality of signals, wherein the second set of signals is received from at least one second sensor of the plurality of sensors other than the first sensor during operation of the autonomous vehicle. In some such embodiments, the determination that the first sensor is malfunctioning may be based upon a determination of an inconsistency between the first set of signals and the second set of signals. The first set of signals may be considered outside the first sensor range when the first set of signals includes one or more indications that data from the first sensor is unavailable.

In further embodiments, the first sensor may be selected in response to additional sensor data indicating a collision

involving the autonomous vehicle, such as where the first sensor is disposed within an area of the autonomous vehicle involved in the collision. Alternatively, the first sensor may be determined to be malfunctioning without any indication of a vehicle collision. Determining the first sensor is malfunctioning may include determining a probability of malfunctioning based upon the sensor data, which probability of malfunctioning may indicate a probability of future failure of the first sensor based upon comparison with data from a plurality of other vehicles.

In some embodiments, the method may further include determining, via the one or more processors, a cause of the first sensor's malfunction based upon the received sensor data. The received sensor data used in such determination may include a plurality of signals at different times from each of the plurality of sensors, each signal being associated with a timestamp indicating a time associated with the signal. The method may further include determining, via the one or more processors, an apportionment of liability for a cost of repair or replacement of the first sensor based upon the received sensor data. The apportionment of liability may be made between one or more of: a manufacturer of the first sensor, a manufacturer of the autonomous vehicle, an installer of the first sensor, an insurer of the autonomous vehicle, an owner of the autonomous vehicle, or an owner, operator, or insurer of a second vehicle. The action performed by the method may further include automatically scheduling, via the one or more processors, repair or replacement of the first sensor by a third party based upon the determined apportionment of liability. In further embodiments, the method may include receiving additional information associated with a plurality of other vehicles regarding a plurality of sensor malfunctions and/or determining one or more repairs to correct the first sensor's malfunctioning based upon the received sensor data and additional information.

In further embodiments, the performed action includes generating, via the one or more processors, an alert regarding the first sensor's malfunctioning. The alert may be presented to one or more of the following: an operator of the autonomous vehicle or an owner of the autonomous vehicle. The alert may include a recommendation to take one or more of the following actions: repair the first sensor, replace the first sensor, avoid using one or more autonomous operation features of the autonomous vehicle, or avoid using one or more settings associated with the one or more autonomous operation features. The alert may include an indication of an adjustment to a cost or coverage associated with an insurance policy covering operation of the autonomous vehicle based upon the determination that the first sensor is malfunctioning. Such adjustment to the cost or coverage associated with the insurance policy may be based upon a determination of an increase in a risk based upon the first sensor's malfunctioning. Such adjustment may also be contingent upon usage of one or more autonomous operation features of the autonomous vehicle that utilize data from the first sensor to control the autonomous vehicle.

In yet further embodiments, the action performed by the method may include identifying, via the one or more processors, one or more autonomous operation features of the autonomous vehicle that utilize data from the first sensor to control the autonomous vehicle; determining, by one or more processors, a risk level for each of the identified autonomous operation features; and/or limiting, via the one or more processors, operation of at least one of the identified one or more autonomous operation features based upon the associated risk level exceeding a safety threshold level. The risk levels may indicate one or more risks associated with operation of the autonomous operation feature when the first sensor is malfunctioning. Limiting operation of the at least one of the identified one or more autonomous operation features may include disabling operation of the at least one of the identified one or more autonomous operation features. Additionally or alternatively the plurality of sensors may include a sensor of a smart infrastructure component and/or a personal electronic device.

In another aspect, a computer-implemented method for improving the functioning of a computer and/or detecting sensor malfunctions in a smart home may be provided. The method may include, via one or more processors, transceivers, and/or sensors: (1) receiving sensor data including a plurality of signals from a plurality of sensors during operation of the smart home; (2) selecting, by one or more processors, a first sensor from the plurality of sensors; (3) obtaining, by one or more processors, a first set of signals associated with the first sensor from the plurality of signals; (4) determining, by one or more processors, a first sensor range indicative of a range of signal values associated with proper functioning of the first sensor; (6) determining, by one or more processors, that the first sensor is malfunctioning when at least one signal in the first set of signals associated with the first sensors is outside the first sensor range and/or (7) performing, by one or more processors, an action in response to determining that the first sensor is malfunctioning. The method may include additional, less, or alternate actions, including those discussed elsewhere herein.

For instance, in some embodiments, the first sensor range may be determined based upon a baseline plurality of signals received from the first sensor during a plurality of previous time frames of operation of the smart home. In additional embodiments, the first sensor range may be determined by predicting values of signals associated with the first sensor based upon a second set of signals from the plurality of signals, wherein the second set of signals is received from at least one second sensor of the plurality of sensors other than the first sensor during operation of the smart home. In some such embodiments, the determination that the first sensor is malfunctioning may be based upon a determination of an inconsistency between the first set of signals and the second set of signals. The first set of signals may be considered outside the first sensor range when the first set of signals includes one or more indications that data from the first sensor is unavailable.

In further embodiments, the first sensor may be selected in response to additional sensor data indicating an event involving the smart home, such as where the first sensor is disposed within an area of the smart home involved in the event. Alternatively, the first sensor may be determined to be malfunctioning without any indication of an event. Determining the first sensor is malfunctioning may include determining a probability of malfunctioning based upon the sensor data, which probability of malfunctioning may indicate a probability of future failure of the first sensor based upon comparison with data from a plurality of other smart homes.

In some embodiments, the method may further include determining, via the one or more processors, a cause of the first sensor's malfunction based upon the received sensor data. The received sensor data used in such determination may include a plurality of signals at different times from each of the plurality of sensors, each signal being associated with a timestamp indicating a time associated with the signal. The method may further include determining, via the

one or more processors, an apportionment of liability for a cost of repair or replacement of the first sensor based upon the received sensor data. The apportionment of liability may be made between one or more of: a manufacturer of the first sensor, a manufacturer of a smart equipment, an installer of the first sensor, an insurer of the smart home, an owner of the smart home, or an owner, operator, or insurer of a second smart home. The action performed by the method may further include automatically scheduling, via the one or more processors, repair or replacement of the first sensor by a third party based upon the determined apportionment of liability. In further embodiments, the method may include receiving additional information associated with a plurality of other smart homes regarding a plurality of sensor malfunctions and/or determining one or more repairs to correct the first sensor's malfunctioning based upon the received sensor data and additional information.

In further embodiments, the performed action includes generating, via the one or more processors, an alert regarding the first sensor's malfunctioning. The alert may be presented to one or more of the following: an occupant of a smart home or an owner of the smart home. The alert may include a recommendation to take one or more of the following actions: repair the first sensor, replace the first sensor, avoid using one or more autonomous operation features of the smart home, or avoid using one or more settings associated with the one or more autonomous operation features. The alert may include an indication of an adjustment to a cost or coverage associated with an insurance policy covering operation of the smart home based upon the determination that the first sensor is malfunctioning. Such adjustment to the cost or coverage associated with the insurance policy may be based upon a determination of an increase in a risk based upon the first sensor's malfunctioning. Such adjustment may also be contingent upon usage of one or more autonomous operation features of the smart home that utilize data from the first sensor to control the smart home.

In yet further embodiments, the action performed by the method may include identifying, via the one or more processors, one or more autonomous operation features of the smart home that utilize data from the first sensor to control the autonomous vehicle; determining, by one or more processors, a risk level for each of the identified autonomous operation features; and/or limiting, via the one or more processors, operation of at least one of the identified one or more autonomous operation features based upon the associated risk level exceeding a safety threshold level. The risk levels may indicate one or more risks associated with operation of the autonomous operation feature when the first sensor is malfunctioning. Limiting operation of the at least one of the identified one or more autonomous operation features may include disabling operation of the at least one of the identified one or more autonomous operation features. Additionally or alternatively the plurality of sensors may include a sensor of a personal electronic device.

Systems or computer-readable media storing instructions for implementing all or part of the methods described above may also be provided in some aspects. Systems for implementing such methods may include one or more of the following: a special-purpose assessment computing device, a mobile computing device, an on-board computer, a remote server, one or more sensors, one or more communication modules configured to communicate wirelessly via radio links, radio frequency links, and/or wireless communication channels, and/or one or more program memories coupled to one or more processors of the mobile computing device, on-board computer, or remote server. Such program memories may store instructions to cause the one or more processors to implement part or all of the method described above. Additional or alternative features described herein below may be included in some aspects.

BRIEF DESCRIPTION OF THE DRAWINGS

Advantages will become more apparent to those skilled in the art from the following description of the preferred embodiments which have been shown and described by way of illustration. As will be realized, the present embodiments may be capable of other and different embodiments, and their details are capable of modification in various respects. Accordingly, the drawings and description are to be regarded as illustrative in nature and not as restrictive.

The figures described below depict various aspects of the applications, methods, and systems disclosed herein. It should be understood that each figure depicts an embodiment of a particular aspect of the disclosed applications, systems and methods, and that each of the figures is intended to accord with a possible embodiment thereof. Furthermore, wherever possible, the following description refers to the reference numerals included in the following figures, in which features depicted in multiple figures are designated with consistent reference numerals.

FIG. **1**A illustrates a block diagram of an exemplary autonomous vehicle data system for autonomous vehicle operation, monitoring, and related functions;

FIG. **1**B illustrates a block diagram of an exemplary autonomous vehicle monitoring system, showing a plurality of vehicles and smart infrastructure components;

FIG. **2** illustrates a block diagram of an exemplary on-board computer or mobile device;

FIG. **3** illustrates a flow diagram of an exemplary autonomous vehicle operation computer-implemented method;

FIGS. **4**A-B illustrate flow diagrams of exemplary autonomous operation monitoring computer-implemented methods for obtaining and recording information during autonomous operation;

FIG. **5** illustrates a flow diagram of an exemplary incident response computer-implemented method for detecting and responding to incidents involving a vehicle and/or smart home while engaged in fully autonomous operation or in the absence of a vehicle operator and/or smart home occupant;

FIG. **6** illustrates a flow diagram of an exemplary salvage assessment computer-implemented method for automatically determining damage and/or salvage potential for components of an autonomous vehicle and/or a smart home;

FIG. **7** illustrates a flow diagram of an exemplary malfunction detection computer-implemented method for identifying malfunctioning sensors of an autonomous vehicle and/or a smart home;

FIG. **8** illustrates a flow diagram of an exemplary malfunction assessment computer-implemented method for determining the impact of malfunctioning components on the operation of an autonomous vehicle and/or a smart home;

FIG. **9** illustrates a flow diagram of an exemplary autonomous repair computer-implemented method for identifying and repairing malfunctioning components of an autonomous vehicle and/or a smart home; and

FIG. **10** illustrates a flow diagram of an exemplary autonomous environment control software evaluation computer-implemented method for testing the quality of control

decisions generated by autonomous operation feature of an autonomous vehicle and/or smart home.

DETAILED DESCRIPTION

The systems and methods disclosed herein generally relate to various aspects of autonomous operation feature, component, and software monitoring and/or assessment. Responses to accidents, collisions, and other events causing malfunctions or damage are discussed below. Assessment of components and features may be performed as part of detecting malfunctions, determining repairs, determining component operating status, or generally evaluating effectiveness or reliability of components and features. To this end, the systems and methods may include collecting, communicating, evaluating, predicting, and/or utilizing data associated with autonomous or semi-autonomous operation features for controlling a vehicle. The autonomous operation features may take full control of the vehicle under certain conditions, viz. fully autonomous operation, or the autonomous operation features may assist the vehicle operator in operating the vehicle, viz. partially autonomous operation.

Fully autonomous operation features may include systems within the vehicle that pilot the vehicle to a destination with or without a vehicle operator present (e.g., an operating system for a driverless car) and/or systems within smart homes capable of automatically controlling smart equipment disposed therein. Partially autonomous operation features may assist the vehicle operator in limited ways (e.g., automatic braking or collision avoidance systems). Fully or partially autonomous operation features may perform specific functions to control or assist in controlling some aspect of vehicle operation, or such features may manage or control other autonomous operation features. For example, a vehicle operating system may control numerous subsystems that each fully or partially control aspects of vehicle operation.

In addition to information regarding the position or movement of a vehicle, autonomous operation features may collect and utilize other information, such as data about other vehicles or control decisions of the vehicle. Such additional information may be used to improve vehicle operation, route the vehicle to a destination, warn of component malfunctions, advise others of potential hazards, or for other purposes described herein. Information may be collected, assessed, and/or shared via applications installed and executing on computing devices associated with various vehicles or vehicle operators, such as on-board computers of vehicles or smartphones of vehicle operators. By using computer applications to obtain data, the additional information generated by autonomous features of autonomous vehicles and/or smart homes may be used to assess the autonomous features themselves while in operation or to provide pertinent information to non-autonomous vehicles and/or smart homes through an electronic communication network. These and other advantages are further described below.

Autonomous operation features utilize data not available to a human operator, respond to conditions in the vehicle operating environment faster than human operators, and do not suffer fatigue or distraction. Thus, the autonomous operation features may also significantly affect various risks associated with operating a vehicle and/or a smart home. Alternatively, autonomous operation features may be incapable of some actions typically taken by human operators, particularly when the features or other components of the vehicle are damaged or inoperable and/or a smart home is unoccupied. Moreover, combinations of autonomous operation features may further affect operating risks due to synergies or conflicts between features. To account for these effects on risk, some embodiments evaluate the quality of each autonomous operation feature and/or combination of features. This may be accomplished by testing the features and combinations in controlled environments, as well as analyzing the effectiveness of the features in the ordinary course of vehicle operation. New autonomous operation features may be evaluated based upon controlled testing and/or estimating ordinary-course performance based upon data regarding other similar features for which ordinary-course performance is known.

Some autonomous operation features may be adapted for use under particular conditions, such as city driving or highway driving. Additionally, the vehicle operator may be able to configure settings relating to the features or may enable or disable the features at will. Therefore, some embodiments monitor use of the autonomous operation features, which may include the settings or levels of feature use during operation. Information obtained by monitoring feature usage may be used to determine risk levels associated with operation, either generally or in relation to a vehicle operator and/or smart home occupant. In such situations, total risk may be determined by a weighted combination of the risk levels associated with operation while autonomous operation features are enabled (with relevant settings) and the risk levels associated with operation while autonomous operation features are disabled. For fully autonomous vehicles, settings or configurations relating to vehicle operation may be monitored and used in determining vehicle operating risk.

In some embodiments, information regarding the risks associated with operation with and without the autonomous operation features may be used to determine risk categories or premiums for a vehicle insurance policy covering a vehicle with autonomous operation features and/or for a home insurance policy covering a smart home with autonomous operation features, as described elsewhere herein. Risk category or price may be determined based upon factors relating to the evaluated effectiveness of the autonomous features. The risk or price determination may also include traditional factors, such as location, vehicle type, and level of vehicle use. For fully autonomous vehicles, factors relating to vehicle operators may be excluded entirely. For partially autonomous vehicles, factors relating to vehicle operators may be reduced in proportion to the evaluated effectiveness and monitored usage levels of the autonomous operation features. For vehicles with autonomous communication features that obtain information from external sources (e.g., other vehicles or infrastructure), the risk level and/or price determination may also include an assessment of the availability of external sources of information. Location and/or timing of vehicle use may thus be monitored and/or weighted to determine the risk associated with operation of the vehicle.

Exemplary Autonomous Vehicle Operation System

FIG. **1**A illustrates a block diagram of an exemplary autonomous vehicle data system **100** on which the exemplary methods described herein may be implemented. The high-level architecture includes both hardware and software applications, as well as various data communications channels for communicating data between the various hardware and software components. The autonomous vehicle data system **100** may be roughly divided into front-end components **102** and back-end components **104**. The front-end components **102** may obtain information regarding a vehicle **108** (e.g., a car, truck, motorcycle, etc.) and the surrounding

environment. An on-board computer **114** may utilize this information to operate the vehicle **108** according to an autonomous operation feature or to assist the vehicle operator in operating the vehicle **108**. To monitor the vehicle **108**, the front-end components **102** may include one or more sensors **120** installed within the vehicle **108** that may communicate with the on-board computer **114**. The front-end components **102** may further process the sensor data using the on-board computer **114** or a mobile device **110** (e.g., a smart phone, a tablet computer, a special purpose computing device, smart watch, wearable electronics, etc.) to determine when the vehicle is in operation and information regarding the vehicle.

In some embodiments of the system **100**, the front-end components **102** may communicate with the back-end components **104** via a network **130**. Either the on-board computer **114** or the mobile device **110** may communicate with the back-end components **104** via the network **130** to allow the back-end components **104** to record information regarding vehicle usage. The back-end components **104** may use one or more servers **140** to receive data from the front-end components **102**, store the received data, process the received data, and/or communicate information associated with the received or processed data.

The front-end components **102** may be disposed within or communicatively connected to one or more on-board computers **114**, which may be permanently or removably installed in the vehicle **108**. The on-board computer **114** may interface with the one or more sensors **120** within the vehicle **108** (e.g., a digital camera, a LIDAR sensor, an ultrasonic sensor, an infrared sensor, an ignition sensor, an odometer, a system clock, a speedometer, a tachometer, an accelerometer, a gyroscope, a compass, a geolocation unit, radar unit, etc.), which sensors may also be incorporated within or connected to the on-board computer **114**.

The front end components **102** may further include a communication component **122** to transmit information to and receive information from external sources, including other vehicles, infrastructure, or the back-end components **104**. In some embodiments, the mobile device **110** may supplement the functions performed by the on-board computer **114** described herein by, for example, sending or receiving information to and from the mobile server **140** via the network **130**, such as over one or more radio frequency links or wireless communication channels. In other embodiments, the on-board computer **114** may perform all of the functions of the mobile device **110** described herein, in which case no mobile device **110** may be present in the system **100**.

Either or both of the mobile device **110** or on-board computer **114** may communicate with the network **130** over links **112** and **118**, respectively. Either or both of the mobile device **110** or on-board computer **114** may run a Data Application for collecting, generating, processing, analyzing, transmitting, receiving, and/or acting upon data associated with the vehicle **108** (e.g., sensor data, autonomous operation feature settings, or control decisions made by the autonomous operation features) or the vehicle environment (e.g., other vehicles operating near the vehicle **108**). Additionally, the mobile device **110** and on-board computer **114** may communicate with one another directly over link **116**.

The mobile device **110** may be either a general-use personal computer, cellular phone, smart phone, tablet computer, smart watch, wearable electronics, or a dedicated vehicle monitoring or control device. Although only one mobile device **110** is illustrated, it should be understood that a plurality of mobile devices **110** may be used in some embodiments. The on-board computer **114** may be a general-use on-board computer capable of performing many functions relating to vehicle operation or a dedicated computer for autonomous vehicle operation. Further, the on-board computer **114** may be installed by the manufacturer of the vehicle **108** or as an aftermarket modification or addition to the vehicle **108**. In some embodiments or under certain conditions, the mobile device **110** or on-board computer **114** may function as thin-client devices that outsource some or most of the processing to the server **140**.

The sensors **120** may be removably or fixedly installed within the vehicle **108** and may be disposed in various arrangements to provide information to the autonomous operation features. Among the sensors **120** may be included one or more of a GPS unit, a radar unit, a LIDAR unit, an ultrasonic sensor, an infrared sensor, an inductance sensor, a camera, an accelerometer, a tachometer, or a speedometer. Some of the sensors **120** (e.g., radar, LIDAR, or camera units) may actively or passively scan the vehicle environment for obstacles (e.g., other vehicles, buildings, pedestrians, etc.), roadways, lane markings, signs, or signals. Other sensors **120** (e.g., GPS, accelerometer, or tachometer units) may provide data for determining the location or movement of the vehicle **108**. Other sensors **120** may be directed to the interior or passenger compartment of the vehicle **108**, such as cameras, microphones, pressure sensors, thermometers, or similar sensors to monitor the vehicle operator and/or passengers within the vehicle **108**. Information generated or received by the sensors **120** may be communicated to the on-board computer **114** or the mobile device **110** for use in autonomous vehicle operation.

In further embodiments, the front-end components may include an infrastructure communication device **124** for monitoring the status of one or more infrastructure components **126**. Infrastructure components **126** may include roadways, bridges, traffic signals, gates, switches, crossings, parking lots or garages, toll booths, docks, hangars, or other similar physical portions of a transportation system's infrastructure. The infrastructure communication device **124** may include or be communicatively connected to one or more sensors (not shown) for detecting information relating to the condition of the infrastructure component **126**. The sensors (not shown) may generate data relating to weather conditions, traffic conditions, or operating status of the infrastructure component **126**.

The infrastructure communication device **124** may be configured to receive the sensor data generated and determine a condition of the infrastructure component **126**, such as weather conditions, road integrity, construction, traffic, available parking spaces, etc. The infrastructure communication device **124** may further be configured to communicate information to vehicles **108** via the communication component **122**. In some embodiments, the infrastructure communication device **124** may receive information from one or more vehicles **108**, while, in other embodiments, the infrastructure communication device **124** may only transmit information to the vehicles **108**. The infrastructure communication device **124** may be configured to monitor vehicles **108** and/or communicate information to other vehicles **108** and/or to mobile devices **110**.

In some embodiments, the communication component **122** may receive information from external sources, such as other vehicles or infrastructure. The communication component **122** may also send information regarding the vehicle **108** to external sources. To send and receive information, the communication component **122** may include a transmitter and a receiver designed to operate according to predeter-

mined specifications, such as the dedicated short-range communication (DSRC) channel, wireless telephony, Wi-Fi, or other existing or later-developed communications protocols. The received information may supplement the data received from the sensors **120** to implement the autonomous operation features. For example, the communication component **122** may receive information that an autonomous vehicle ahead of the vehicle **108** is reducing speed, allowing the adjustments in the autonomous operation of the vehicle **108**.

In addition to receiving information from the sensors **120**, the on-board computer **114** may directly or indirectly control the operation of the vehicle **108** according to various autonomous operation features. The autonomous operation features may include software applications or modules implemented by the on-board computer **114** to generate and implement control commands to control the steering, braking, or throttle of the vehicle **108**. To facilitate such control, the on-board computer **114** may be communicatively connected to control components of the vehicle **108** by various electrical or electromechanical control components (not shown). When a control command is generated by the on-board computer **114**, it may thus be communicated to the control components of the vehicle **108** to effect a control action. In embodiments involving fully autonomous vehicles, the vehicle **108** may be operable only through such control components (not shown). In other embodiments, the control components may be disposed within or supplement other vehicle operator control components (not shown), such as steering wheels, accelerator or brake pedals, or ignition switches.

In some embodiments, the front-end components **102** communicate with the back-end components **104** via the network **130**. The network **130** may be a proprietary network, a secure public internet, a virtual private network or some other type of network, such as dedicated access lines, plain ordinary telephone lines, satellite links, cellular data networks, combinations of these. The network **130** may include one or more radio frequency communication links, such as wireless communication links **112** and **118** with mobile devices **110** and on-board computers **114**, respectively. Where the network **130** comprises the Internet, data communications may take place over the network **130** via an Internet communication protocol.

The back-end components **104** include one or more servers **140**. Each server **140** may include one or more computer processors adapted and configured to execute various software applications and components of the autonomous vehicle data system **100**, in addition to other software applications. The server **140** may further include a database **146**, which may be adapted to store data related to the operation of the vehicle **108** and/or a smart home (not depicted) and its autonomous operation features. Such data might include, for example, dates and times of vehicle use, duration of vehicle use, use and settings of autonomous operation features, information regarding control decisions or control commands generated by the autonomous operation features, speed of the vehicle **108**, RPM or other tachometer readings of the vehicle **108**, lateral and longitudinal acceleration of the vehicle **108**, vehicle accidents, incidents or near collisions of the vehicle **108**, hazardous or anomalous conditions within the vehicle operating environment (e.g., construction, accidents, etc.), communication between the autonomous operation features and external sources, environmental conditions of vehicle operation (e.g., weather, traffic, road condition, etc.), errors or failures of autonomous operation features, or other data relating to use of the vehicle **108** and the autonomous operation features, which may be uploaded to the server **140** via the network **130**. The server **140** may access data stored in the database **146** when executing various functions and tasks associated with the evaluating feature effectiveness or assessing risk relating to an autonomous vehicle.

Although the autonomous vehicle data system **100** is shown to include one vehicle **108**, one mobile device **110**, one on-board computer **114**, and one server **140**, it should be understood that different numbers of vehicles **108**, mobile devices **110**, on-board computers **114**, and/or servers **140** may be utilized. For example, the system **100** may include a plurality of servers **140** and hundreds or thousands of mobile devices **110** or on-board computers **114**, all of which may be interconnected via the network **130**. Furthermore, the database storage or processing performed by the one or more servers **140** may be distributed among a plurality of servers **140** in an arrangement known as "cloud computing." This configuration may provide various advantages, such as enabling near real-time uploads and downloads of information as well as periodic uploads and downloads of information. This may in turn support a thin-client embodiment of the mobile device **110** or on-board computer **114** discussed herein.

The server **140** may have a controller **155** that is operatively connected to the database **146** via a link **156**. It should be noted that, while not shown, additional databases may be linked to the controller **155** in a known manner. For example, separate databases may be used for various types of information, such as autonomous operation feature information, vehicle accidents, road conditions, vehicle insurance policy information, or vehicle use information. Additional databases (not shown) may be communicatively connected to the server **140** via the network **130**, such as databases maintained by third parties (e.g., weather, construction, or road network databases). The controller **155** may include a program memory **160**, a processor **162** (which may be called a microcontroller or a microprocessor), a random-access memory (RAM) **164**, and an input/output (I/O) circuit **166**, all of which may be interconnected via an address/data bus **165**. It should be appreciated that although only one microprocessor **162** is shown, the controller **155** may include multiple microprocessors **162**. Similarly, the memory of the controller **155** may include multiple RAMs **164** and multiple program memories **160**. Although the I/O circuit **166** is shown as a single block, it should be appreciated that the I/O circuit **166** may include a number of different types of I/O circuits. The RAM **164** and program memories **160** may be implemented as semiconductor memories, magnetically readable memories, or optically readable memories, for example. The controller **155** may also be operatively connected to the network **130** via a link **135**.

The server **140** may further include a number of software applications stored in a program memory **160**. The various software applications on the server **140** may include an autonomous operation information monitoring application **141** for receiving information regarding the vehicle **108** and its autonomous operation features (which may include control commands or decisions of the autonomous operation features), a feature evaluation application **142** for determining the effectiveness of autonomous operation features under various conditions and/or determining operating condition of autonomous operation features or components, a real-time communication application **143** for communicating information regarding vehicle or environmental conditions between a plurality of vehicles, a navigation application **144** for assisting autonomous or semi-autonomous vehicle

operation, and an accident detection application **145** for identifying accidents and providing assistance. The various software applications may be executed on the same computer processor or on different computer processors.

FIG. **1**B illustrates a block diagram of an exemplary autonomous vehicle monitoring system **180** on which the exemplary methods described herein may be implemented. In one aspect, system **180** may include a network **130**, N number of vehicles **182.1-182**.N and respective mobile computing devices **184.1-184**.N, an external computing device **186**, N number of smart homes **187.1-187**.N, N number of personal electronic devices **189.1-189**.N, and/or a smart infrastructure component **188**. In one aspect, mobile computing devices **184** may be an implementation of mobile computing device **110**, while vehicles **182** may be an implementation of vehicle **108**. The vehicles **182** may include a plurality of vehicles **108** having autonomous operation features, as well as a plurality of other vehicles not having autonomous operation features. As illustrated, the vehicle **182.1** may include a vehicle controller **181.1**, which may be an on-board computer **114** as discussed elsewhere herein, while vehicle **182.2** may lack such a component. Each of vehicles **182.1** and **182.2** may be configured for wireless inter-vehicle communication, such as vehicle-to-vehicle (V2V) wireless communication and/or data transmission via the communication component **122**, directly via the mobile computing devices **184**, or otherwise.

As illustrated, the autonomous vehicle monitoring system **180** may monitor devices other than the vehicles **182**. For instance, the autonomous vehicle monitoring system **180** may monitor the smart home **187.1**. The smart home **187.1** may be associated with a smart home controller **185.1**. Similar to how the vehicle controller **181.1** monitors a plurality of sensors associated with the vehicle **182.1**, the smart home controller **185.1** may monitor a plurality of sensors associated with the smart home **187.1**. To this end, the smart home **187.1** may include a plurality of sensors (not depicted) disposed on or proximate to the smart home **187.1**. For example, the smart home **187.1** may include a smoke sensor, a temperature sensor, a flood level sensor, a motion sensor, an image sensor, a thermal image sensor, and so on.

In embodiments, the smart home **187.1** may include a plurality of smart equipment (not depicted). The smart equipment may include appliances, electronics, electrical systems, gas systems, water systems, windows, doors, shutters, and so on configured to communicate with the smart home controller **185.1**. The smart equipment may include one or more sensors that monitor the operation of the smart equipment. Additional details describing a smart home environment may be found in co-owned U.S. patent application Ser. No. 14/693,032 entitled "SYSTEMS AND METHODS FOR AUTOMATICALLY MITIGATING RISK OF PROPERTY DAMAGE," the entire disclosure of which is hereby incorporated by reference in its entirety. In an aspect, the smart home controller may communicate over the network **130** via a communication link **183***g*.

In an aspect, another example of a device other than the vehicles **182** the autonomous vehicle monitoring system **180** may monitor include personal electronic device **189**. The personal electronic devices **189** may include any type of electronic device that monitors conditions associated with an individual. For example, the personal electronic device **189.1** may be a smart watch, a fitness tracker, a personal medical device (e.g., a pace maker, an insulin pump, etc.) and/or monitoring devices thereof, smart implants, and so on. The personal electronic device **189** may monitor the conditions of the individual while the individual is present in the vehicle **182.1** and/or operating the vehicle **182.1** in a semi-autonomous mode. In some embodiments, when the personal electronic device **189.1** is within and/or proximate to the vehicle **182.1**, the personal electronic device may be in communication with the vehicle controller **181.1** and/or the mobile computing device **184.1**. Additionally or alternatively, the personal electronic device **189.1** may communicate over the network **130** via a communication link **183***h*.

Although system **180** is shown in FIG. **1**B as including one network **130**, two mobile computing devices **184.1** and **184.2**, two vehicles **182.1** and **182.2**, one external computing device **186**, one smart home **187.1**, one personal electronic device **189.1**, and/or one smart infrastructure component **188**, various embodiments of system **180** may include any suitable number of networks **130**, mobile computing devices **184**, vehicles **182**, external computing devices **186**, smart homes **187**, personal electronic devices **189** and/or infrastructure components **188**. The vehicles **182** included in such embodiments may include any number of vehicles **182**.*i* having vehicle controllers **181**.*i* (such as vehicle **182.1** with vehicle controller **181.1**) and vehicles **182**.*j* not having vehicles controllers (such as vehicle **182.2**). Moreover, system **180** may include a plurality of external computing devices **186** and more than two mobile computing devices **184**, any suitable number of which being interconnected directly to one another and/or via network **130**.

In one aspect, each of mobile computing devices **184.1** and **184.2** may be configured to communicate with one another directly via peer-to-peer (P2P) wireless communication and/or data transfer over a radio link or wireless communication channel. In other aspects, each of mobile computing devices **184.1** and **184.2** may be configured to communicate indirectly with one another and/or any suitable device via communications over network **130**, such as external computing device **186**, smart home controller **185.1**, personal electronic device **189.1**, and/or smart infrastructure component **188**, for example. In still other aspects, each of mobile computing devices **184.1** and **184.2** may be configured to communicate directly and/or indirectly with other suitable devices, which may include synchronous or asynchronous communication.

In one aspect, each of mobile computing devices **184.1** and **184.2** may be configured to communicate with one another, and/or with the personal electronic device **189.1** and/or the smart home controller **185.1**, directly via peer-to-peer (P2P) wireless communication and/or data transfer over a radio link or wireless communication channel. In other aspects, each of mobile computing devices **184.1** and **184.2**, and/or with the personal electronic device **189.1** and/or the smart home controller **185.1**, may be configured to communicate indirectly with one another and/or any suitable device via communications over network **130**, such as external computing device **186** and/or smart infrastructure component **188**, for example. In still other aspects, each of mobile computing devices **184.1** and **184.2**, and/or with the personal electronic device **189.1** and/or the smart home controller **185.1**, may be configured to communicate directly and/or indirectly with other suitable devices, which may include synchronous or asynchronous communication.

Each of mobile computing devices **184.1** and **184.2**, and/or with the personal electronic device **189.1** and/or the smart home controller **185.1**, may be configured to send data to and/or receive data from one another and/or via network **130** using one or more suitable communication protocols, which may be the same communication protocols or different communication protocols. For example, mobile computing devices **184.1** and **184.2** may be configured to commu-

nicate with one another via a direct radio link **183***a*, which may utilize, for example, a Wi-Fi direct protocol, an ad-hoc cellular communication protocol, etc. Mobile computing devices **184.1** and **184.2** may also be configured to communicate with vehicles **182.1** and **182.2**, respectively, utilizing a Bluetooth communication protocol (radio link not shown). In some embodiments, this may include communication between a mobile computing device **184.1** and a vehicle controller **181.1**. In other embodiments, it may involve communication between a mobile computing device **184.2** and a vehicle telephony, entertainment, navigation, or information system (not shown) of the vehicle **182.2** that provides functionality other than autonomous (or semi-autonomous) vehicle control. Thus, vehicles **182.2** without autonomous operation features may nonetheless be connected to mobile computing devices **184.2** in order to facilitate communication, information presentation, or similar non-control operations (e.g., navigation display, hands-free telephony, or music selection and presentation).

To provide additional examples, mobile computing devices **184.1** and **184.2** may be configured to communicate with one another via radio links **183***b* and **183***c* by each communicating with network **130** utilizing a cellular communication protocol. As an additional example, mobile computing devices **184.1** and/or **184.2** may be configured to communicate with external computing device **186** via radio links **183***b*, **183***c*, and/or **183***e*. Still further, one or more of mobile computing devices **184.1** and/or **184.2** may also be configured to communicate with one or more smart infrastructure components **188** directly (e.g., via radio link **183***d*) and/or indirectly (e.g., via radio links **183***c* and **183***f* via network **130**) using any suitable communication protocols. As yet another example, the one or more of mobile computing devices **184.1** and/or **184.2** may also be configured to communicate with one or more personal electronic devices **189** directly (not depicted) and/or indirectly (e.g., via radio links **183***c* and **183***h* via network **130**) using any suitable communication protocols. As still another example, the one or more of mobile computing devices **184.1** and/or **184.2** may also be configured to communicate with one or more smart home controllers **185** directly (not depicted) and/or indirectly (e.g., via radio links **183***c* and **183***g* via network **130**) using any suitable communication protocols. Similarly, one or more vehicle controllers **181.1** may be configured to communicate directly to the network **130** (via radio link **183***b*) or indirectly through mobile computing device **184.1** (via radio link **183***b*). Vehicle controllers **181.1** may also communicate with other vehicle controllers and/or mobile computing devices **184.2** directly or indirectly through mobile computing device **184.1** via local radio links **183***a*. As discussed elsewhere herein, network **130** may be implemented as a wireless telephony network (e.g., GSM, CDMA, LTE, etc.), a Wi-Fi network (e.g., via one or more IEEE 802.11 Standards), a WiMAX network, a Bluetooth network, etc. Thus, links **183***a*-**183***h* may represent wired links, wireless links, or any suitable combination thereof. For example, the links **183***e* and/or **183***f* may include wired links to the network **130**, in addition to, or instead of, wireless radio connections.

In some embodiments, the external computing device **186** may mediate communication between the mobile computing devices **184.1** and **184.2**, and/or the smart home controllers **185** and/or the personal electronic devices **189**, based upon location or other factors. In embodiments in which mobile computing devices **184.1** and **184.2** communicate directly with one another in a peer-to-peer fashion, network **130** may be bypassed and thus communications between mobile computing devices **184.1** and **184.2** and external computing device **186** may be unnecessary. For example, in some aspects, mobile computing device **184.1** may broadcast geographic location data and/or telematics data directly to mobile computing device **184.2**. In this case, mobile computing device **184.2** may operate independently of network **130** to determine operating data, risks associated with operation, control actions to be taken, and/or alerts to be generated at mobile computing device **184.2** based upon the geographic location data, sensor data, and/or the autonomous operation feature data. In accordance with such aspects, network **130** and external computing device **186** may be omitted.

However, in other aspects, one or more of mobile computing devices **184.1** and/or **184.2**, and/or the smart home controllers **185** and/or the personal electronic devices **189**, may work in conjunction with external computing device **186** to determine operating data, risks associated with operation, control actions to be taken, and/or alerts to be generated. For example, in some aspects, mobile computing device **184.1** may broadcast geographic location data and/or autonomous operation feature data, which is received by external computing device **186**. In this case, external computing device **186** may be configured to determine whether the same or other information should be sent to mobile computing device **184.2** based upon the geographic location data, autonomous operation feature data, or data derived therefrom.

Mobile computing devices **184.1** and **184.2** may be configured to execute one or more algorithms, programs, applications, etc., to determine a geographic location of each respective mobile computing device (and thus their associated vehicle) to generate, measure, monitor, and/or collect one or more sensor metrics as telematics data, to broadcast the geographic data and/or telematics data via their respective radio links, to receive the geographic data and/or telematics data via their respective radio links, to determine whether an alert should be generated based upon the telematics data and/or the geographic location data, to generate the one or more alerts, and/or to broadcast one or more alert notifications. Such functionality may, in some embodiments be controlled in whole or part by a Data Application operating on the mobile computing devices **184**, as discussed elsewhere herein. Such Data Application may communicate between the mobile computing devices **184**, the smart home controllers **185**, the personal electronic devices **189**, and one or more external computing devices **186** (such as servers **140**) to facilitate centralized data collection and/or processing.

In some embodiments, the Data Application may facilitate control of a vehicle **182** by a user, such as by selecting vehicle destinations and/or routes along which the vehicle **182** will travel. The Data Application may further be used to establish restrictions on vehicle use or store user preferences for vehicle use, such as in a user profile. In further embodiments, the Data Application may monitor vehicle operation or sensor data in real-time to make recommendations or for other purposes as described herein. The Data Application may further facilitate monitoring and/or assessment of the vehicle **182**, such as by evaluating operating data to determine the condition of the vehicle or components thereof (e.g., sensors, autonomous operation features, etc.).

External computing device **186** may be configured to execute various software applications, algorithms, and/or other suitable programs. External computing device **186** may be implemented as any suitable type of device to facilitate the functionality as described herein. For example,

external computing device **186** may be a server **140** as discuses elsewhere herein. As another example, the external computing device **186** may be another computing device associated with an operator or owner of a vehicle **182**, such as a desktop or notebook computer. Although illustrated as a single device in FIG. **1**B, one or more portions of external computing device **186** may be implemented as one or more storage devices that are physically co-located with external computing device **186**, or as one or more storage devices utilizing different storage locations as a shared database structure (e.g. cloud storage).

In some embodiments, external computing device **186** may be configured to perform any suitable portion of the processing functions remotely that have been outsourced by one or more of mobile computing devices **184.1** and/or **184.2** (and/or vehicle controllers **181.1**), and/or the smart home controllers **185** and/or the personal electronic devices **189**. For example, mobile computing device **184.1** and/or **184.2** may collect data (e.g., geographic location data and/or telematics data) as described herein, but may send the data to external computing device **186** for remote processing instead of processing the data locally. In such embodiments, external computing device **186** may receive and process the data to determine whether an anomalous condition exists and, if so, whether to send an alert notification to one or more mobile computing devices **184.1** and **184.2** or take other actions.

In one aspect, external computing device **186** may additionally or alternatively be part of an insurer computing system (or facilitate communications with an insurer computer system), and as such may access insurer databases, execute algorithms, execute applications, access remote servers, communicate with remote processors, etc., as needed to perform insurance-related functions. Such insurance-related functions may include assisting insurance customers in evaluating autonomous operation features, limiting manual vehicle operation based upon risk levels, providing information regarding risk levels associated with autonomous and/or manual vehicle operation along routes, and/or determining repair/salvage information for damaged vehicles. For example, external computing device **186** may facilitate the receipt of autonomous operation or other data from one or more mobile computing devices **184.1**-**184**.N, which may each be running a Data Application to obtain such data from autonomous operation features or sensors **120** associated therewith.

In aspects in which external computing device **186** facilitates communications with an insurer computing system (or is part of such a system), data received from one or more mobile computing devices **184.1**-**184**.N, and/or the smart home controllers **185** and/or personal electronic devices **189**, may include user credentials, which may be verified by external computing device **186** or one or more other external computing devices, servers, etc. These user credentials may be associated with an insurance profile, which may include, for example, insurance policy numbers, a description and/or listing of insured assets, vehicle identification numbers of insured vehicles, addresses of insured structures, contact information, premium rates, discounts, etc.

In this way, data received from one or more mobile computing devices **184.1**-**184**.N, and/or the smart home controllers **185** and/or personal electronic devices **189**, may allow external computing device **186** to uniquely identify each insured customer and/or whether each identified insurance customer has installed the Data Application. In addition, external computing device **186** may facilitate the communication of the updated insurance policies, premiums, rates, discounts, etc., to insurance customers for their review, modification, and/or approval—such as via wireless communication or data transmission to one or more mobile computing devices **184.1**-**184**.N over one or more radio frequency links or wireless communication channels.

In some aspects, external computing device **186** may facilitate indirect communications between one or more of mobile computing devices **184**, vehicles **182**, smart home controllers **185**, personal electronic devices **189**, and/or smart infrastructure component **188** via network **130** or another suitable communication network, wireless communication channel, and/or wireless link. Smart infrastructure components **188** may be implemented as any suitable type of traffic infrastructure components configured to receive communications from and/or to send communications to other devices, such as mobile computing devices **184** and/or external computing device **186**. Thus, smart infrastructure components **188** may include infrastructure components **126** having infrastructure communication devices **124**. For example, smart infrastructure component **188** may be implemented as a traffic light, a railroad crossing signal, a construction notification sign, a roadside display configured to display messages, a billboard display, a parking garage monitoring device, etc.

In some embodiments, the smart infrastructure component **188** may include or be communicatively connected to one or more sensors (not shown) for detecting information relating to the condition of the smart infrastructure component **188**, which sensors may be connected to or part of the infrastructure communication device **124** of the smart infrastructure component **188**. The sensors (not shown) may generate data relating to weather conditions, traffic conditions, or operating status of the smart infrastructure component **188**. The smart infrastructure component **188** may be configured to receive the sensor data generated and determine a condition of the smart infrastructure component **188**, such as weather conditions, road integrity, construction, traffic, available parking spaces, etc.

In some aspects, smart infrastructure component **188** may be configured to communicate with one or more other devices directly and/or indirectly. For example, smart infrastructure component **188** may be configured to communicate directly with mobile computing device **184.2** via radio link **183***d* and/or with mobile computing device **184.1** via links **183***b* and **183***f* utilizing network **130**. As another example, smart infrastructure component **188** may communicate with external computing device **186** via links **183***e* and **183***f* utilizing network **130**. To provide some illustrative examples of the operation of the smart infrastructure component **188**, if smart infrastructure component **188** is implemented as a smart traffic light, smart infrastructure component **188** may change a traffic light from green to red (or vice-versa) or adjust a timing cycle to favor traffic in one direction over another based upon data received from the vehicles **182**. If smart infrastructure component **188** is implemented as a traffic sign display, smart infrastructure component **188** may display a warning message that an anomalous condition (e.g., an accident) has been detected ahead and/or on a specific road corresponding to the geographic location data.

FIG. **2** illustrates a block diagram of an exemplary mobile device **110**, smart home controller **185**, or an exemplary on-board computer **114** consistent with the system **100** and the system **180**. The mobile device **110**, smart home controller **185**, or the on-board computer **114** may include a display **202**, a GPS unit **206**, a communication unit **220**, an accelerometer **224**, one or more additional sensors (not shown), a user-input device (not shown), and/or, like the

server **140**, a controller **204**. In some embodiments, the mobile device **110** and on-board computer **114** may be integrated into a single device, or either may perform the functions of both. The on-board computer **114** (or mobile device **110**) interfaces with the sensors **120** to receive information regarding the vehicle **108** and its environment, which information is used by the autonomous operation features to operate the vehicle **108**. Similarly, the smart home controller **185** interfaces with a plurality of sensors dispose on and/or proximate to a smart home **187**, which information is used by the autonomous operation features to operate the smart home **187**.

Similar to the controller **155**, the controller **204** may include a program memory **208**, one or more microcontrollers or microprocessors (MP) **210**, a RAM **212**, and an I/O circuit **216**, all of which are interconnected via an address/data bus **214**. The program memory **208** includes an operating system **226**, a data storage **228**, a plurality of software applications **230**, and/or a plurality of software routines **240**. The operating system **226**, for example, may include one of a plurality of general purpose or mobile platforms, such as the Android™, iOS®, or Windows® systems, developed by Google Inc., Apple Inc., and Microsoft Corporation, respectively. Alternatively, the operating system **226** may be a custom operating system designed for autonomous vehicle operation using the on-board computer **114**. The data storage **228** may include data such as user profiles and preferences, application data for the plurality of applications **230**, routine data for the plurality of routines **240**, and other data related to the autonomous operation features. In some embodiments, the controller **204** may also include, or otherwise be communicatively connected to, other data storage mechanisms (e.g., one or more hard disk drives, optical storage drives, solid state storage devices, etc.) that reside within the vehicle **108** and/or the smart home **187**.

As discussed with reference to the controller **155**, it should be appreciated that although FIG. **2** depicts only one microprocessor **210**, the controller **204** may include multiple microprocessors **210**. Similarly, the memory of the controller **204** may include multiple RAMs **212** and multiple program memories **208**. Although FIG. **2** depicts the I/O circuit **216** as a single block, the I/O circuit **216** may include a number of different types of I/O circuits. The controller **204** may implement the RAMs **212** and the program memories **208** as semiconductor memories, magnetically readable memories, or optically readable memories, for example.

The one or more processors **210** may be adapted and configured to execute any of one or more of the plurality of software applications **230** or any one or more of the plurality of software routines **240** residing in the program memory **204**, in addition to other software applications. One of the plurality of applications **230** may be an autonomous vehicle operation application **232** that may be implemented as a series of machine-readable instructions for performing the various tasks associated with implementing one or more of the autonomous operation features according to the autonomous operation method **300**, described further below. Similarly, one of the plurality of applications **230** may be a smart home operation application (not depicted) for performing various tasks associated with implementing one or more of the autonomous operation features of the smart home **187**. Another of the plurality of applications **230** may be an autonomous communication application **234** that may be implemented as a series of machine-readable instructions for transmitting and receiving autonomous operation information to or from external sources via the communication module **220**. Still another application of the plurality of applications **230** may include an autonomous operation monitoring application **236** that may be implemented as a series of machine-readable instructions for sending information regarding autonomous operation of the vehicle to the server **140** via the network **130**. The Data Application for collecting, generating, processing, analyzing, transmitting, receiving, and/or acting upon autonomous operation feature data may also be stored as one of the plurality of applications **230** in the program memory **208** of the mobile computing device **110**, the on-board computer **114**, and/or the smart home controller **185**, which may be executed by the one or more processors **210** thereof.

The plurality of software applications **230** may call various of the plurality of software routines **240** to perform functions relating to autonomous vehicle and/or smart home operation, monitoring, or communication. One of the plurality of software routines **240** may be a configuration routine **242** to receive settings from the vehicle operator and/or smart home occupant to configure the operating parameters of an autonomous operation feature. Another of the plurality of software routines **240** may be a sensor control routine **244** to transmit instructions to a sensor **120** and receive data from the sensor **120**. Still another of the plurality of software routines **240** may be an autonomous control routine **246** that performs a type of autonomous control, such as collision avoidance, lane centering, speed control, fire prevention, or temperature control. In some embodiments, the autonomous vehicle operation application **232** may cause a plurality of autonomous control routines **246** to determine control actions required for autonomous vehicle operation.

Similarly, one of the plurality of software routines **240** may be a monitoring and reporting routine **248** that transmits information regarding autonomous vehicle and/or smart home operation to the server **140** via the network **130**. Yet another of the plurality of software routines **240** may be an autonomous communication routine **250** for receiving and transmitting information between the vehicle **108**, the smart home **187**, and external sources to improve the effectiveness of the autonomous operation features. Any of the plurality of software applications **230** may be designed to operate independently of the software applications **230** or in conjunction with the software applications **230**.

When implementing the exemplary autonomous operation method **300**, the controller **204** of the on-board computer **114** may implement the autonomous vehicle operation application **232** to communicate with the sensors **120** to receive information regarding the vehicle **108** and its environment and process that information for autonomous operation of the vehicle **108**. In some embodiments including external source communication via the communication component **122** or the communication unit **220**, the controller **204** may further implement the autonomous communication application **234** to receive information for external sources, such as other autonomous vehicles, smart infrastructure (e.g., electronically communicating roadways, traffic signals, or parking structures), personal electronic devices, or other sources of relevant information (e.g., weather, traffic, local amenities). Some external sources of information may be connected to the controller **204** via the network **130**, such as the server **140** or internet-connected third-party databases (not shown). Although the autonomous vehicle operation application **232** and the autonomous communication application **234** are shown as two separate applications, it should be understood that the functions of the autonomous opera-

tion features may be combined or separated into any number of the software applications **230** or the software routines **240**.

When implementing the autonomous operation feature monitoring method **400**, the controller **204** may further implement the autonomous operation monitoring application **236** to communicate with the server **140** to provide information regarding autonomous operation. This may include information regarding settings or configurations of autonomous operation features, data from the sensors **120** and/or sensors associated with the smart home **187** regarding the environment, data from the sensors **120** and/or sensors associated with the smart home **187** regarding the response of the vehicle **108** and/or the smart home **187** to its environment, respectively, communications sent or received using the communication component **122** or the communication unit **220**, operating status of the autonomous vehicle operation application **232** and the autonomous communication application **234**, and/or control commands sent from the on-board computer **114** and/or the smart home controller **185** to the control components (not shown) to operate the vehicle **108** and/or the smart home **187**.

In some embodiments, control commands generated by the on-board computer **114** and/or the smart home controller **185** but not implemented may also be recorded and/or transmitted for analysis of how the autonomous operation features would have responded to conditions if the features had been controlling the relevant aspect or aspects of vehicle operation. The information may be received and stored by the server **140** implementing the autonomous operation information monitoring application **141**, and the server **140** may then determine the effectiveness of autonomous operation under various conditions by implementing the feature evaluation application **142**, which may include an assessment of autonomous operation features compatibility. The effectiveness of autonomous operation features and the extent of their use may be further used to determine one or more risk levels associated with operation of the autonomous vehicle by the server **140**.

In addition to connections to the sensors **120** that are external to the mobile device **110** or the on-board computer **114**, the mobile device **110** or the on-board computer **114** may include additional sensors **120**, such as the GPS unit **206** or the accelerometer **224**, which may provide information regarding the vehicle **108** for autonomous operation and other purposes. Such sensors **120** may further include one or more sensors of a sensor array **225**, which may include, for example, one or more cameras, accelerometers, gyroscopes, magnetometers, barometers, thermometers, proximity sensors, light sensors, Hall Effect sensors, etc. The one or more sensors of the sensor array **225** may be positioned to determine telematics data regarding the speed, force, heading, and/or direction associated with movements of the vehicle **108**. Furthermore, the communication unit **220** may communicate with other autonomous vehicles, infrastructure, or other external sources of information to transmit and receive information relating to autonomous vehicle operation. The communication unit **220** may communicate with the external sources via the network **130** or via any suitable wireless communication protocol network, such as wireless telephony (e.g., GSM, CDMA, LTE, etc.), Wi-Fi (802.11 standards), WiMAX, Bluetooth, infrared or radio frequency communication, etc. Furthermore, the communication unit **220** may provide input signals to the controller **204** via the I/O circuit **216**. The communication unit **220** may also transmit sensor data, device status information, control signals, or other output from the controller **204** to one or more external sensors within the vehicle **108**, mobile devices **110**, on-board computers **114**, or servers **140**.

The mobile device **110**, the smart home controller **185**, and/or the on-board computer **114** may include a user-input device (not shown) for receiving instructions or information from the vehicle operator and/or smart home occupant, such as settings relating to an autonomous operation feature. The user-input device (not shown) may include a "soft" keyboard that is displayed on the display **202**, an external hardware keyboard communicating via a wired or a wireless connection (e.g., a Bluetooth keyboard), an external mouse, a microphone, or any other suitable user-input device. The user-input device (not shown) may also include a microphone capable of receiving user voice input.

Data Application

The mobile device **110**, the smart home controller **185** and/or on-board computer **114** may run a Data Application to collect, transmit, receive, and/or process autonomous operation feature data. Such autonomous operation feature data may include data directly generated by autonomous operation features, such as control commands used in operating the vehicle **108** and/or the smart home **187**. Similarly, such autonomous operation feature data may include shadow control commands generated by the autonomous operation features but not actually used in operating the vehicle and/or the smart home, such as may be generated when the autonomous operation features are disabled. The autonomous operation feature data may further include non-control data generated by the autonomous operation features, such as determinations regarding environmental conditions in the vehicle operating environment in which the vehicle **108** and/or the smart home **187** operates (e.g., traffic conditions, construction locations, pothole locations, worn lane markings, corners with obstructed views, weather conditions, crime conditions, etc.). The autonomous operation feature data may yet further include sensor data generated by (or derived from sensor data generated by) sensors **120** and/or sensor associated with the smart home **185** utilized by the autonomous operation features. For example, data from LIDAR and ultrasonic sensors may be used by vehicles for autonomous operation. As another example, an accelerometer may be used by smart homes to detect an earthquake and autonomously initiate an appropriate response. Such data captures a much more detailed and complete representation of the conditions in which the vehicle **108** and/or smart home **187** operates than traditional operation metrics (e.g., miles driven) or non-autonomous telematics data (e.g., acceleration, position, and time).

Autonomous operation feature data may be processed and used by the Data Application to determine information regarding the vehicle **108** and/or the smart home **187**, its operation, or its operating environment. The autonomous operation feature data may further be communicated by the Data Application to a server **140** via network **130** for processing and/or storage. In some embodiments, the autonomous operation feature data (or information derived therefrom) may be transmitted directly via radio links **183** or indirectly via network **130** from the vehicle **108** and/or the smart home **187** to other vehicles and/or smart homes (or to mobile devices **110**). By communicating information associated with the autonomous operation feature data to other nearby vehicles and/or smart homes, the other vehicles and/or smart homes or their operators may make use of such data for routing, control, or other purposes. This may be particularly valuable in providing detailed information regarding an operating environment (e.g., traffic, accidents, flooding, ice, etc.) collected by a Data Application of an

autonomous vehicle **108** and/or the smart home **187** to a driver of a non-autonomous vehicle and/or an occupant of a non-smart home via a Data Application of a mobile device **110** associated with the driver and/or occupant. For example, ice patches may be identified by an autonomous operation feature of a vehicle controller **181.1** of vehicle **182.1** and transmitted via the Data Application operating in the mobile computing device **184.1** over the network **130** to the mobile computing device **184.2**, where a warning regarding the ice patches may be presented to the driver of vehicle **182.2**. As another example, locations of emergency vehicles or accidents may be determined and communicated between vehicles **182**, such as between an autonomous vehicle **182.1** and a traditional (non-autonomous) vehicle **182.2**.

In further embodiments, a Data Application may serve as an interface between the user and an autonomous vehicle **108** and/or the smart home **187**, via the user's mobile device **110**, the vehicle's on-board computer **114**, and/or the smart home controller **185**. The user may interact with the Data Application to locate, retrieve, or park the vehicle **108** and/or control or monitor the vehicle **108** and/or the smart home **187**. For example, the Data Application may be used to select a destination and route the vehicle **108** to the destination, which may include controlling the vehicle to travel to the destination in a fully autonomous mode. In some embodiments, the Data Application may further determine and/or provide information regarding the vehicle **108**, such as the operating status or condition of autonomous operation features, sensors, or other vehicle components (e.g., tire pressure). In yet further embodiments, the Data Application may be configured to assess risk levels associated with operation based upon location, autonomous operation feature use (including settings), operating conditions, or other factors. Such risk assessment may be further used in recommending autonomous feature use levels, generating warnings to a vehicle operator and/or smart home occupant, or adjusting an insurance policy associated with the vehicle **108** and/or the smart home **187**.

Data Applications may be installed and running on a plurality of mobile devices **110**, on-board computers **114**, and/or smart home controllers **185** in order to facilitate data sharing and other functions as described herein. Additionally, such Data Applications may provide data to, and receive data from, one or more servers **140**. For example, a Data Application running on a user's mobile device **110** may communicate location data to a server **140** via the network **130**. The server **140** may then process the data to determine a route, risk level, recommendation, or other action. The server **140** may then communicate the determined information to the mobile device **110**, the on-board computer **114**, and/or the smart home controller **185**, which may cause the vehicle **108** and/or the smart home **187** to operate in accordance with the determined information (e.g., travel along a determined optimal route, initiate measures to prevent weather/environmental damage, etc.). Thus, the Data Application may facilitate data communication between the front-end components **102** and the back-end components **104**, allowing more efficient processing and data storage.

Exemplary Autonomous Operation Method

FIG. **3** illustrates a flow diagram of an exemplary autonomous operation method **300**, which may be implemented by the autonomous vehicle data system **100**. The method **300** may begin when the controller **204** receives a start signal (block **302**). The start signal may be a command from the vehicle operator through the user-input device to enable or engage one or more autonomous operation features of the vehicle **108** and/or a command from a smart home occupant through the user-input device to enable or engage one or more autonomous operation features of the smart home **187**. In some embodiments, the vehicle operator and/or smart home occupant may further specify settings or configuration details for the autonomous operation features. For fully autonomous vehicles, the settings may relate to one or more destinations, route preferences, fuel efficiency preferences, speed preferences, or other configurable settings relating to the operation of the vehicle **108**. In some embodiments, fully autonomous vehicles may include additional features or settings permitting them to operate without passengers or vehicle operators within the vehicle. For example, a fully autonomous vehicle may receive an instruction to find a parking space within the general vicinity, which the vehicle may do without the vehicle operator. The vehicle may then be returned to a selected location by a request from the vehicle operator via a mobile device **110** or otherwise. This feature may further be adapted to return a fully autonomous vehicle if lost or stolen.

For some autonomous vehicles and/or smart homes, the settings may include enabling or disabling particular autonomous operation features, specifying thresholds for autonomous operation, specifying warnings or other information to be presented to the vehicle operator and/or occupant, specifying autonomous communication types to send or receive, specifying conditions under which to enable or disable autonomous operation features, or specifying other constraints on feature operation. For example, a vehicle operator may set the maximum speed for an adaptive cruise control feature with automatic lane centering. In some embodiments, the settings may further include a specification of whether the vehicle **108** should be operating as a fully or partially autonomous vehicle.

In embodiments where only one autonomous operation feature is enabled, the start signal may consist of a request to perform a particular task (e.g., autonomous parking or engage weather-proofing) or to enable a particular feature (e.g., autonomous braking for collision avoidance or engage autonomous lighting that follows an occupant). In other embodiments, the start signal may be generated automatically by the controller **204** based upon predetermined settings (e.g., when the vehicle **108** exceeds a certain speed or is operating in low-light conditions). In some embodiments, the controller **204** may generate a start signal when communication from an external source is received (e.g., when the vehicle **108** is on a smart highway, near another autonomous vehicle, or a national weather service issues an alert). In some embodiments, the start signal may be generated by or received by the Data Application running on a mobile device **110**, on-board computer **114** within the vehicle **108**, and/or smart home controller within the smart home **187**. The Data Application may further set or record settings for one or more autonomous operation features of the vehicle **108** and/or the smart home **187**.

After receiving the start signal at block **302**, the controller **204** receives sensor data from the sensors **120**, and/or sensors associated with the smart home **187**, during operation (block **304**). In some embodiments, the controller **204** may also receive information from external sources through the communication component **122** or the communication unit **220**. The sensor data may be stored in the RAM **212** for use by the autonomous vehicle operation application **232**. In some embodiments, the sensor data may be recorded in the data storage **228** or transmitted to the server **140** via the network **130**. The Data Application may receive the sensor data, or a portion thereof, and store or transmit the received sensor data. In some embodiments, the Data Application

may process or determine summary information from the sensor data before storing or transmitting the summary information. The sensor data may alternately either be received by the controller **204** as raw data measurements from one of the sensors **120** and/or sensors associated with the smart home **187** or may be preprocessed by the sensor **120** and/or sensors associated with the smart home **187** prior to being received by the controller **204**. For example, a tachometer reading may be received as raw data or may be preprocessed to indicate vehicle movement or position. As another example, a sensor **120** comprising a radar or LIDAR unit may include a processor to preprocess the measured signals and send data representing detected objects in 3-dimensional space to the controller **204**.

The autonomous vehicle operation application **232** or other applications **230** or routines **240** may cause the controller **204** to process the received sensor data in accordance with the autonomous operation features (block **306**). The controller **204** may process the sensor data to determine whether an autonomous control action is required or to determine adjustments to the controls of the vehicle **108** and/or the smart home **187** (i.e., control commands). For example, the controller **204** may receive sensor data indicating a decreasing distance to a nearby object in the vehicle's path and process the received sensor data to determine whether to begin braking (and, if so, how abruptly to slow the vehicle **108**).

As another example, the controller **204** may process the sensor data to determine whether the vehicle **108** is remaining with its intended path (e.g., within lanes on a roadway). If the vehicle **108** is beginning to drift or slide (e.g., as on ice or water), the controller **204** may determine appropriate adjustments to the controls of the vehicle to maintain the desired bearing. If the vehicle **108** is moving within the desired path, the controller **204** may nonetheless determine whether adjustments are required to continue following the desired route (e.g., following a winding road). Under some conditions, the controller **204** may determine to maintain the controls based upon the sensor data (e.g., when holding a steady speed on a straight road).

As still another example, the controller **204** may process the sensor data to determine whether fire containment and/or extinguishing response is actually containing and/or extinguishing a fire located at the smart home **187**. If the fire continues to spread, the controller **204** may determine appropriate adjustments to the containment and/or extinguishing response. If the fire is properly contained, the controller **204** may continue to monitor the fire containment and/or extinguishing response to prevent collateral damage.

In some embodiments, the Data Application may record information related to the processed sensor data, including whether the autonomous operation features have determined one or more control actions to control the vehicle and/or details regarding such control actions. The Data Application may record such information even when no control actions are determined to be necessary or where such control actions are not implemented. Such information may include information regarding the vehicle operating environment determined from the processed sensor data (e.g., construction, other vehicles, pedestrians, anomalous environmental conditions, etc.). The information collected by the Data Application may further include an indication of whether and/or how the control actions are implemented using control components of the vehicle **108** and/or the smart home **187**.

When the controller **204** determines an autonomous control action is required (block **308**), the controller **204** may cause the control components of the vehicle **108** to adjust the operating controls of the vehicle **108** and/or the smart home **187** achieve desired operation (block **310**). For example, the controller **204** may send a signal to open or close the throttle of the vehicle **108** to achieve a desired speed. Alternatively, the controller **204** may control the steering of the vehicle **108** to adjust the direction of movement. In some embodiments, the vehicle **108** may transmit a message or indication of a change in velocity or position using the communication component **122** or the communication module **220**, which signal may be used by other autonomous vehicles to adjust their controls. As discussed elsewhere herein, the controller **204** may also log or transmit the autonomous control actions to the server **140** via the network **130** for analysis. In some embodiments, an application (which may be a Data Application) executed by the controller **204** may communicate data to the server **140** via the network **130** or may communicate such data to the mobile device **110** for further processing, storage, transmission to nearby vehicles, smart homes, infrastructure, and/or communication to the server **140** via network **130**.

The controller **204** may continue to receive and process sensor data at blocks **304** and **306** until an end signal is received by the controller **204** (block **312**). The end signal may be automatically generated by the controller **204** upon the occurrence of certain criteria (e.g., the destination is reached, environmental conditions require manual operation of the vehicle **108** by the vehicle operator, or an occupant-defined end condition is satisfied). Alternatively, the vehicle operator and/or smart home occupant may pause, terminate, or disable the autonomous operation feature or features using the user-input device or by manually operating the vehicle's controls, such as by depressing a pedal or turning a steering instrument, and/or by manually interacting with smart equipment disposed in the smart home **187**. When the autonomous operation features are disabled or terminated, the controller **204** may either continue operation without the autonomous features or may shut off the vehicle **108** and/or various smart equipment, depending upon the circumstances.

Where control of the vehicle **108** must be returned to the vehicle operator and/or control of the smart home **187** must be returned to the smart home occupant, the controller **204** may alert the vehicle operator and/or smart home occupant in advance of returning to manual operation. The alert may include a visual, audio, or other indication to obtain the attention of the vehicle operator and/or smart home occupant. In some embodiments, the controller **204** may further determine whether the vehicle operator is capable of resuming manual operation before terminating autonomous operation. If the vehicle operator is determined not to be capable of resuming operation, the controller **204** may cause the vehicle to stop or take other appropriate action.

The autonomous operation features may generate and implement control decisions relating to the control of the motive, steering, and stopping components of the vehicle **108** and/or the various components of the smart home **187**. The control decisions may include or be related to control commands issued by the autonomous operation features to control such control components of the vehicle **108** and/or the smart home **187** during operation. In some embodiments, control decisions may include decisions determined by the autonomous operation features regarding control commands such feature would have issued under the conditions then occurring, but which control commands were not issued or implemented. For example, an autonomous operation feature may generate and record shadow control decisions it would have implemented if engaged to operate the vehicle

108 and/or the smart home 187 even when the feature is disengaged (or engaged using other settings from those that would produce the shadow control decisions).

Data regarding the control decisions actually implemented and/or the shadow control decisions not implemented to control the vehicle 108 and/or the smart home 187 may be recorded for use in assessing autonomous operation feature effectiveness, accident and/or event reconstruction and fault determination, feature use or settings recommendations, risk determination and insurance policy adjustments, or other purposes as described elsewhere herein. For example, actual control decisions may be compared against control decisions that would have been made by other systems, software versions, or with additional sensor data or communication data.

As used herein, the terms "preferred" or "preferably made" control decisions mean control decisions that optimize some metric associated with risk under relevant conditions. Such metric may include, among other things, a statistical correlation with one or more risks (e.g., risks related to a vehicle collision) or an expected value associated with risks (e.g., a risk-weighted expected loss associated with potential vehicle accidents). The preferably made, or preferred or recommended, control decisions discussed herein may include control decisions or control decision outcomes that are less risky, have lower risk or the lowest risk of all the possible or potential control decisions given various operating conditions, and/or are otherwise ideal, recommended, or preferred based upon various operating conditions, including autonomous system or feature capability; current road, environmental or weather, traffic, or construction conditions through which the vehicle is traveling; and/or current versions of autonomous system software or components that the autonomous vehicle is equipped with and using.

The preferred or recommended control decisions may result in the lowest level of potential or actual risk of all the potential or possible control decisions given a set of various operating conditions and/or system features or capabilities. Alternatively, the preferred or recommended control decisions may result in a lower level of potential or actual risk (for a given set of operating conditions) to the autonomous vehicle and passengers, and other people or vehicles, than some of the other potential or possible control decisions that could have been made by the autonomous system or feature.

Exemplary Monitoring Method

FIG. 4A is a flow diagram depicting an exemplary autonomous operation monitoring method 400, which may be implemented by the autonomous vehicle data system 100. The method 400 monitors the operation of the vehicle 108, the smart home 187, and/or the personal electronic device 189 and transmits information regarding the vehicle 108, the smart home 187, and/or the personal electronic device 189 to the server 140, which information may then be used to determine autonomous operation feature usage or effectiveness. The method 400 may be used for monitoring the state of the vehicle 108, the smart home 187, and/or the personal electronic device 189, for providing data to other vehicles 182 and/or smart homes, for responding to emergencies or unusual situations during operation, for testing autonomous operation features in a controlled environment, for determining actual feature use during operation outside a test environment, for assessment of feature operation, and/or for other purposes described herein. In alternative embodiments, the method 400 may be implemented whenever the vehicle 108, the smart home 187, and/or the personal electronic device 189 is in operation (manual or autonomous) or only when the autonomous operation features are enabled.

The method 400 may likewise be implemented as either a real-time process, in which information regarding the vehicle 108, the smart home 187, and/or the personal electronic device 189 is communicated to the server 140 while monitoring is ongoing, or as a periodic process, in which the information is stored within the vehicle 108, the smart home 187, and/or the personal electronic device 189 and communicated to the server 140 at intervals (e.g., upon completion of a trip or when an incident occurs, when a loss-event occurs, etc.). In some embodiments, the method 400 may communicate with the server 140 in real-time when certain conditions exist (e.g., when a sufficient data connection through the network 130 exists or when no roaming charges would be incurred). In further embodiments, a Data Application executed by the mobile device 110, the on-board computer 114, the smart home controller 185, and/or the personal electronic device 189 may perform such monitoring, recording, and/or communication functions, including any of the functions described below with respect to blocks 402-434.

The method 400 may begin when the controller 204 receives an indication of vehicle, smart home, and/or personal electronic device operation (block 402). The indication may be generated when the vehicle 108 is started, when the smart home 187 becomes occupied, or when an autonomous operation feature is enabled by the controller 204 or by input from the vehicle operator and/or smart home occupant, as discussed above. In response to receiving the indication, the controller 204 may create a timestamp (block 404). The timestamp may include information regarding the date, time, location, operating environment, condition, and autonomous operation feature settings or configuration information. The date and time may be used to identify one vehicle trip or one period of autonomous operation feature use, in addition to indicating risk levels due to various factors, such as traffic, weather, and so on.

The additional location and environmental data may include information regarding the position of the vehicle 108 from the GPS unit 206 and its surrounding environment (e.g., road conditions, weather conditions, nearby traffic conditions, type of road, construction conditions, presence of pedestrians, presence of other obstacles, availability of autonomous communications from external sources, etc.). Condition information may include information regarding the type, make, and model of the vehicle 108, the age or mileage of the vehicle 108, the status of vehicle equipment (e.g., tire pressure, non-functioning lights, fluid levels, etc.), the type, make, and model of smart devices within the smart home 187, or other information relating to the vehicle 108, the smart home 187, and/or the personal electronic device 189. In some embodiments, condition information may further include information regarding the sensors 120, such as type, configuration, or operational status (which may be determined, for example, from analysis of actual or test data from the sensors). In some embodiments, the timestamp may be recorded on the client device 114, the mobile device 110, or the server 140.

The autonomous operation feature settings may correspond to information regarding the autonomous operation features, such as those described above with reference to the autonomous operation method 300. The autonomous operation feature configuration information may correspond to information regarding the number and type of the sensors 120 (which may include indications of manufacturers and

models of the sensors **120**), the disposition of the sensors **120** within the vehicle **108**, the smart home **187**, and/or the personal electronic device **189** (which may include disposition of sensors **120** within one or more mobile devices **110**), the one or more autonomous operation features (e.g., the autonomous vehicle operation application **232** or the software routines **240**), autonomous operation feature control software, versions of the software applications **230** or routines **240** implementing the autonomous operation features, or other related information regarding the autonomous operation features.

For example, the configuration information may include the make and model of the vehicle **108** (indicating installed sensors **120** and the type of on-board computer **114**), an indication of smart devices and the type of smart home controller **185** within the smart home **187**, an indication of a malfunctioning or obscured sensor **120** in part of the vehicle **108**, the smart home **187**, and/or the personal electronic device **189**, information regarding additional aftermarket sensors **120** installed within the vehicle **108**, the smart home **187**, and/or the personal electronic device **189**, a software program type and version for a control program installed as an application **230** on the on-board computer **114**, the smart home controller **185**, and/or the personal electronic device **189**, and software program types and versions for each of a plurality of autonomous operation features installed as applications **230** or routines **240** in the program memory **208** of the on-board computer **114**, the smart home controller **185**, and/or the personal electronic device **189**.

During operation, the sensors **120** may generate sensor data regarding the vehicle **108**, the smart home **187**, and/or the personal electronic device **189** and its environment, which may include other vehicles **182** or smart homes within the operating environment of the vehicle **108**, the smart home **187**, and/or the personal electronic device **189**. In some embodiments, one or more of the sensors **120** may preprocess the measurements and communicate the resulting processed data to the on-board computer **114**, the smart home controller **185**, and/or the personal electronic device **189** and/or the mobile device **110**. The controller **204** may receive sensor data from the sensors **120** (block **406**). The sensor data may include information regarding the vehicle's position, speed, acceleration, direction, and responsiveness to controls.

The sensor data may further include information regarding the location and movement of obstacles or obstructions (e.g., other vehicles, buildings, barriers, pedestrians, animals, trees, or gates), weather conditions (e.g., precipitation, wind, visibility, or temperature), road conditions (e.g., lane markings, potholes, road material, traction, or slope), signs or signals (e.g., traffic signals, construction signs, building signs or numbers, or control gates), or other information relating to the operating environment. In some embodiments, sensors **120** may indicate the number of passengers within the vehicle **108** and/or occupants within the smart home **187**, including an indication of whether the vehicle and/or smart home is entirely empty.

In addition to receiving sensor data from the sensors **120**, in some embodiments the controller **204** may receive autonomous communication data from the communication component **122** or the communication module **220** (block **408**). The communication data may include information from other autonomous vehicles (e.g., sudden changes to vehicle speed or direction, intended vehicle paths, hard braking, vehicle failures, collisions, or maneuvering or stopping capabilities), infrastructure (road or lane boundaries, bridges, traffic signals, control gates, or emergency stopping areas), other smart homes (e.g., the presence of potentially hazardous conditions), or other external sources (e.g., map databases, weather databases, or traffic and accident databases). In some embodiments, the communication data may include data from non-autonomous vehicles and/or homes, which may include data regarding operation or anomalies within the operating environment determined by a Data Application operating on a mobile device **110**, on-board computer **114**, the smart home controller **185**, and/or the personal electronic device **189**. The communication data may be combined with the received sensor data received to obtain a more robust understanding of the operating environment.

For example, the server **140** or the controller **204** may combine sensor data indicating frequent changes in speed relative to tachometric data with map data relating to a road upon which the vehicle **108** is traveling to determine that the vehicle **108** is in an area of hilly terrain. As another example, weather data indicating recent snowfall in the vicinity of the vehicle **108** may be combined with sensor data indicating frequent slipping or low traction to determine that the vehicle **108** is traveling on a snow-covered or icy road.

The controller **204** may process the sensor data, the communication data, and the settings or configuration information to determine whether an incident has occurred (block **410**). As used herein, an "incident" is an occurrence during operation of an autonomous vehicle, smart home, and/or personal electronic device outside of normal safe operating conditions, such that one or more of the following occurs: (i) there is an interruption of ordinary operation, (ii) there is damage to the vehicle, smart home, personal electronic device or other property, (iii) there is injury to a person, (iv) the conditions require action to be taken by an operator, occupant, autonomous operation feature, pedestrian, or other party to avoid damage or injury, and/or (v) an anomalous condition is detected that requires an adjustment outside of ordinary vehicle operation. Incidents from categories (ii) and (iii) above may be considered "loss-events." Incidents may include collisions, hard braking, hard acceleration, evasive maneuvering, loss of traction, detection of objects within a threshold distance from the vehicle **108**, alerts presented to the vehicle operator, component failure, inconsistent readings from sensors **120**, or attempted unauthorized access to the on-board computer by external sources. Incidents may also include accidents, vehicle breakdowns, flat tires, empty fuel tanks, or medical emergencies. Incidents may further include identification of construction requiring the vehicle to detour or stop, hazardous conditions (e.g., fog or road ice), or other anomalous environmental conditions.

In some embodiments, the controller **204** may anticipate or project an expected incident based upon sensor or external data, allowing the controller **204** to send control signals to minimize the negative effects of the incident. For example, the controller **204** may cause the vehicle **108** to slow and move to the shoulder of a road immediately before running out of fuel. As another example, adjustable seats within the vehicle **108** may be adjusted to better position vehicle occupants in anticipation of a collision, windows may be opened or closed, or airbags may be deployed. As yet another example, storm shutters for windows of the smart home **187** may be activated in anticipation of a weather event.

When an incident is determined to have occurred (block **412**), information regarding the incident and the vehicle, smart home, and/or personal electronic device status may be recorded (block **414**), either in the data storage **228** or the

database **146**. The information recorded may include sensor data, communication data, and settings or configuration information prior to, during, and immediately following the incident. In some embodiments, a preliminary determination of fault may also be produced and stored. The information may further include a determination of whether the vehicle **108**, the smart home **187**, and/or the personal electronic device **189** has continued operating (either autonomously or manually) or whether the vehicle **108**, the smart home **187**, and/or the personal electronic device **189** is capable of continuing to operate in compliance with applicable safety and legal requirements. If the controller **204** determines that the vehicle **108**, the smart home **187**, and/or the personal electronic device **189** has discontinued operation or is unable to continue operation (block **416**), the method **400** may terminate. If the vehicle **108**, the smart home **187**, and/or the personal electronic device **189** continues operation, then the method **400** may continue as described below with reference to block **418**.

FIG. **4**B illustrates an alternative portion of the method **400** following an incident. When an incident is determined to have occurred (block **412**), the controller **204** or the server **140** may record status and operating information (block **414**), as above. In some instances, the incident may interrupt communication between the vehicle **108**, the smart home **187**, and/or the personal electronic device **189** and the server **140** via network **130**, such that not all information typically recorded will be available for recordation and analysis by the server **140**. Based upon the recorded data, the server **140** or the controller **204** may determine whether assistance may be needed at the location of the vehicle **108**, the smart home **187**, and/or the personal electronic device **189** (block **430**). For example, the controller **204** may determine that a head-on collision has occurred based upon sensor data (e.g., airbag deployment, automatic motor shut-off, LIDAR data indicating a collision, etc.) and may further determine based upon information regarding the speed of the vehicle **108** and other information that medical, police, and/or towing services will be necessary. The determination that assistance is needed may further include a determination of types of assistance needed (e.g., police, ambulance, fire, towing, vehicle maintenance, fuel delivery, etc.). This determination may include analysis of the type of incident, the sensor data regarding the incident (e.g., images from outward facing or inward facing cameras installed within the vehicle, the smart home, and/or the personal electronic device, identification of whether any passengers and/or occupants were present within the vehicle and/or smart home, determination of whether any pedestrians or passengers in other vehicles were involved in the incident, etc.). The determination of whether assistance is needed may further include information regarding the determined status of the vehicle **108**, the smart home **187**, and/or the personal electronic device **189**.

In some embodiments, the determination regarding whether assistance is needed may be supplemented by a verification attempt, such as a phone call or communication through the on-board computer **114**, the smart home controller **189**, and/or the personal electronic device **189**. Where the verification attempt indicates assistance is required or communication attempts fail, the server **140** or controller **204** would then determine that assistance is needed, as described above. For example, when assistance is determined to be needed following an accident involving the vehicle **108** and/or a loss-event at the smart home **187**, the server **140** may direct an automatic telephone call to a mobile telephone number associated with the vehicle **108**, the smart home **187**, and/or the personal electronic device **189** and/or operator and/or occupant thereof. If no response is received, or if the respondent indicates assistance is required, the server **140** may proceed to cause a request for assistance to be generated.

When assistance is determined to be needed (block **432**), the controller **204** or the server **140** may send a request for assistance (block **434**). The request may include information regarding the vehicle **108**, the smart home **187**, and/or the personal electronic device **189**, such as the location, the type of assistance required, other vehicles or homes involved in the incident, pedestrians involved in the incident, vehicle operators or passengers involved in the incident, and/or other relevant information. The request for assistance may include telephonic, data, or other requests to one or more emergency or vehicular service providers (e.g., local police, fire departments, state highway patrols, emergency medical services, public or private ambulance services, hospitals, towing companies, roadside assistance services, vehicle rental services, local claims representative offices, etc.). After sending a request for assistance (block **434**) or when assistance is determined not to be needed (block **432**), the controller **204** or the server **140** may next determine whether the vehicle **108**, the smart home **187**, and/or the personal electronic device **189** is operational (block **416**), as described above. The method **400** may then end or continue as indicated in FIG. **4**A.

In some embodiments, the controller **204** may further determine information regarding the likely cause of a collision or other incident. Alternatively, or additionally, the server **140** may receive information regarding an incident from the on-board computer **114**, the smart home controller **185**, and/or the personal electronic device **189** and determine relevant additional information regarding the incident from the sensor data. For example, the sensor data may be used to determine the points of impact on the vehicle **108** and another vehicle involved in a collision, the relative velocities of each vehicle, the road conditions at the time of the incident, and the likely cause or the party likely at fault. This information may be used to determine risk levels associated with autonomous vehicle operation, as described below, even where the incident is not reported to the insurer.

The controller **204** may determine whether a change or adjustment to one or more of the settings or configuration of the autonomous operation features has occurred (block **418**). Changes to the settings may include enabling or disabling an autonomous operation feature or adjusting the feature's parameters (e.g., resetting the speed on an adaptive cruise control feature). For example, an operator may selectively enable or disable autonomous operation features such as automatic braking, lane centering, temperature control, or even fully autonomous operation at different times. If the settings or configuration are determined to have changed, the new settings or configuration may be recorded (block **422**), either in the data storage **228** or the database **146**. For example, the Data Application may log autonomous operation feature use and changes in a log file, including timestamps associated with the features in use.

Next, the controller **204** may record the operating data relating to the vehicle **108**, the smart home **187**, and/or the personal electronic device **189** in the data storage **228** or communicate the operating data to the server **140** via the network **130** for recordation in the database **146** (block **424**). The operating data may include the settings or configuration information, the sensor data, and/or the communication data discussed above. In some embodiments, operating data related to normal autonomous operation of the vehicle **108**, the smart home **187**, and/or the personal electronic device

189 may be recorded. In other embodiments, only operating data related to incidents of interest may be recorded, and operating data related to normal operation may not be recorded. In still other embodiments, operating data may be stored in the data storage 228 until a sufficient connection to the network 130 is established, but some or all types of incident information may be transmitted to the server 140 using any available connection via the network 130.

The controller 204 may then determine whether operation of the vehicle 108, the smart home 187, and/or the personal electronic device 189 remains ongoing (block 426). In some embodiments, the method 400 may terminate when all autonomous operation features are disabled, in which case the controller 204 may determine whether any autonomous operation features remain enabled. When the vehicle 108 is determined to be operating (or operating with at least one autonomous operation feature enabled), the method 400 may continue through blocks 406-426 until operation has ended. When the vehicle 108, the smart home 187, and/or the personal electronic device 189 is determined to have ceased operating (or is operating without autonomous operation features enabled), the controller 204 may record the completion of operation (block 428), either in the data storage 228 or the database 146. In some embodiments, a second timestamp corresponding to the completion of operation may likewise be recorded, as above.

Exemplary Incident Response Methods

FIG. 5 illustrates a flow diagram of an exemplary incident response method 500 for detecting and responding to incidents involving a vehicle 108, a smart home 187, and/or a personal electronic device 189 while engaged in fully autonomous operation or in the absence of an operator and/or an occupant. The vehicle 108, the smart home 187, and/or the personal electronic device 189 may be operating in a fully autonomous mode of operation without any control decisions being made by a vehicle operator and/or smart home occupant, excluding navigation decisions, such as selection of a destination or route, and/or preference decisions, such as selection of a desired temperature for a room. In some embodiments, the vehicle 108 and/or the smart home 187 may be operating without any passengers and/or occupants or with only passengers and/or occupants who are physically or legally unable to operate the vehicle 108 and/or the smart home 187 in a manual or semi-autonomous mode of operation (e.g., children, persons suffering acute illness, physically handicapped persons, intoxicated or otherwise impaired persons, etc.). Alternatively, the vehicle 108 may be parked in a non-operating state. Particularly when the vehicle 108 and/or the smart home 187 is unoccupied, detection and response to collisions or other incidents interrupting ordinary autonomous operation pose particular challenges that do not arise during manual operation or semi-autonomous operation. Such incidents are typically unintentional and unexpected, and such incidents frequently coincide with damage to sensor components (including sensors 120) or structural components that are essential for safe operation of the vehicle and/or smart home. Additionally, autonomous vehicles and/or smart homes may be incapable of performing actions typically performed by operators and/or occupants in response to manual incidents (e.g., moving a vehicle out of a traffic lane, replacing a tire, moving debris, assessing damage, providing information to authorities, etc.). The incident response method 500 addresses at least these issues.

The incident response method 500 may begin by monitoring the condition of the vehicle 108, the smart home 187, and/or the personal electronic device 189 (block 502), which may include monitoring operating data from the vehicle 108, the smart home 187, and/or the personal electronic device 189 during autonomous operation. If an indication of an unusual condition is detected (block 504), further analysis may be performed to determine whether an incident has occurred (block 506). If an incident (or an incident having sufficient impact upon operation of the vehicle 108, the smart home 187, and/or the personal electronic device 189) is determined to have occurred (block 508), damage to the vehicle 108, the smart home 187, the personal electronic device 189, and/or to other objects may be assessed (block 510). Such assessment may include determining the operating capabilities of the vehicle 108, the smart home 187, and/or the personal electronic device 189, which may be diminished by damage to sensors 120 or other components.

Based upon the determination of damage, one or more responses to the incident may then be determined (block 512). The vehicle 108, the smart home 187, and/or the personal electronic device 189 then implements the one or more responses to address the incident (block 514). In some embodiments, additional responses may be implemented by a server 140 or other device. The method 500 then determines whether monitoring should continue (block 516). If the vehicle 108, the smart home 187, and/or the personal electronic device 189 is continuing to operate or it is otherwise determined that monitoring should continue, the method 500 continues to monitor the autonomous operation (block 502). If operation of the vehicle 108, the smart home 187, and/or the personal electronic device 189 has concluded, the method 500 terminates.

If no indication of an unusual condition is detected (block 504) or no incident having a sufficient impact upon autonomous operation is determined to have occurred (block 508), the method 500 may continue to monitor operation of the vehicle 108, the smart home 187, and/or the personal electronic device 189 as long as vehicle operation continues or it is otherwise determined that monitoring should continue (block 516). Although the method 500 is described with reference to the on-board computer 114, the smart home controller 185, and/or the personal electronic device 189 for simplicity, the described method may be readily modified for implementation by other systems or devices, including one or more of mobile devices 110 and/or servers 140.

At block 502, the on-board computer 114, the smart home controller 185, and/or the personal electronic device 189 of the vehicle 108 and/or the smart home 187 may monitor the condition of the vehicle 108, the smart home 187, and/or the personal electronic device 189. This may include receiving and processing operating data from one or more sensors 120 and/or other components within the vehicle 108, the smart home 187, and/or the personal electronic device 189. The on-board computer 114, the smart home controller 185, and/or the personal electronic device 189 may begin monitoring autonomous operation automatically whenever the vehicle 108, the smart home 187, and/or the personal electronic device 189 is started and/or becomes occupied, or whenever the vehicle 108, the smart home 187, and/or the personal electronic device 189 begins fully autonomous operation. Alternatively, the on-board computer 114, the smart home controller 185, and/or the personal electronic device 189 may begin monitoring when it detects that the vehicle 108, the smart home 187, and/or the personal electronic device 189 is being operated in a fully autonomous mode without passengers and/or occupants. In some embodiments, the on-board computer 114, the smart home 187, and/or the personal electronic device 189 may monitor

the condition of the vehicle **108**, the smart home **187**, and/or the personal electronic device **189** when not in use, such as while the vehicle **108** is parked and/or while the smart home **187** is unoccupied. In such embodiments, the on-board computer **114**, the smart home **187**, and/or the personal electronic device **189**, may begin and/or continue monitoring the vehicle, smart home, and/or personal electronic device condition when the vehicle **108** is parked or shut down, or monitoring may begin and/or continue when the operator exits the vehicle **108** and/or egresses the smart home **187**.

To conserve energy and/or processor usage (particularly in electric vehicles or when parked, and/or smart homes operating on power derived from a local generator), the on-board computer **114**, the smart home controller **185**, and/or the personal electronic device **189** may monitor the vehicle **108**, the smart home **187**, and/or the personal electronic device **189** with a limited set of operating data or data from a limited set of sensors **120**. In further embodiments, the on-board computer **114**, the smart home controller **185**, and/or the personal electronic device **189** may monitor the vehicle, smart home, and/or personal electronic device condition by comparing received operating data at time intervals longer than the time intervals between ordinary sensor data readings used for autonomous operation. For example, the on-board computer **114**, the smart home controller **185**, and/or the personal electronic device **189** may process received operating data every thirty seconds or every minute to detect indications of incidents that may affect autonomous operation. In some embodiments, the on-board computer **114**, the smart home **187**, and/or the personal electronic device **189** may control one or more of the sensors **120** to generate sensor data at such intervals, particularly where the vehicle **108** is not presently operating (e.g., when parked) and/or when the smart home **187** is unoccupied.

The on-board computer **114**, the smart home controller **185**, and/or the personal electronic device **189** may monitor the operating data for indications of unusual conditions that are indicative of a likelihood of an incident, which may require further assessment and response. Such indications of unusual conditions may include discontinuities in the operating data, divergence between sensor data from one or more sensors and control data from one or more autonomous operation features, a plurality of sensor malfunctions, sudden sensor failure (particularly when multiple sensors fail at substantially the same time), and/or sensed conditions associated with incidents (e.g., distance to a sensed object reaching zero, unexpected lane departures, etc.). In some embodiments, indications of unusual conditions may be directly received from sensors **120**, autonomous operation features (i.e., hardware or software components performing particular aspects of autonomous operation), and/or other components of the vehicle **108**, the smart home **187**, and/or the personal electronic device **189** as error signals or alerts. For example, a sensor **120** may perform a self-diagnostic routine at start-up or periodically and may further send an alert to the on-board computer **114**, the smart home controller **185**, and/or the personal electronic device **189** when the sensor **120** is self-determined to be damaged or otherwise malfunctioning.

Indications of unusual conditions may include data points that are associated with a likelihood of a collision or other incident requiring a response, even though such indications may be insufficient to determine such response without further analysis. For example, unexpected or inaccurate sensor data from a nonessential sensor **120** may be caused by damage or by temporary obstruction (e.g., by ice or dirt accumulation).

In yet further embodiments, an indication of an unusual condition may be determined or received with respect to another vehicle, smart home, pedestrian, or object within the current environment of the vehicle **108**, the smart home **187**, and/or the personal electronic device **189**. Such indication may include information regarding an occurrence or likelihood of an incident not directly involving the vehicle **108**, the smart home **187**, and/or the personal electronic device **189**. For example, the incident may involve another autonomous, semi-autonomous, or traditional vehicle within a predetermined or variable distance of the vehicle **108**. In a particular embodiment, the vehicle **108**, the smart home **187**, and/or the personal electronic device **189** may receive an autonomous communication message including the indication of the unusual condition from another vehicle and/or smart home via short-range wireless communication transmission and via the communication component **122**. For example, the other vehicle and/or smart home may automatically send a distress signal upon determining it has been involved in a collision or otherwise detects an emergency condition, which distress signal may be received and processed by the vehicle **108**, the smart home **187**, and/or the personal electronic device **189** to determine and implement an appropriate response.

At block **504**, the on-board computer **114**, the smart home controller **185**, and/or the personal electronic device **189** may determine whether any indications of unusual conditions have been detected. If no such indication of unusual conditions have been identified by the on-board computer **114**, the smart home controller **185**, and/or the personal electronic device **189**, the method **500** may continue by determining whether to continue monitoring (block **516**), as discussed below. If one or more unusual conditions are identified by the on-board computer **114**, the smart home controller **185**, and/or the personal electronic device **189**, the method **500** may instead continue to determine whether an incident requiring a response has occurred (block **506**).

At block **506**, the on-board computer **114**, the smart home controller **185**, and/or the personal electronic device **189** determines whether an incident has occurred. This determination may include determining the type of incident, as well as determining whether the incident requires a response. The on-board computer **114**, the smart home controller **185**, and/or the personal electronic device **189** may receive or collect additional data regarding the vehicle **108**, the smart home **187**, and/or the personal electronic device **189** or the autonomous environment for the determination. In some embodiments, this may include obtaining or accessing additional operating data that had been previously generated. In further embodiments, the on-board computer **114**, the smart home controller **185**, and/or the personal electronic device **189** may cause one or more sensors **120** or other components to generate additional operating data for the determination. In yet further embodiments, the on-board computer **114**, the smart home controller **185**, and/or the personal electronic device **189** may obtain communication data from other vehicles, smart homes, infrastructure components, or other data sources. The operating data to be used in determining whether an incident has occurred may be selected in part based upon the one or more identified indications of unusual conditions. For example, the on-board computer **114**, the smart home controller **185**, and/or the personal electronic device **189** may activate additional sensors **120** positioned in the same area of a vehicle and/or smart home as an identified

potentially malfunctioning sensor **120** in order to obtain additional relevant data regarding the identified sensor **120**.

The on-board computer **114**, the smart home controller **185**, and/or the personal electronic device **189** may determine whether an incident has occurred by analyzing the operating data and/or other data to identify incidents, such as collisions with other vehicles, infrastructure, pedestrians, animals, or other objects. Other incidents that may be determined may include component failure events (e.g., tire blowouts, sensor failure, etc.), software malfunctions (e.g., hacking attempts, cyber-attacks, corrupted software, unresponsive routines, etc.), impassible roadways (e.g., due to accidents, police action, flooding, debris, etc.), severe weather (e.g., dense fog, high winds, or other conditions preventing autonomous operation), and/or other incidents that may require a response outside of the ordinary operation of the vehicle **108**, the smart home **187**, and/or the personal electronic device **189**. Although incidents are described as directly affecting the operation of the vehicle **108**, the smart home **187**, and/or the personal electronic device **189**, some embodiments may include determining whether incidents are occurring that impact the operation of another vehicle, smart home, personal electronic device, or person in the operating environment of the vehicle **108**, the smart home **187**, and/or the personal electronic device **189**.

Determining the occurrence of an incident may include determining a type of incident (e.g., collision, component failure, software malfunction, impassible roadway, severe weather, etc.). In some embodiments, determining the occurrence of an incident may further include determining whether the incident has a sufficient impact on autonomous operation to require a response (i.e., is the incident of sufficient severity or urgency as to require an immediate response). In yet further embodiments, determining an incident requires a response may include determining that the incident increases one or more risks associated with autonomous operation above a maximum threshold level for safe operation of the vehicle **108**, the smart home **187**, and/or the personal electronic device **189** in a fully autonomous mode. Determining an incident requires a response may further include determining whether a legal or other obligation requires a response, such as reporting a collision or remaining at the location of a collision. In some instances, determining an incident requires a response may include determining whether a response is required to assist an injured pedestrian, passenger of another vehicle, an occupant, and/or that similar assistance is needed.

The on-board computer **114**, the smart home controller **185**, and/or the personal electronic device **189** may determine an occurrence (which may include the severity or impact) of the incident based upon an analysis of the obtained data. This determination may include comparing the obtained operating data and/or other data with expected or baseline data to determine whether the obtained data is outside an ordinary or expected range. This determination may further include comparing data from a plurality of sources to determine inconsistencies and identify sources of such inconsistencies (e.g., identifying which of a plurality of sensors **120** is malfunctioning when inconsistent data is received). In some embodiments, this determination may further include analyzing or reconstructing a portion of a time period associated with the unusual condition to determine whether the incident has occurred. For example, the on-board computer **114** and/or smart home controller **185** may process operating data for a time period during which an incident has occurred to reconstruct the incident and obtain relevant information, such as location, force of impact, indications that autonomous safety features were triggered, etc.

In further embodiments, the on-board computer **114**, the smart home controller **185**, and/or the personal electronic device **189** may test components of the vehicle **108**, the smart home **187**, and/or the personal electronic device **189** that may be affected to determine operating status. For example, the on-board computer **114**, the smart home controller **185**, and/or the personal electronic device **189** may determine a tire of the vehicle **108** has gone flat based upon vehicle heading relative to control data from one or more autonomous operation features in response to an indication from a tire pressure sensor that the tire pressure has dropped. In embodiments associated with the vehicle **108**, the degree of divergence between the control commands and the observed vehicle trajectory may be further used to determine the urgency of repairing or replacing the tire. As another example, the on-board computer **114**, the smart home controller **185**, and/or the personal electronic device **189** may determine whether an incident has occurred based upon operating data (such as sensor data from accelerometers) and, if so, whether the incident requires a response.

At block **508**, the on-board computer **114**, the smart home controller **185**, and/or the personal electronic device **189** may determine whether an incident, including a cyber-attack, has been determined to have occurred. As discussed above, the on-board computer **114**, the smart home controller **185**, and/or the personal electronic device **189** may ignore incidents not requiring a response. If no incident is determined to have occurred (or if no response is required), the method **500** may continue by determining whether to continue monitoring (block **516**), as discussed below. If at least one incident requiring a response is determined to have occurred, the method **500** may continue by determining damage associated with the incident (block **510**).

At block **510**, the on-board computer **114**, the smart home controller **185**, and/or the personal electronic device **189** may determine damage associated with the determined incident. Such damage determination may include assessing or estimating damage to the vehicle **108**, the smart home **187**, and/or the personal electronic device **189** or another vehicle, another smart home, an injury to a pedestrian or passenger, or damage to another object in the autonomous operating environment. The damage may include physical damage to the sensors **120** or other components of the vehicle **108**, the smart home controller **185**, and/or the personal electronic device **189**, such as the sort of damage that typically occurs during collisions and/or other loss-events. The damage may likewise include electronic damage to software involved in autonomous operation, such as the sort of damage that typically results from unauthorized access to a computer system or infection of a computer system by malicious code, such as when the component is the target of a cyber-attack. The on-board computer **114**, the smart home controller **185**, and/or the personal electronic device **189** may determine the damage based upon the obtained operating data and/or other data described elsewhere herein, which may include data from one or more sensors **120**. In some embodiments, determining damage may include determining whether the vehicle **108**, the smart home controller **185**, and/or the personal electronic device **189** can continue to operate in a fully or partially autonomous operation mode within predetermined safety parameters and/or whether a passenger and/or occupant is capable of operating the vehicle **108**, the smart home **187**, and/or the personal electronic device **189** in a manually and/or semi-

autonomously within predetermined safety parameters (i.e., having risk levels for such operation below predetermined safe operation threshold levels of risk).

Determining damage to components of the vehicle **108**, the smart home **187**, and/or the personal electronic device **189** may include determining that sensors **120** are not functioning properly based upon conflicting sensor readings, error signals, and/or sensor unresponsiveness. In some embodiments, multiple sensor failures in a region of the vehicle **108**, the smart home **187**, and/or the personal electronic device **189** may be used to determine damage to other components (e.g., body or structural damage in the area of the sensors). For example, the on-board computer **114** may determine that damage to multiple sensors **120** in the front-right portion of the vehicle **108** following a collision further indicates that headlights, signal lights, and the front bumper in that area are likely also damaged. As another example, the smart home controller **185** may determine damage to the basement of the smart home **187** further indicates that electronic devices in the basement are likely also damaged. In further embodiments, operating data regarding the vehicle **108**, the smart home **187**, and/or the personal electronic device **189** (such as data indicating the vehicle's movement or the location of other objects in the autonomous operating environment) may be used by the on-board computer **114**, the smart home controller **185**, and/or the personal electronic device **189** to determine damage to the vehicle **108**, the smart home **187**, and/or the personal electronic device **189**, damage to other vehicles and/or smart homes, damage to other objects, or injuries to persons in the operating environment. Such operating data may include telematics data regarding vehicle movement, position, direction, and/or speed, as well as data regarding impact location and/or force.

At block **512**, the on-board computer **114**, the smart home controller **185**, and/or the personal electronic device **189** may determine a response to the incident. Such response may be determined based upon the type of incident and/or the damage involved. Additional factors may also be used to determine the appropriate response to the incident, such as location, urgency of an injury, importance of an interrupted vehicle trip, availability of a vehicle operator to reach the vehicle location, safety considerations, legal obligations regarding the incident, or other factors. The on-board computer **114**, the smart home controller **185**, and/or the personal electronic device **189** may select from a plurality of potential responses, ranging from completely shutting down to continuing to operate in a fully autonomous mode along the remainder of an unmodified route to a destination without any changes. In some embodiments, the determined response may include one or more notifications to an interested party remote from the vehicle **108** and/or the smart home **185**, such as an owner, occupant, operator, or insurer of the vehicle **108**, the smart home **187**, and/or the personal electronic device **189**. Such notifications may be generated by the on-board computer **114**, the smart home controller **185**, and/or the personal electronic device **189** or by the server **140** based upon information received from the on-board computer **114**, the smart home controller **185**, and/or the personal electronic device **189** and may be transmitted via the network **130**.

In some embodiments, the response may further include notifications to one or more parties associated with another object involved in the incident, such as an owner, occupant, or insurer of another vehicle and/or smart home. Such notices may be communicated directly using communication components of the vehicle **108**, the smart home controller **185**, and/or the personal electronic device **189** or may be communicated via the network **130** when a relevant party is remote from the site of the incident. For example, a notification to a utility company may be sent in response to determining that the vehicle **108** has collided with a utility pole or other infrastructure (or utility infrastructure has collided with the vehicle **108**) and/or in response to determining that the utility has been cut off at the smart home **187**, which may require inspection and/or repair.

In situations in which the determined damage has significantly impaired the ability of the vehicle **108**, the smart home **187**, and/or the personal electronic device **189** to operate safely in a fully autonomous operation mode, the determined response may include a determination not to continue operation or to cease autonomous operation of the vehicle **108**, the smart home **187**, and/or the personal electronic device **189**. In some embodiments, the vehicle **108**, the smart home **187**, and/or the personal electronic device **189** may be completely inoperable, and the response may include automatically contacting a third party to have the vehicle towed to a service or disposal facility and/or have the smart home site cleared for rebuilding. In these embodiments, the response may additionally include contacting an autonomous vehicle dispatch center to dispatch a replacement autonomous vehicle to the location of the vehicle **108**. If the vehicle **108** is capable of being operated at least short distances, the on-board computer **114** may identify a position out of the flow of traffic to which to move the vehicle **108**. In such instances, the on-board computer **114** may determine a response including moving the vehicle **108** out of a traffic lane to a nearby location, such as a roadway shoulder, a parking lane, or a parking lot. In some embodiments, the response may include such movement regardless of whether the vehicle **108** is able to safely complete the original vehicle trip, such as in situations in which the on-board computer **114** has determined the vehicle **108** should remain at the incident location.

The response may include causing the vehicle **108** to remain at the site of the incident for a number of reasons, including legal obligations, further assessment of the incident, further analysis of the functional state of the vehicle **108**, or communicating with or aiding another party involved in the incident. Thus, some embodiments may include determining a response that includes establishing communication between persons in the vicinity of the vehicle **108**, the smart home **187**, and/or the personal electronic device **189** and a remote owner, operator, or other party associated with the vehicle **108**, the smart home **187**, and/or the personal electronic device **189** via the network **130**. Such communication may be established using one or more speakers, microphones, cameras or image capture devices, displays **202**, or other components of the vehicle **108**, the smart home **187**, and/or the personal electronic device **189** to facilitate two-way communication. In this manner, a remote owner or agent may communicate with persons at the location of the incident, such as police, paramedics, operators of other vehicles, pedestrians, etc. This communication may be necessary to provide or exchange information regarding the vehicle **108**, the smart home **187**, and/or the personal electronic device **189** or the incident, or for emergency response coordination.

In some embodiments, the response may include an emergency action and/or response. Such emergency action and/or response may include automatically communicating with an emergency response service to obtain emergency medical, fire, or police assistance, which may include communication via the server **140** or via a remote agent con-

tacting an appropriate emergency responder. In response to determining that an incident has resulted in a serious injury to a pedestrian, an occupant, or a passenger of another vehicle, for example, the on-board computer **114**, the smart home controller **185**, and/or the personal electronic device **189** may determine an emergency action and/or response that includes communication to request emergency assistance from an emergency response service. The emergency action and/or response may further include establishing communication with the injured person or other persons in the vicinity of the vehicle **108**, the smart home **187**, and/or the personal electronic device **189**, as discussed above.

Such emergency communication may be established between an emergency assistance representative (e.g., a representative of the owner, occupant, operator, insurer, or other interested party or a representative of an emergency response service) and the injured person or other persons in the vicinity of the vehicle **108**, the smart home **187**, and/or the personal electronic device **189** using communication components of the vehicle **108**, the smart home **187**, and/or the personal electronic device **189**. Emergency actions and/or responses may additionally, or alternatively, include use of the vehicle **108** to transport one or more persons from the location of the incident to an emergency or other appropriate facility. If the vehicle **108** is determined to be operable with risk levels below a safe operation threshold, the emergency action and/or response may include facilitating access to the vehicle **108** and using the vehicle **108** to transport the one or more persons to the emergency facility (such as a hospital) in a fully autonomous mode.

In some embodiments, the response may include granting limited access to operate the vehicle **108**, the smart home **187**, and/or the personal electronic device **189** to other persons. Such access may likewise be granted to allow manual or autonomous operation of the vehicle **108**, the smart home **187**, and/or the personal electronic device **189**, such as for emergency transportation, to move the vehicle **108** out of the path of traffic, and/or to enable fire equipment at the smart homer **187**. For example, access may be granted to allow the vehicle **108** to be moved to a shoulder of a road, an emergency stopping area, or a nearby parking lot. The response may thus include unlocking doors and allowing control for vehicle and/or smart home operation up to a threshold (e.g., a distance threshold such as one mile, a time threshold such as ten minutes, etc.). The access granted may include manual access to allow a vehicle operator to drive the vehicle **108** or autonomous access to allow a local or remote vehicle operator to direct the vehicle **108** to a user-selected location. In some embodiments, such access may only be granted to authorized emergency personnel, such as police, fire, or medical personnel. This limited access may be achieved by wireless communication of an official verification signal to the vehicle **108**, the smart home **187**, and/or the personal electronic device **189** via the communication component **122**. Similarly, a remote vehicle operator at an emergency response facility may be granted control over the vehicle **108** to control the vehicle's movements in an autonomous mode from a remote location, such as by selecting a parking location out of the flow of traffic (e.g., along a shoulder of a road).

In further embodiments, the on-board computer **114**, the smart home controller **185**, and/or the personal electronic device **189** may determine that the vehicle **108**, the smart home **187**, and/or the personal electronic device **189** should be repaired. For example, one or more sensors **120** of the vehicle **108**, the smart home **187**, and/or the personal electronic device **189** may be malfunctioning, necessitating repair or replacement. In instances in which the vehicle **108** is capable of continued safe operation in a fully autonomous mode, the response may include selecting a repair facility and routing the vehicle **108** to the repair facility by fully autonomous operation to be repaired. The selection of the repair facility may include a determination that the repair facility is capable of providing the necessary repairs, has a sufficient stock of components determined to be required, and/or is able to perform the repairs within timing and budgetary constraints. Selection may further include communicating with the repair facility (either automatically by the on-board computer **114**, the smart home controller **185**, and/or the personal electronic device **189**, or server **140** or manually by a person associated with the vehicle **108**, the smart home **187**, and/or the personal electronic device **189**) to schedule or confirm an appointment for the repairs.

In some embodiments, a determination regarding liability or insurance coverage for the costs associated with the repairs may be made, and the relevant payor may be required to authorize the repairs. In further embodiments, alternative transportation and/or lodging may be automatically arranged for a vehicle and/or smart home owner or operator while the vehicle **108** and/or smart home **187** is undergoing repair. Said alternative transportation may include taxi service, temporary vehicle-sharing membership, vehicle rental, or similar temporary replacement transportation. Similarly, alternative lodging may include a hotel, a time-share, a peer-to-peer lodging, a rental, or other temporary lodging services.

In yet further embodiments, the response may include automatically and permanently replacing the vehicle **108** with an equivalent vehicle. An equivalent replacement vehicle may be one of equivalent make, model, year, style, color, mileage, age, equipment, components, or similar characteristics. Information regarding the exchange of the vehicles may be automatically provided to vehicle owners, insurers, lienholders, government or private registries, or other relevant individuals or organizations. Additionally, personal items within the vehicle **108** may be transferred to the replacement vehicle, and settings and configurations may be transferred by electronic communication to the replacement vehicle. In this manner, the exchange of the vehicle **108** for the replacement vehicle may not require any action by an owner or operator of the vehicle **108**. In some embodiments, however, the owner may confirm or verify authorization to exchange the vehicle **108** for the replacement vehicle.

At block **514**, the one or more responses may be implemented. The on-board computer **114**, the smart home controller **185**, and/or the personal electronic device **189** may control the vehicle **108**, the smart home **187**, and/or the personal electronic device **189** to take actions necessary to implement the determined responses, including controlling movement of the vehicle **108**, controlling components of the vehicle **108**, the smart home **187**, and/or the personal electronic device **189** to facilitate communication, controlling components of the vehicle **108**, the smart home **187**, and/or the personal electronic device **189** to obtain additional information or take actions, enabling or disabling motive functionality of the vehicle **108**, the smart home **187**, and/or the personal electronic device **189**, and/or shutting down the vehicle **108**, the smart home **187**, and/or the personal electronic device **189**. In some embodiments, this may include causing the vehicle **108** to operate in a fully autonomous manner along a route to a destination, which may be the original destination or a new destination (e.g., an emergency facility, a repair facility, etc.). If the vehicle **108**

is routed to a new destination, it may thereafter further be routed from the new destination to the original destination (such as after completion of repairs at a repair facility). In some embodiments, part of the implementation of the determined one or more responses may be implemented by the server **140** or another device remote from the vehicle **108**.

At block **516**, the on-board computer **114**, the smart home controller **185**, and/or the personal electronic device **189** may determine whether to continue monitoring the vehicle **108**, the smart home **187**, and/or the personal electronic device **189** following the commencement or completion of implementation of the response. This determination may include determining whether the vehicle **108**, the smart home **187**, and/or the personal electronic device **189** is continuing to operate in a fully autonomous mode. This determination may further include determining whether other factors indicate that monitoring should continue, such as a continued risk of further damage or additional incidents. For example, monitoring may continue when the vehicle **108** is stopped within a traffic lane or on a shoulder of a roadway because such position involves an increased risk of further incidents, such as collisions with other vehicles. If operation or monitoring is determined to continue, the method **500** may continue with the on-board computer **114**, the smart home controller **185**, and/or the personal electronic device **189** monitoring operating data and/or other data for further indications of unusual conditions (block **502**). Such monitoring may, of course, exclude known indications of unusual conditions (e.g., known damaged or malfunctioning sensors). If monitoring is determined not to continue, the method **500** may terminate.

In some embodiments, determination of incident occurrence (blocks **506** and **508**), damage assessment (block **510**), and/or response determination (block **512**) may involve a remotely located human reviewer. The reviewer may be an owner, occupant, operator, insurer, or agent associated with the vehicle **108**, the smart home **187**, and/or the personal electronic device **189** or otherwise authorized to take action regarding the vehicle **108**, the smart home **187**, and/or the personal electronic device **189**. Such review may be used to verify or confirm assessments made by the on-board computer **114**, the smart home controller **185**, and/or the personal electronic device **189** or to make additional determinations where the on-board computer **114**, the smart home controller **185**, and/or the personal electronic device **189** cannot adequately assess the situation.

In some such embodiments, the on-board computer **114**, the smart home controller **185**, and/or the personal electronic device **189** may send information via the network **130** to the remote reviewer, who may access the information via the network **130** or through the server **140**. Such information may include operating data (or a subset of relevant operating data), images, or video recordings of the incident. In some embodiments, the remote reviewer may, with permission, operate one or more cameras of the vehicle **108**, the smart home **187**, and/or the personal electronic device **189** to obtain streaming video or periodic images from the vehicle **108**, the smart home **187**, and/or the personal electronic device **189** during review. When operating data is received from the vehicle **108**, the smart home **187**, and/or the personal electronic device **189**, the server **140** may further process the operating data to present it in a human-readable format (e.g., a table, chart, or graphical depiction) based upon calculations made from non-human-readable operating data.

The remote reviewer may then verify, modify, or determine an occurrence, type of occurrence, and/or damage or severity of the occurrence based upon the information received from the vehicle **108**, the smart home **187**, and/or the personal electronic device **189**. This may include communicating with persons in the vicinity of the vehicle **108**, the smart home **187**, and/or the personal electronic device **189** using the communication components of the vehicle **108**, the smart home **187**, and/or the personal electronic device **189**, as described above. The remote reviewer may further verify, modify, or determine one or more responses to the incident and may cause one or more responses to be implemented by the vehicle **108**, the smart home controller **187**, and/or the personal electronic device **189**.

Exemplary Salvage Assessment Methods

FIG. **6** illustrates a flow diagram of an exemplary salvage assessment method **600** for automatically determining damage and/or salvage potential for components of an autonomous vehicle, smart home, and/or personal electronic device. Such method **600** may be implemented following a collision or other loss-event associated with a vehicle **108**, a smart home **187**, and/or a personal electronic device **189** to determine which components are damaged and which components may be salvaged for use as replacement parts in other autonomous vehicles, smart homes, and/or personal electronic devices. For traditional environments without autonomous operation features, similar salvage assessment typically involves physical inspection of the damaged component. Unlike damage to components of non-autonomous environments, damage to some components of autonomous environments may not be evident to visible inspection. Even when components of an autonomous environment appear to be functioning, signals or output from such components may be inaccurate due to unobserved damage. Therefore, the method **600** may be used to evaluate vehicle components of an autonomous vehicle, a smart home, and/or a personal electronic device to determine salvage potential.

The exemplary salvage assessment method **600** may begin by determining that damage to a vehicle **108**, a smart home **187**, and/or a personal electronic device **189** has occurred (block **602**). Following such determination, a salvage assessment device may be connected to the vehicle **108**, the smart home **187**, and/or the personal electronic device **189** to evaluate component salvage potential (block **604**), and one or more components of the vehicle **108**, the smart home **187**, and/or the personal electronic device **189** may be selected for salvageability assessment (block **606**). For each selected component, the salvage assessment device may cause a test signal to be sent to the component (block **608**), which may include sending the test signal through the on-board computer **114** of the vehicle **108**, the smart home controller **185** of the smart home **187**, and/or the personal electronic device **189**.

The salvage assessment device may then detect or receive a response from the component (block **610**), which may include detecting that the component is unresponsive. An expected response may also be obtained by the salvage assessment device (block **612**), which may be compared against the received response (block **614**). Based upon such comparison, the salvage assessment device may then determine the salvage potential of the component (block **616**). In some embodiments, the salvage assessment device may further determine salvage potential for an additional component of the vehicle **108**, the smart home **187**, and/or the personal electronic device **189** based upon the determined salvage potential of the one or more selected components (block **618**).

At block **602**, the method **600** may begin by determining that damage to the vehicle **108**, the smart home **187**, and/or

the personal electronic device **189** has occurred. Such determination may be made automatically by an on-board computer **114**, the smart home controller **185**, the personal electronic device **189**, and/or a server **140** based upon operating data or other information from the vehicle **108**, the smart home **187**, and/or the personal electronic device **189**. For example, such determination may be made following an indication of an unusual condition or loss-event involving the vehicle **108**, the smart home **187**, and/or the personal electronic device **189**, as discussed elsewhere herein. Such determination may, alternatively, be received from an owner, occupant, operator, or other interested party. In some embodiments, the determination may include determining that the vehicle **108**, the smart home **187**, and/or the personal electronic device **189** is sufficiently damaged that it requires extensive repair or is irreparably damaged. In further embodiments, an additional determination may be made that the vehicle **108**, the smart home **187**, and/or the personal electronic device **189** is sufficiently damaged that the cost of repair would exceed the value of the vehicle **108**, the smart home **187**, and/or the personal electronic device **189** repaired after being repaired, or that the vehicle, smart home, or personal electronic device is a total loss.

At block **604**, the method **600** may continue with the connection of a salvage assessment device to the vehicle **108**, the smart home **187**, and/or the personal electronic device **189**. This may include connecting the salvage assessment device to an on-board computer **114** of the vehicle **108**, the smart home controller **185** of the smart home **187**, and/or the personal electronic device **189**, or it may include bypassing the on-board computer **114** and/or the smart home controller **185**, to directly assess the other components of the vehicle **108** and/or the smart home **187**. Bypassing the on-board computer **114** and/or the smart home controller **185** may be beneficial when the on-board computer **114** and/or the smart home controller **185** is or may be malfunctioning. In further embodiments, the salvage assessment device may preliminarily evaluate the operation of the on-board computer **114** and/or the smart home controller **185**, then determine whether to connect to the components through the on-board computer **114** or to bypass the on-board computer **114** and/or the smart home controller **185** based upon the results of preliminary evaluation. In such embodiments, the salvage assessment device may be configured to present test commands to the on-board computer **114** and/or the smart home controller **185** or may cause the on-board computer **114** and/or the smart home controller **185** to run one or more self-diagnostic routines. In some embodiments, the salvage assessment device may connect to the on-board computer **114** and/or the smart home controller **185** to control the on-board computer **114** and/or the smart home controller **185** to generate, transmit, and/or receive signals related to assessing components of the vehicle **108**, the smart home **187**, and/or the personal electronic device **189**. In further embodiments, the on-board computer **114** and/or the smart home controller **185** may be used as the salvage assessment device, in which case no additional connection may be required.

The salvage assessment device may be a mobile device **110**, as described elsewhere herein, which may be a special-purpose computing device or a general purpose computing device (e.g., a smartphone or tablet computer). The salvage assessment device may include or be connected to a special-purpose connector configured to connect to a communication port of the vehicle **108**, the smart home controller **185**, and/or the personal electronic device **189**. Such communication port may be an on-board diagnostic (OBD) port, such as an OBD-II or EOBD port, a universal serial bus (USB) port, an Ethernet port, or other ports that support the interconnection between two electronic devices. In further embodiments, the salvage assessment device may be configured to connect to the on-board computer **114**, the smart home controller **185**, and/or the personal electronic device **189** wirelessly via a WiFi, Bluetooth, or other wireless electronic communications. Establishing the wired or wireless communication connection between the salvage assessment device and the vehicle **108**, the smart home **187**, and/or the personal electronic device **189** may include causing the on-board computer **114**, the smart home controller **185**, and/or the personal electronic device **189** and/or other components of the vehicle **108**, the smart home **187**, and/or the personal electronic device **189** to enter into a diagnostic mode for evaluation.

At block **606**, the salvage assessment device may determine one or more components of the vehicle **108**, the smart home **187**, and/or the personal electronic device **189** to assess. Such components may include sensors **120**, part or all of the on-board computer **114**, the smart home controller **185**, and/or the personal electronic device **189**, and/or separate autonomous operation feature components. Determining the one or more components of the vehicle **108**, the smart home **187**, and/or the personal electronic device **189** to assess may include selecting the components from a plurality of components of the vehicle **108**. To this end, the salvage assessment device may receive information regarding the plurality of components of the vehicle **108**, the smart home **187**, and/or the personal electronic device **189**, which may include accessing such information from a program memory **208** or a database **146**. The salvage assessment device may then identify one or more components of the vehicle **108**, the smart home **187**, and/or the personal electronic device **189** for evaluation. Such identification may include selecting the one or more components based upon operating data received from the vehicle **108**, the smart home **187**, and/or the personal electronic device **189**, which operating data may be associated with a collision or other loss-event resulting in damage to the vehicle **108**, the smart home **187**, and/or the personal electronic device **189**. The salvage assessment device may determine that some components of the vehicle **108**, the smart home **187**, and/or the personal electronic device **189** should or should not be evaluated because of high probabilities that such components either are or are not damaged based upon the operating data. For example, in a high-speed head-on collision, the salvage assessment device may determine that sensors located in the front bumper of the vehicle **108** are highly likely to be damaged, therefore determining not to select such sensors for evaluation. As another example, in a tree-fall event, the salvage assessment device may determine that sensors located on the roof of the smart home **187** are highly likely to be damaged, and similarly are determined not to be selected for evaluation. In further embodiments, the salvage assessment device may iteratively evaluate and assess all components capable of electronic communication with the salvage assessment device that can be identified as being disposed within the vehicle **108**, the smart home **187**, and/or the personal electronic device **189**.

At block **608**, the salvage assessment device may cause one or more test signals to be sent to each of the determined components. The salvage assessment device may generate and communicate such test signals to the components, or the salvage assessment device may control the on-board computer **114**, the smart home controller **185**, and/or the personal electronic device **189** to generate and/or communicate

the test signals to the components. The test signals may cause the components to return one or more response signals to the on-board computer **114**, the smart home controller **185**, and/or the personal electronic device **189** or the salvage assessment device. Such response signals may indicate a self-assessment of the component, an acknowledgement of receipt of the test signal by the component, a value measured or determined by the component, or another response by the component upon receipt of the test signal.

At block **610**, the salvage assessment device may receive the one or more responses from the one or more components. The responses may be received via the on-board computer **114**, the smart home controller **185**, and/or the personal electronic device **189** in some embodiments. The responses may include response signals from the components or information based thereon from the on-board computer **114**, the smart home controller **185**, and/or the personal electronic device **189**. In some embodiments, the responses may include an implied response indicating component disconnection or malfunctioning (e.g., as a result of damage), which may be inferred by the salvage assessment device or on-board computer **114**, the smart home controller **185**, and/or the personal electronic device **189** from an absence of a response signal within a usual time period for response from the component. Such received or implied responses may then be used to determine damage or salvageability of components of the vehicle **108**, the smart home **187**, and/or the personal electronic device **189**.

At block **612**, the salvage assessment device may obtain one or more expected responses for the one or more components. Such expected responses may be indicative of ordinary or usual responses of the one or more components to the one or more test signals, and the expected responses may be obtained from a program memory **208** or a database **146**. The expected responses may include ranges of response signals associated with proper operation of components, such as ranges of sensor data generated by a sensor **120** when functioning properly.

In some embodiments, the expected responses may be based at least in part upon operating data received from additional components of the vehicle **108**, the smart home **187**, and/or the personal electronic device **189**. For example, sensor data from other sensors **120** may be used to determine an expected response from a component to be evaluated. In further embodiments, such operating data may be received from other components determined to be operating properly or may be received from a plurality of other components of unknown status, in which latter case the expected responses may include a plurality of ranges based upon whether the other components are functioning properly or are malfunctioning. In yet further embodiments, known characteristics of the autonomous environment at the time of assessment (e.g., distance from objects near the vehicle **108**, the smart home **187**, and/or the personal electronic device **189**) may be used to determine expected responses of the one or more components.

At block **614**, the salvage assessment device may compare the received responses and the expected responses for the one or more components to evaluate the operating status or condition of the one or more components. This may include determining whether a received response is within a range of acceptable responses based upon one or more associated expected responses indicative of proper functioning of the component. In some embodiments, this may include comparing received responses and expected responses for a plurality of components to determine whether the received responses are consistent with other received responses, particularly with those received responses that are consistent with the expected responses.

At block **616**, the salvage assessment device may then determine a salvage potential indicative of whether each of the one or more components is salvageable based upon such comparisons between received and expected responses. The salvage potential of a component may be associated with an estimate of damage, which may include an estimate of a level, type, or extent of damage. For example, a component may be determined to have suffered minor damage based upon a shift in an average value of the one or more response signals associated with the component, even though the responses are generally within an acceptable range based upon the expected responses associated with the component. A component determined to be damaged may be further determined not to be salvageable or may be determined to be partially salvageable. In instances in which multiple response signals are associated with a component (e.g., where a component includes multiple sensors **120**), the component may be determined to be partially malfunctioning and partially operational due to subcomponent damage. In some embodiments, such situations may further be evaluated by the salvage assessment device to determine whether the subcomponents of the component may be repaired or replaced, which may be further used to determine whether the component is salvageable.

At block **618**, in some embodiments, the salvage assessment device may further determine a salvage potential of one or more additional components of the vehicle **108**, the smart home **187**, and/or the personal electronic device **189** based upon the determined salvage potential or damage associated with one or more components. The additional components may be disposed within the vehicle **108**, the smart home **187**, and/or the personal electronic device **189** in physical proximity to a set of the one or more components, such that the additional components may be expected to have suffered similar damage levels as the set of evaluated components. In some embodiments, the additional components may include components that are not sensors or autonomous operation features.

Such additional components may not be configured for electronic communication with the on-board computer **114**, the smart home controller **185**, and/or the personal electronic device **189**, even if the additional components are controlled by the on-board computer **114**, the smart home controller **185**, and/or the personal electronic device **189**. For example, the additional components may include headlights, signal lights, body panels, roofing, siding, support beams, and/or other structural or non-communicating parts of the vehicle **108**, the smart home **187**, and/or the personal electronic device **189**. Determining the salvage potential of such additional components may include determining an estimated level of damage for an area of the vehicle **108**, the smart home **187**, and/or the personal electronic device **189** associated with an additional component based upon estimated levels and/or types of damages associated with the set of components.

In some embodiments, the salvage assessment device may further communicate the determined salvage potential of the components and/or additional components to a server **140** for storage in a database **146** or to a mobile device **110** for storage in a program memory **208**. The salvage assessment device may additionally, or alternatively, present information indicating the salvage potential of the components to a user of the salvage assessment device. This may include a report summarizing the salvage potential of the vehicle **108**, the smart home **187**, and/or the personal electronic device

189 and/or the components thereof. In some embodiments, information regarding costs or values associated with the components may be used to estimate salvage values of one or more components or of the vehicle **108**, the smart home **187**, and/or the personal electronic device **189**.

Exemplary Malfunction Detection Methods

FIG. **7** illustrates a flow diagram of an exemplary malfunction detection method **700** for identifying malfunctioning sensors of an autonomous vehicle **108** and/or a smart home **187**. Such method **700** may be used to detect sensors of an autonomous vehicle and/or smart home that are malfunctioning and, in some instances, to correct the malfunction. The method **700** may be implemented during operation to ensure the vehicle **108** and/or the smart home **187** is functioning properly and to detect malfunctions caused by damage, environmental conditions, or other causes. Because autonomous vehicles rely heavily on accurate sensor data to make control decisions to operate the vehicle, damaged or otherwise malfunctioning sensors may pose a hazard to the vehicle, other vehicles, passengers, or pedestrian in the vehicle's operating environment. Similarly, smart homes rely heavily on accurate sensor data (e.g., home telematics data) to ensure proper operation of smart equipment and/or to detect emergencies that threaten damage to the smart home, damaged or otherwise malfunctioning sensors may lead to improper reporting of conditions pose hazards to occupants, passersby, and/or other property. Such sensors may malfunction for various reasons, including manufacturing defects, ordinary wear, collision damage, cyber-attacks, or weather damage. In many cases, such damaged or otherwise malfunctioning sensors may appear to be operating properly to both a vehicle operator and to an on-board computer **114** of the vehicle **108** and/or a smart home controller **185** of the smart home **187**. The method **700** evaluates the sensors to detect malfunctions and take actions to address the hazard posed by such malfunctions. Although the method **700** is described below as being performed by the on-board computer **114** and/or the smart home controller **187**, for simplicity, it should be understood that one or more mobile devices **110** or servers **140** may alternatively, or additionally, be used to perform part or all of the process.

The exemplary malfunction detection method **700** may begin by receiving sensor data from one or more sensors **120** of the vehicle **108**, sensors interconnected with the smart home controller **187**, and/or a personal electronic device **189** (block **702**). The method **700** may then iteratively evaluate the sensors **120** to identify and respond to sensor malfunctions. A sensor is selected for evaluation (block **704**), and one or more signals associated with the selected sensor are obtained (block **706**). A range of signal values associated with proper functioning of the sensor may be determined (block **708**) and compared against the one or more signals associated with the selected sensor to determine whether the sensor is malfunctioning (block **710**). If the sensor is determined to be malfunctioning (block **712**), a cause of the malfunction and/or other information associated with the malfunction may be determined (block **714**). Based upon the determined information, one or more responses to the malfunction may then be determined (block **716**) and implemented (block **718**). If another sensor is to be evaluated (block **720**), the method **700** selects and evaluates another sensor. If no sensors remain to be evaluated (block **720**), the method **700** may terminate.

At block **702**, the on-board computer **114** may receive sensor data from one or more sensors **120** of the vehicle **108**, sensors interconnected with the smart home controller **187**, and/or a personal electronic device **189**. The sensor data may include a plurality of signals associated with the one or more sensors **120**, which signals may be generated during operation of the vehicle **108**, operation of the smart home **187**, and/or the personal electronic device **189**. The sensor data may be received when the vehicle **108** is first started, when the vehicle **108** is shut down, when an individual enters the smart home **187**, when an individual egresses the smart home **187**, or upon the occurrence of an event. Such events may include a user-initiated request to evaluate the sensors **120** or detection of an indication of an unusual condition, such as a collision involving the vehicle **108**, damage to the smart home **187**, and/or an individual experiencing a medical emergency. In other embodiments, however, the sensor data may be received and evaluated to determine whether a sensor **120** is malfunctioning without any indication of a collision and/or other event. In particular embodiments, the sensor data may be received continuously or periodically during operation of the vehicle **108** by the on-board computer **114** and/or during operation of the smart home **187** by the smart home controller **185**. The on-board computer **114** and/or smart home controller may then process or store the sensor data for future processing.

In some embodiments, the sensor data may additionally or alternatively include sensor data received from a sensor not included in the one or more sensors **120** of the vehicle **108** and/or or one or more sensors located on or proximate to the smart home **187**. As an example, a sensor of the one or more smart infrastructure components **188** may transmit sensor data to the on-board computer **114** via the network **130**. As another example, the sensor data may include sensor data received from the personal electronic device **189**.

At block **704**, the on-board computer **114** and/or smart home controller **185** may select a sensor from the one or more sensors **120**, the one or more sensors located on or proximate to the smart home **187**, the sensors of the one or more smart infrastructure components **188**, and/or the personal electronic device **189** to evaluate. The sensor may be selected based upon an indication of potential malfunction, such as inconsistent or unusual sensor data from the selected sensor. In some scenarios, the inconsistent or unusual sensor data may be indicative of a cyber-attack directed at the vehicle **108**, smart home **185**, personal electronic device **189**, and/or the one or more smart infrastructure components **188**. When the method **700** is implemented in response to a collision and/or other event, the sensor may be selected based at least in part upon a likelihood of damage to the sensor from the collision and/or other event. In further embodiments, the sensor may be selected based upon a hierarchy of sensors **120**, such that higher-level sensors may be evaluated first. If a higher-level sensor is determined to be operating properly, there may be no need to test lower-level sensors associated with the higher-level sensor. This may reduce the processing time requirements for evaluating the sensors **120**, thus enabling more frequent sensor evaluation (particularly during operation of the vehicle **108** and/or occupancy of the smart home **187**).

At block **706**, the on-board computer **114** and/or smart home controller **185** may obtain sensor data associated with the selected sensor. Such sensor data may include a set of signals from the sensor, such as signals generated by the sensor during operation of the vehicle **108** and/or smart home **187**. The set of signals may include raw signal data from the sensor or signal data preprocessed by the sensor or by the on-board computer **114** and/or smart home controller **185**. The signal data may include discrete data points generated by the sensor or samples of continuous data generated by the sensor. The set of signals may be obtained

over a period of time from the sensor, or the set of signals may be accessed from sensor data previously stored in a program memory **208**. In some embodiments, the set of signals associated with the sensor may include indications of sensor unresponsiveness, viz. indications that sensor data was not received from the sensor at times when sensor data was requested of the sensor or expected from the sensor.

At block **708**, the on-board computer **114** and/or smart home controller **185** may determine a range of signals associated with proper functioning of the sensor. The range of signals may include a range of values for the signals that correspond to proper functioning of the sensor. Alternatively, a range of signal values associated with a malfunctioning status of the sensor may be determined. The range of signal values associated with proper functioning of the sensor may be determined based upon specifications for the sensor, historical data from the sensor, or estimates of what the signal values should be based upon contemporaneous sensor data from other sensors of the vehicle **108** and/or smart home **187**. The range of signal values may thus be determined based upon a second set of signals from the sensors **120** of the vehicle **108**, the one or more sensors located on or proximate to the smart home **187**, the sensors of the one or more smart infrastructure components **188**, and/or the personal electronic device **189**.

The second set of signals may include a plurality of signals previously received from the sensor during a plurality of separate previous vehicle trips of the vehicle **108** and/or prior operation of the smart home **187**. The second set of signals may, additionally or alternatively, include a plurality of additional signals from one or more additional sensors **120** of the vehicle **108**, the one or more sensors located on or proximate to the smart home **187**, the sensors of the one or more smart infrastructure components **188**, and/or the personal electronic device **189** other than the selected sensor. The second set of signals may be used to estimate one or more ranges of expected responses of the sensor to various conditions in the vehicle and/or home operating environment. This information may be further used to estimate a range of values for an expected response signal of the sensor based upon concurrent sensor data from the one or more additional sensors. For example, the additional sensors may indicate an obstruction approximate ten feet ahead of the vehicle **108**, in which case the determined range of signal values for the sensor may be associated with detection of an object between nine and eleven feet ahead of the vehicle **108**. As another example, the additional sensors may indicate a temperature in a room proximate to the room of the smart home **187** in which the selected sensor is disposed, in which case, the determined range of signal values may be a threshold variance from the value detected by the additional sensors.

At block **710**, the on-board computer **114** and/or smart home controller **185** may compare the set of signals obtained from the selected sensor against the determined range of signals associated with proper functioning of the sensor. The sensor may thus be determined to be properly functioning when the signal values of the set of signals are within the range of signal values associated with proper functioning, or the sensor may be determined to be malfunctioning when the signal values of the set of signals are outside the range of signal values associated with proper functioning. In some embodiments, the range of signal values associated with proper functioning may exclude values associated with indications that the sensor is unresponsive or that sensor data from the sensor is unavailable, in which case signals from the sensor indicating that the sensor is unresponsive may be outside the range of determined signal values associated with proper functioning. In embodiments in which the range of signals associated with proper functioning is determined using a second set of signals from additional sensors, the comparison may include determining whether the contemporary signals in the set of signals and the second set of signals are consistent or inconsistent. When inconsistencies are determined to exist, the sensor may be determined to be malfunctioning.

At block **712**, the on-board computer **114** and/or smart home controller **185** may then determine whether the sensor is malfunctioning based upon the comparison between the set of signals obtained from the sensor and the determined range of signal values associated with proper functioning of the sensor. In some embodiments, determining that the sensor is malfunctioning based upon the comparison may include determining a probability that the sensor is currently or will be malfunctioning within a predetermined future time period based upon the comparison of signal values.

The probability may indicate a likelihood that the sensor is currently malfunctioning based upon the number, frequency, or magnitude of deviations of the signals from the range of values associated with proper functioning. For example, an outlier signal value in the set of signals from the sensor may be associated with a lower probability of malfunction if it is 5% higher than an upper bound of the range of signal values than if the outlier is 25% higher than the upper bound. Similarly, a set of signals with one outlier may be associated with a lower probability of malfunction than a set having the same number of signals with ten outliers. In some embodiments, the probability may be indicative of a prediction of future failure of the sensor, which prediction may be informed by information regarding failure rates of similar sensors from a plurality of other autonomous vehicles and/or smart homes retrieved from the database **146**.

When the sensor is determined to be malfunctioning, the method **700** may continue to determine and implement a response at blocks **714-718**. When the sensor is determined not to be malfunctioning, the method **700** may continue to determine whether any other sensors remain to be evaluated at block **720**.

At block **714**, the on-board computer **114** may further determine a cause of the malfunction, an extent of the malfunction, or other information associated with the malfunction. This may include accessing information regarding malfunction of similar sensors from a plurality of other autonomous vehicles and/or smart homes retrieved from the database **146**. For example, a malfunction in the one or more smart infrastructure components **188** may be determined by comparing signals received by a plurality of vehicles from the one or more smart infrastructure components **188**. In further embodiments, this may include evaluating operating data (including sensor data) from the vehicle **108**, the smart home **187**, and/or the personal electronic device **189**. Such operating data may be associated with the malfunctioning sensor and/or other sensors **120** within the vehicle **108**, smart home **187**, and/or associated with the personal electronic device **189**. In some embodiments, this may include obtaining and processing time-stamped operating data from a plurality of times, which times may associated with multiple time frames (e.g., trips or occupancy periods) or may be associated with different points within a time period associated with part of one time frame. For example, each of the plurality of times may be periodic sample points at which

the on-board computer **114** and/or the smart home controller **185** stores operating data (such as the signals in the set of signals) during operation.

The on-board computer **114** and/or the smart home controller **185** may analyze the time-stamped operating data to identify an indication of an unusual condition associated with the malfunction, such as a collision or other damage-causing event. In addition to collisions, weather-related events (e.g., frost, water intrusion, excessive heat, etc.), blockage (e.g., dirt, water, or salt build-up on the sensor), or other events may be determined as the cause of the sensor malfunction. Other causes may include age (e.g., years in service) of the sensor, manufacturer defect, improper installation, or inadequate maintenance, among other causes.

In addition to the cause of the sensor malfunction, or as an alternative thereto, the on-board computer **114** and/or the smart home controller **185** may determine other information associated with the sensor malfunction. Such information may include an extent of the damage to the sensor or the degree to which the malfunction results in inaccurate or unreliable sensor data. Such information may similarly include information associated with repair or replacement options or requirements, usual cost to repair or replace the sensor, other sensors that frequently malfunction at the same time, risk levels associated with operation of the vehicle **108** and/or the smart home **187** without the sensor (which may include a plurality of risk levels associated with different levels or settings used for autonomous or semi-autonomous vehicle operation), etc.

In some embodiments, determining the cause of the sensor malfunction may include determining fault or liability for the sensor malfunction. This may include an apportionment of liability for a cost of repair or replacement of the first sensor between one or more of: a manufacturer of the sensor, a manufacturer of the vehicle **108**, a manufacturer of a smart equipment, a manufacturer of the personal electronic device **189**, an installer of the sensor, an insurer of the vehicle **108**, an insurer of the smart home **187**, an owner of the vehicle **108**, an owner of the smart home **187**, or an owner, operator, or insurer of another vehicle and/or smart home. In further embodiments, determining the cause of the sensor malfunction may include determining insurance coverage for repair or replacement of the sensor based upon the determined cause and/or fault. For example, sensor damage determined to be caused by weather (e.g., freezing temperatures resulting in sensor failure) may be determined to be covered under an insurance policy.

In some additional or alternative embodiments, determining the cause of the sensor malfunction may include determining a software version associated with the malfunctioning sensor. To this end, in a cyber-attack scenario, the malfunction may be caused by the sensor having an outdated or corrupted software version that was exploited by the cyber-attack. In another scenario, a software update may enable additional functionality by the sensor and/or the vehicle **108**. In this scenario, the determination of the software version may restrict one or more potential responses to the cyber-attack. In an embodiment, the software on the sensor may be updated remotely to an updated version, or anti-virus software may be initiated on the sensor.

At block **716**, the on-board computer **114** and/or the smart home controller **185** may determine one or more responses to the sensor malfunction based upon the determined cause and/or other information. The one or more responses may be selected or otherwise determined in order to address the malfunction by correcting the malfunction, changing operation of the vehicle **108** and/or the smart home **187** to reduce the impact of the malfunction, warning a vehicle owner or operator of the malfunction, updating a software associated with the malfunctioning sensor and/or the vehicle **108**, dispatching a backup autonomous vehicle, or taking other actions to improve operation of the vehicle **108** and/or smart home **187** after identification of the malfunction. In some embodiments, part or all of the determination of the one or more responses may be performed by the server **140** based upon information received from the on-board computer **114**, the smart home controller **185**, and/or the personal electronic device **189** via the network **130**.

In some embodiments, vehicle-mounted sensors may be able to determine or identify a number and type of passengers, such as zero passengers, two passengers, a child passenger, an elderly passenger, a handicapped or blind passenger, etc. Based upon the number and type passengers, the response determined **716** may be impacted. For instance, changing operation of the vehicle with zero passengers may be easier than with several passengers.

In further embodiments, the one or more responses may be determined based upon additional information received by the on-board computer **114**, the smart home controller **185** or server **140**, which additional information may include information regarding similar sensor malfunctions from a plurality of other vehicles and/or smart homes. Such additional information may be used to determine risks associated with operation of the vehicle and/or smart home while the sensor is malfunctioning, repairs typically required to correct the malfunction, or adjustments to vehicle operation to minimize the effect of the malfunction under various conditions.

An alert or warning to an operator and/or owner of the vehicle **108**, and/or an occupant and/or owner of the smart home **187**, may be generated in order to notify relevant parties of the malfunction. Such notification may be applicable to situations in which other remedial actions may be taken, as well as to situation in which no immediate remedy is available. In some embodiments, additional information may be included as part of the notification, such as information regarding severity of the malfunction, risks associated with operation of the vehicle **108** and/or the smart home **187** with the malfunction occurring, recommendations for correcting the malfunction, recommendations for adjusting vehicle and/or smart home operation until the malfunction is corrected, or costs associated with correcting the malfunction or operating the vehicle **108** and/or the smart home **187** without correcting the malfunction.

The notification may include recommendations to be implemented or selected by an operator, occupant, and/or owner, such as recommendations to take one or more of the following actions: repair the sensor, replace the sensor, avoid using one or more autonomous operation features of the vehicle **108** and/or the smart home **187**, or avoid using one or more settings associated with the one or more autonomous operation features. The notifications may likewise include information regarding risks or costs associated with operation of the vehicle **108** and/or the smart home **187** without correcting the malfunction. This information may include estimates of increased risks for each of various operation settings or levels of autonomous operation feature usage. This information may similarly include adjustments to costs or coverage levels associated with an insurance policy for the vehicle **108** and/or the smart home **187** based upon the sensor malfunction. Such adjustments may be

immediate or may be prospective (i.e., depending upon the actual usage of the vehicle **108** and/or the smart home **187** following the notification).

The one or more responses may include recommending or enacting limitations on use of one or more autonomous operation features or settings. The limitations may be determined based upon risks associated with use of autonomous operation features or setting. Such risks may be determined by identifying one or more autonomous operation features or settings of the vehicle **108** and/or the smart home **187** that utilize sensor data from the malfunctioning sensor, then determining one or more risk levels associated with use of each such autonomous operation feature or setting while the sensor is malfunctioning. Limitations on use of the one or more autonomous operation features or settings may be determined for the operating environment of the vehicle **108** and/or the smart home **187**, in order to reduce risks associated with autonomous or semi-autonomous operation (e.g., to reduce risk levels to below a maximum safe operation threshold level of risk). In some embodiments, determination of such limitations may include comparing risk levels associated with use of the autonomous operation features or settings with risk levels associated with operation by a specific operator and/or occupant without such autonomous operation features or settings.

Where the response includes recommending limited use of one or more autonomous operation features or settings to a specific operator and/or occupant, such recommendation may be conveyed together with an indication of a risk or cost associated with noncompliance with the recommendation. In other embodiments, the response may include enacting such limitations by limiting the operation of one or more autonomous operation features or settings of the vehicle **108** and/or smart home **187**, such as by disabling or locking relevant autonomous operation features or settings. Thus, the on-board computer **114** and/or the smart home controller **185** may disable or lock certain autonomous operation features or settings. In further embodiments, the response may include an option allowing the operator and/or occupant to override such disabling or locking of the autonomous operation features or settings.

The one or more responses may include repairing or replacing the malfunctioning sensor. This response may include a determination of one or more repairs to be performed and/or one or more components to be replaced. Such determination may further be based upon similar repairs previously performed on other similar vehicles and/or smart homes to correct similar sensor malfunctions. In some embodiments, the response may include automatically scheduling repair or replacement of the sensor, which may include arranging for the sensor to be repaired or replaced by a repair service provider, as discussed elsewhere herein. In further embodiments, liability or insurance coverage for such repair service to correct the sensor malfunction may be determined, and the response may include automatically processing a payment for the service. In further embodiments, repairing the malfunctioning sensor may include resetting, restarting, rebooting, recalibrating, or otherwise attempting to clear the malfunction by returning the sensor to a predetermined or default state. This may be of particular use where a software error has caused the malfunction, such that resetting the sensor (such as by rebooting the sensor) may correct the malfunction.

At block **718**, the on-board computer **114** and/or the smart home controller **185** may cause the one or more responses to be implemented. Implementation may include presentation of alerts or warnings to an operator, owner, occupant and/or other interested party. Implementation may likewise include disabling or locking autonomous operation features or settings thereof, which may be overridden by an operator and/or occupant in some embodiments.

In further embodiments, implementation may include monitoring usage of the vehicle **108** and/or the smart home **187**, such as by storing operating data. Usage may be monitored to determine whether the vehicle and/or smart home is being operated in accordance with recommended usage levels and settings for autonomous operation features impacted by the sensor malfunction, as well as to obtain additional information regarding the sensor. In yet further embodiments, such usage information may be used to determine and/or implement an adjustment to a cost or coverage associated with an insurance policy associated with the vehicle **108** and/or the smart home **187**, which adjustment may be based upon risk levels associated with the determined usage. Implementation may likewise include scheduling repair or replacement of the malfunctioning sensor by a repair service provider, which may include automatically controlling the vehicle **108** to travel to a repair location. In some embodiments, a payment for such repair or replacement service may be automatically made or facilitated by the server **140**.

At block **720**, the on-board computer **114** and/or the smart home controller **185** may determine whether to evaluate another sensor of the one or more sensors **120**, the one or more sensors located on or proximate to the smart home **187**, the sensors of the one or more smart infrastructure components **188**, and/or the personal electronic device **189** (which may also determine a type and number of passengers in the vehicle **108** and/or the smart home **187**). When an additional sensor is identified for evaluation, the method **700** may continue with selecting another sensor for evaluation (block **704**). When no additional sensors are identified for evaluation, the method **700** may terminate. Prior to termination in some embodiments, the on-board computer **114** and/or the smart home controller **185** may generate or store a summary report regarding the status of the sensors **120**, the one or more sensors located on or proximate to the smart home **187**, the sensors of the one or more smart infrastructure components **188**, and/or the personal electronic device **189**.

Exemplary Malfunction Assessment Methods

FIG. **8** illustrates a flow diagram of an exemplary malfunction assessment method **800** for determining the impact of malfunctioning components on the operation of an autonomous vehicle **108**. Such method **800** may be useful in determining not only the risk of accidents or other problems caused by component failure within an autonomous vehicle, a smart home or a personal electronic device, but also the extent or severity of such problems. By assessing both risks and results associated with autonomous operation components, the reliability and robustness of the autonomous systems may be determined. Based upon such determinations, some components of the vehicle may be adjusted to reduce the likelihood of severe problems. This may be accomplished by automatically updating, upgrading, repairing, or replacing one or more components. Although the method **800** is described below as being performed by a server **140** for simplicity, it should be understood that one or more mobile devices **110**, on-board computers **114**, smart home controllers **185**, and/or personal electronic devices **189** may alternatively, or additionally, be used to perform part or all of the process.

The exemplary malfunction assessment method **800** may iteratively assess one or more autonomous operation components of the vehicle **108**, the smart home **187**, and/or the

personal electronic device **189** to determine a likelihood and impact of component malfunction. The method **800** may begin with the selection of a component to assess (block **802**). Operating information may be obtained from a plurality of vehicles, smart homes, and/or personal electronic devices having instances of the component (block **804**). Occurrences of component malfunctions may be identified in the operating information (block **806**), from which may be determined risks of malfunction (block **808**), including risks of cyber-attack (block **809**), and results of such malfunctions (block **810**).

The results of malfunctions may be associated with vehicle collisions or other hazardous events. A component profile may then be determined and/or generated for the component based upon the determined risks and results associated with component malfunction (block **812**). A plurality of components may be so assessed, in which case the preceding blocks **802-812** may be repeated until no further components remain to be assessed (block **814**). In some embodiments, the plurality of component profiles thus generated may be further used to determine and/or generate a risk profile for the vehicle **108**, the smart home **187**, and/or the personal electronic device **189** (block **816**). In yet further embodiments, the method **800** may include determining one or more actions to reduce risk levels associated with the vehicle **108**, the smart home **187**, and/or the personal electronic device **189** (block **818**) and implement such determined actions (block **820**).

At block **802**, the server **140** may select a component of a type used in autonomous operation of the vehicle **108**. Such components may be limited to autonomous operation component types of which the vehicle **108** has at least one instance or copy installed. This selection may include selecting components of particular interest, such as components newly installed within the vehicle **108**, the smart home **187**, and/or the personal electronic device **189**, or components recently updated or upgraded (e.g., by updating of software associated with a component to a new version). This selection may also include simply selecting each known component associated with autonomous operation of the vehicle **108**, the smart home **187**, and/or the personal electronic device **189**, in turn. In some embodiments, this may include automatically identifying at the on-board computer **114**, the smart home controller **185**, and/or personal electronic device **189** all autonomous operation components of the vehicle **108**, the smart home **187**, and/or personal electronic device **189**, respectively, such as by generating or processing a device registry of the components.

The components may include distinct autonomous operation features, hardware components associated therewith (e.g., sensors or controllers), versions of software programs for implementing part or all of an autonomous operation feature, version of operating systems for controlling autonomous operation of the vehicle **108**, the smart home **187**, and/or the personal electronic device **189**, or types of sensors configured to provide sensor data for autonomous or semi-autonomous operation of the vehicle **108**, the smart home **187**, and/or the personal electronic device **189**. The component may be a general type of component used in autonomous operation (e.g., a LIDAR unit) or may be a particular type of a component (e.g., a specific model of a LIDAR unit produced by a particular manufacturer).

At block **804**, the server **140** may obtain operating information from a plurality of autonomous vehicles, smart homes, and/or personal electronic devices having the selected component or type of component. Such operating information may be limited to operating information associated with the selected component, or it may include additional operating information associated with the vehicles, smart homes, and/or personal electronic devices. The information may be obtained by accessing a database **146** storing information regarding operation of a plurality of vehicles, smart homes, and/or personal electronic devices in full or summary form. In some embodiments, the operating information may include operating data (including sensor data and/or control data), as described elsewhere herein. In other embodiments, the operating information may include information derived from operating data and/or loss data associated with vehicle accidents and/or loss events, component failure, or other incidents involving the selected component for the plurality of vehicles, smart homes, and/or personal electronic devices.

At block **806**, the server **140** may identify occurrences of the selected component malfunctioning in the plurality of vehicles, smart homes, and/or personal electronic devices based upon the operating information. This may include identifying recorded occurrences of component malfunction events, occurrences of repairs associated with the component, or occurrences of collisions or other loss events (which may be further analyzed to determine whether the component was malfunctioning prior to the collision or other loss event). In some embodiments, this may include evaluating operating data associated with the plurality of vehicles, smart homes, and/or personal electronic devices to identify indications of component malfunctions based upon signals that are out of an expected range or are inconsistent with other contemporaneous signals associated with other components of the same vehicle, smart home, and/or personal electronic device.

At block **808**, the server **140** may determine one or more risks of component malfunction based upon the identified occurrences of malfunctioning in the plurality of vehicles. The one or more risks may be associated with probabilities of component malfunction occurrences, which may further be associated with types of component malfunctions (e.g., inaccurate operation, unresponsiveness, etc.). The one or more risks may likewise be associated with locations of operation, times of operation, durations of the presence of the component in the autonomous vehicle, smart home, and/or personal electronic device, extent of use of the component in the autonomous vehicle, smart home, and/or personal electronic device, or other relevant factors.

The duration of the presence of the component in the autonomous vehicle, smart home, and/or personal electronic device may be measured in total time, total operating time, or total distance traveled by the vehicle with the component installed within the vehicle. The extent of use of the component in the autonomous vehicle, smart home, and/or personal electronic device may be measured in total operating time or total distance traveled by the vehicle while the component was engaged in operation of the vehicle.

At block **809**, the server **140** may additionally or alternatively determine one or more risks of cyber-attack directed at the component of one or more autonomous vehicles, smart homes, and/or personal electronic devices. The server **140** may determine the software version and/or operating system of the component. The database **146** may additionally include an indication of a latest software version and/or operating system version distributed by the component manufacturer, a date the latest version was released, and/or a number of vulnerabilities corrected by the latest version. The corrected vulnerabilities may be organized by severity (e.g., low, mid, high, critical, etc.). In some scenarios, several versions may have been released between

the version executing on the component and the latest version. In these scenarios, the controller may aggregate the vulnerabilities from each version subsequent to the currently executing version.

The risk of cyber-attack may be determined by generating a vulnerability score indicating a risk level associated the known vulnerabilities in the current software version and/or operating system version executing on the component. In an embodiment, one or more vulnerabilities may be associated with particular functions and/or features that may be maliciously controlled by exploiting the vulnerability. In this embodiment, the vulnerability score may be further based upon the operation and/or performance of the functions and/or features exposed in the component's currently executing software version and/or operating system version.

At block **810**, the server **140** may further determine results associated with each identified occurrence of the component malfunctioning. Such results may include immediate and longer-term results, including both events (e.g., collisions) and non-events (e.g., no significant change in autonomous operation). Each result may be indicative of an impact of the component malfunction on the operation of the vehicle.

Such impact may include an impact on a risk or severity of a vehicle collision involving the vehicle and/or other loss event involving the vehicle, smart home, and/or personal electronic device. Such impact may similarly include an impact on a risk or severity of a loss of control event, on an inability to operate in a fully autonomous or semi-autonomous mode, on a collision or loss of control event involving another vehicle, smart home, and/or personal electronic device in the operating environment, or other aspects of autonomous control (e.g., recognition and/or appropriate response to environmental conditions, pedestrians, other vehicles, etc.). The result may further include information regarding the impact, such as occurrence and/or extent of damage to the vehicle, smart home, and/or personal electronic device, damage to other vehicles, smart homes, and/or personal electronic devices, damage to other property, costs associated with repair of damage, injuries to passengers of the vehicle or other vehicles, injuries to pedestrians and/or passersby, or costs associated with injuries.

In some embodiments, determining the results associated with the identified occurrences of component malfunctioning may include determining the influence of mitigation by one or more actions of the vehicle, smart home, and/or personal electronic device to offset the component malfunction. Such mitigating actions taken by the vehicle, smart home, and/or personal electronic device in response to the component malfunction may include making adjustments to the operation of one or more autonomous operation features associated with the malfunctioning component, placing restrictions or limitations on use of the one or more autonomous operation features, or engaging additional components to compensate for the malfunction. Where the malfunctioning component is or includes a sensor, the mitigating actions may include ignoring sensor data from such sensor and/or using sensor data from one or more redundant sensors (which may be of the same general type as the malfunctioning sensor) to operate the vehicle, smart home, and/or personal electronic device. In some embodiments, redundant sensors or other components may not be activated until the on-board computer **114**, smart home controller **185**, and/or personal electronic device **189** determines that the component is malfunctioning.

In some embodiments, the mitigating actions may be associated with a version of a software program associated with an autonomous operation feature or a version of an operating system for autonomous operation of the vehicle, smart home, and/or personal electronic device. For example, newer versions of software used by the vehicle, smart home, and/or personal electronic device may include additional functionality to take mitigating actions not included in older versions of such software. As another example, new version of software may reduce the vulnerability of the vehicle, smart home, and/or personal electronic device to cyber-attacks.

At block **812**, the server **140** may determine and/or generate a component profile based upon the determined risks of component malfunction and results of component malfunction. The component profile may indicate one or more combinations of risk levels, including cyber-attack risk levels, and impacts associated with malfunctions of the component, which may depend upon one or more settings associated with the component. Such combinations may be further associated with a plurality of operating conditions, as well as other aspects of the vehicle, smart home, and/or personal electronic device. Such conditions and aspects may have significant influence on the probability and severity of incidents resulting from component malfunctions. Operating conditions of vehicle use, smart home use, and/or personal electronic device use may include operating environments through which a vehicle travels, an environment proximate to the smart home, and/or environments in which the person monitored by the personal electronic device travels, which may include location, weather, traffic, road type, time of day, etc.

Aspects of the vehicle, smart home, and/or personal electronic device may include fixed or adjustable characteristics of a vehicle, smart home, and/or personal electronic device that may interact with the component, including other components of the vehicle, smart home, and/or personal electronic device, extent of use of autonomous operation features, settings of the autonomous operation features used, etc. For example, each combination in the component profile may be associated with a configuration of additional components (which may include settings thereof) that interact with the component to operate the vehicle, smart home, and/or personal electronic device.

In some embodiments, the component profile may include one or more scores associated with risks and results associate with the component under one or more sets of conditions and/or aspects. Such scores may be indicative of an expected value of the impact of component malfunctions, including cyber-attacks. In further embodiments, the component profile may additionally, or alternatively, indicate an expected usable lifetime of the component. Such expected usable lifetime may be associated with a duration of time or extent of distance traveled by the vehicle with the component installed or functioning before the component reaches a predetermined failure rate (e.g., 50% probability of malfunction, 70% probability of malfunction, etc.).

At block **814**, the server **140** may determine whether there is a further component of the vehicle **108**, the smart home **187**, and/or the personal electronic device **189** to assess. When a further component is identified, the method **800** may continue with selection of the next component to assess (block **802**). When no further component is identified, the method **800** may terminate or may proceed to determination and/or generation of a risk profile for the autonomous vehicle, smart home, and/or personal electronic device (block **816**).

At block **816**, in some embodiments, the server **140** may determine and/or generate a risk profile for the vehicle **108**, the smart home **187**, and/or the personal electronic device

189 based upon a plurality of component profiles determined for a plurality of autonomous operation components of the vehicle **108**, the smart home **187**, and/or the personal electronic device **189**. The risk profile may be determined based upon the entries in the plurality of component profiles. The risk profile may be generated by the server **140** by appending the component profiles, or the risk profile may be generated by the server **140** by processing combining the entries in the component profiles. Combining the entries in the component profiles may include generating conditional risk levels or impact estimates, as well as conditional expected value estimates associated with various conditions and/or components. In some embodiments, some or all of the entries in the risk profile may represent total risk levels or total expected values that incorporate risks and results for a plurality of components of the vehicle **108**, the smart home **187**, and/or the personal electronic device **189**.

At block **818**, in some embodiments, the server **140** may determine one or more actions to reduce one or more risks associated with autonomous operation based upon the determined risk profile for the vehicle **108**, the smart home **187**, and/or the personal electronic device **189**. The one or more actions may be associated with reducing the risks (or results) associated with malfunctions of one or a plurality of the components of the vehicle **108**, the smart home **187**, and/or the personal electronic device **189**. To determine actions to reduce risks the server **140** may determine one or more repairs, upgrades, replacements, or updates that may be made to the one or more components. For example, the server **140** may identify a software version associated with an autonomous operation feature that would reduce the expected damage caused by a component failure and/or reduce the risk of exposure of the component to a cyber-attack.

Based upon such determination of actions to reduce risks or impacts from component malfunctions and/or cyber-attacks, the server **140** may further determine additional information necessary to implement such actions. For example, information regarding repair or replacement options or costs may be determined, as may information regarding repair service providers. Where the one or more actions include updating or upgrading software, the server **140** may determine to automatically update or upgrade the software when the vehicle **108**, the smart home **187**, and/or the personal electronic device **189** is not in operation, and/or at a time generally associated with low risk of impacting other components (e.g., around 3 A.M.). The one or more actions may thus include causing the vehicle **108**, the smart home **187**, and/or the personal electronic device **189** to update or upgrade one or more components automatically. Similarly, the one or more actions may include scheduling an appointment to repair or replace one or more components of the vehicle **108**, the smart home **187**, and/or the personal electronic device **189**. The one or more actions may further include causing the vehicle **108** to travel in a fully autonomous mode to a repair service provider for repair or replacement of the one or more components.

Alternatively, or additionally, the one or more responses may include generating one or more messages regarding the components for presentation to an owner or operator of the vehicle **108**, an occupant or owner of the smart home **187**, and/or the person monitored by the personal electronic device **189**. Such messages may include notifications or recommendations regarding the determined repairs, upgrades, replacements, or updates that may be made to the one or more components. The messages may similarly include recommendations regarding usage of the one or more components, such as recommendations of conditions and/or settings for use of such components to reduce risk. Such messages may further include information regarding costs associated with the recommendations, which may include cost savings or reductions in costs associated with a vehicle insurance policy.

At block **820**, in some embodiments, the server **140** may implement the determined one or more actions. This may include generating and communicating messages to owners and/or operators of the vehicle **108**, the occupants and/or owners of the smart home **187**, and/or the persons monitored by the personal electronic device **189** for presentation via a display **202**. In some embodiments, such actions may be implemented by scheduling appointments to repair or replace components, as well as controlling vehicles to travel to service locations for such appointments. In further embodiments, the actions may be implemented by automatically updating or upgrading software associated with one or more autonomous operation features of the vehicle **108**, the smart home **187**, and/or the personal electronic device **189**. The server **140** may communicate with the on-board computer **114**, the smart home controller **185**, and/or the personal electronic device **189** to implement such actions.

Exemplary Component Repair Methods

FIG. **9** illustrates a flow diagram of an exemplary autonomous component repair method **900** for identifying and repairing malfunctioning components of an autonomous vehicle **108**, a smart home **187** and/or a personal electronic device **189**. Such method **900** may be utilized to automatically detect and correct malfunctions affecting components of a vehicle **108**, a smart home **187** and/or a personal electronic device **189** that are associated with autonomous operation. Unlike traditional devices, autonomous vehicles, smart homes and/or personal electronic devices may be capable of self-diagnosis using the on-board computer **114** and/or the smart home controller **185**. In embodiments associated with autonomous vehicles, the autonomous vehicle **108** may be further capable of automatic travel to facilities capable of repairing or replacing malfunctioning components. In circumstances in which malfunctions are not so severe as to preclude autonomous operation, the on-board computer **114** may automatically schedule an appointment for such repairs and control the vehicle **108** to travel to such appointment, either with or without the involvement of a vehicle owner or operator. When the malfunctions preclude autonomous operation, or in embodiments associated with the smart home **187** and/or the personal electronic device **189**, however, the on-board computer **114** may nonetheless alert an owner, occupant, or operator to the situation, which may also include scheduling an appointment for the vehicle **108**, the smart home **187** and/or the personal electronic device **189** to be repaired. Although the method **900** is described below as being performed by the on-board computer **114**, the smart home controller **185**, the personal electronic device **189** for simplicity, it should be understood that one or more mobile devices **110** or servers **140** may alternatively, or additionally, be used to perform part or all of the process.

The exemplary autonomous component repair method **900** may begin by receiving data associated with operation of the vehicle **108**, the smart home **187** and/or the personal electronic device **189** (block **902**). When an indication of an unusual condition is identified in the received data, a determination to evaluate one or more autonomous operation components of the vehicle **108**, the smart home **187** and/or the personal electronic device **189** may be made (block **904**), and status data regarding the one or more components may

be obtained (block **906**). A malfunction of at least one of the components may be determined based upon the status data (block **908**). One or more repairs may then be determined to correct the malfunction (block **910**), and such repairs may be scheduled with a repair service provider (block **912**). In embodiments associated with the autonomous vehicle **108**, if the vehicle **108** is able to operate fully autonomously despite the malfunction (block **914**), the vehicle **108** may travel autonomously to a repair location associated with the scheduled appointment (block **916**). If the vehicle **108** is unable to operate fully autonomously with the malfunction (block **914**), an alert regarding the malfunction may be generated and presented to a vehicle owner or operator (block **918**). In some embodiments, the repair may be scheduled or rescheduled for a current location of the vehicle **108** when the vehicle **108** is unable to operate fully autonomously (block **920**). In further embodiments, insurance or other coverage for the repair may be determined and payments made automatically (block **922**).

At block **902**, the on-board computer **114**, the smart home controller **185** and/or the personal electronic device **189** may receive data associated with operation of the vehicle **108**, the smart home **187** and/or the personal electronic device **189**. This may include receiving operating data associated with the vehicle **108**, the smart home **187** and/or the personal electronic device **189**, or other information regarding operation. In some embodiments, the data may be received from a vehicle operator and/or smart home occupant. A vehicle operator and/or smart home occupant may manually enter input or select an option indicative of a general operating status of the vehicle **108**, the smart home **187** and/or the personal electronic device **189**. For example, a vehicle operator and/or smart home occupant may select an option to begin a diagnostic and repair routine via the on-board computer **114**, the smart home controller **185**, the personal electronic device **189**, and/or a mobile device **110**, such as when the vehicle operator and/or smart home occupant observes something to be amiss in autonomous operation. In further embodiments, the data may include a summary indicator of whether an unusual condition or an incident has occurred, which summary indicator may be generated by a monitoring or response method, as described elsewhere herein (particularly with reference to method **500**).

At block **904**, the on-board computer **114**, the smart home controller **185**, and/or the personal electronic device **189** may determine to assess one or more autonomous operation components of the vehicle **108**, the smart home **187** and/or the personal electronic device **189** based upon the received data. In some embodiments, the determination may be based upon an indication in the data of an anomaly associated with part of the received data related to the one or more components. For example, a discrepancy between sensor data received from two or more sensors may be detected, indicating that at least one of the two or more sensors may be malfunctioning without directly indicating which sensor or sensors are malfunctioning. In further embodiments, determining to assess the one or more autonomous operation features may include determining the occurrence of a loss-event, such as a collision involving the vehicle **108**, a loss of control of the vehicle **108**, a near collision of the vehicle **108** with an object within a threshold distance, damage to the vehicle **108**, the smart home **187** and/or the personal electronic device **189**, and/or the presence of unsafe conditions associated with the smart home **187**. The determination may further include determining which components to assess based upon the received data, such as by determining a collision involving a front portion of the vehicle **108** or loss occurred in the basement of the smart home **187**.

At block **906**, the on-board computer **114**, the smart home controller **185** and/or the personal electronic device **189** may obtain status data regarding the one or more components of the vehicle **108**, the smart home **187** and/or the personal electronic device **189**. This may include requesting, accessing, or receiving such status data from a program memory **208** or from the component itself. The status data may include operating data associated with the one or more components, such as sensor data from a plurality of sensors **120** of the vehicle **108**, the smart home **187** and/or the personal electronic device **189**. In some embodiments, the status data may be indicative of a self-diagnosis of the component or may be received over a sample period of time.

In further embodiments, the status data may be received in summary form, such as a summary of operating data associated with the one or more components (e.g., summaries of control decisions made by an autonomous operation feature). Such status data may further include or be associated with information regarding conditions in the autonomous operation environment. In embodiments in which a loss-event is determined to have occurred, the on-board computer **114**, the smart home controller **185** and/or the personal electronic device **189** may request the status data in response to such determination of the incident.

At block **908**, the on-board computer **114**, the smart home **187** and/or the personal electronic device **189** may evaluate the one or more components using the status data to determine at least one of the components is malfunctioning. This determination may include identifying at least one of the components that is malfunctioning by iteratively evaluating the one or more components against predetermined or dynamically determined expected ranges of operation, such as discussed elsewhere herein (particularly with reference to method **700**). This determination may further include identifying a type of malfunction, cause of the malfunction, and/or extent of the malfunction. In some embodiments, the determination may include a prediction of future failure of the component based upon current or prior status data regarding the component. Such prediction may be further based upon a comparison with information regarding similar components of a plurality of other vehicles, smart homes, or personal electronic devices, which may be received from the server **140** or the database **146**. In some embodiments, the server **140** may determine such prediction and communicate the prediction of future failure of the component.

At block **910**, the on-board computer **114**, the smart home controller **185** and/or the personal electronic device **189** may determine one or more repairs to correct the determined malfunction. Such repairs may include adjusting or replacing a component or portion thereof. The repairs may be determined based upon the status data or information derived therefrom, such as the cause of the malfunction. The repairs may further be based upon information regarding repairs made to a plurality of other vehicles, smart homes, and/or personal electronic devices having similar component malfunctions. In some embodiments, determining the one or more repairs may include further determining one or more requirements associated with the repairs that indicate parts required for the repairs or skill levels required for the repairs.

In some embodiments, the one or more repairs may be determined by the server **140** based upon information received from the on-board computer **114**, the smart home **187** and/or the personal electronic device **189**. In further embodiments, the determined repairs may be verified by a

human reviewer, such as an agent of an insurer. Such verification may be performed remotely or at a repair facility or other site associated with the reviewer, in which case the vehicle **108** may be caused to travel to the site for review. In yet further embodiments, external photographic or video evidence of damage to the vehicle **108**, the smart home **187** and/or the personal electronic device **189** may be captured and stored by a human reviewer, regardless of whether the human reviewer is required to verify the determined repairs. This may be particularly useful where a third party may be liable for the malfunction.

At block **912**, the on-board computer **114**, the smart home controller **185** and/or the personal electronic device **189** may automatically schedule an appointment with a repair service provider to perform the one or more repairs. Such scheduling may be performed in conjunction with the server **140**, which may be instructed by the on-board computer **114**, the smart home controller **185**, and/or the personal electronic device **189** to schedule an appointment based upon the determined one or more component malfunctions and/or repairs. Scheduling the appointment may include first identifying one or more repair service providers capable of performing the determined one or more repairs to correct the component malfunction. Identifying the repair service providers may include determining that the repair service providers are capable of meeting one or more requirements associated with the repairs that indicate parts required for the repairs or skill levels required for the repairs. In some embodiments, the on-board computer **114**, the smart home controller **185**, the personal electronic device **189** and/or server **140** may provide information regarding the one or more determined component malfunction and repairs to the repair service provider in order to schedule the appointment.

If multiple repair service providers are determined to be capable of performing the repair, one of the repair service providers may be selected based upon scheduling availability, cost, location, quality metrics associated with previous repairs, or other criteria. The appointment may be scheduled for a service time and service location for the repairs to be performed immediately or at some future point following scheduling. In some embodiments, the appointment may be scheduled for a time when the vehicle **108**, the smart home **187** and/or the personal electronic device **189** is ordinarily not in use in order to minimize the impact of the repairs on owners, occupants, or operators.

In further embodiments, the appointment may be presented to an owner, occupant, or operator for confirmation prior to being set. In yet further embodiments, alternative transportation may be scheduled for the vehicle owner or operator during the scheduled repairs. Such alternative transportation may include taxi service, temporary vehicle-sharing membership, vehicle rental, or similar temporary replacement transportation.

At block **914**, in embodiments associated with the vehicle **108**, the on-board computer **114** may determine whether the vehicle **108** is capable of fully autonomous operation to travel to the repair service provider location. In some embodiments, such determination may be made prior to or while scheduling the appointment, which may influence the selection of the time and location of the appointment. The determination of whether the vehicle **108** is capable of fully autonomous operation may include determining that the risk associated with fully autonomous operation of the vehicle **108** by its autonomous operation features is below a risk level below a risk threshold associated with safe operation, despite the component malfunction. When the vehicle **108** is determined to be capable of fully autonomous operation, the on-board computer **114** may control the vehicle to travel to the service location for the scheduled appointment (block **916**). If fully autonomous operation of the vehicle **108** by its autonomous operation features would result in a risk above the risk threshold, the vehicle **108** may be determined unfit for fully autonomous operation. When the vehicle **108** is determined not to be capable of fully autonomous operation, the on-board computer **114** may alter an owner or operator of the vehicle **108** of the component malfunction and inability of the vehicle **108** to operate fully autonomously (block **918**).

At block **916**, in embodiments associated with the vehicle **108**, the on-board computer **114** may control the vehicle **108** to travel fully autonomously to the service location to arrive at or before the scheduled service time using the autonomous operation features. The on-board computer **114** may select autonomous operation features or settings associated therewith to minimize risks or risk-weighted impacts associated with accidents during autonomous operation to the scheduled appointment. This may include limiting or eliminating use of one or more autonomous operation features that depend upon the one or more malfunctioning components.

The on-board computer **114** may further select a route to minimize risks of damage or injury, such as by avoiding highways or road segments previously determined to be associated with high risk for autonomous operation. The on-board computer **114** may further adjust settings to reduce risk, such as by limiting vehicle operation to travel below a specific speed or only travelling during daylight hours without precipitation. To meet such requirements, in some embodiments, the on-board computer **114** may cause the vehicle **108** to travel to the service location in advance of the service time. Information regarding the scheduled appointment or the fully autonomous operation of the vehicle **108** may be presented to an owner or operator of the vehicle **108** for review, adjustment, or approval.

At block **918**, the on-board computer **114**, the smart home **187** and/or the personal electronic device **189** may generate an alert to an owner, occupant, or operator of the vehicle **108**, the smart home **187** and/or the personal electronic device **189** when the vehicle **108**, the smart home **187** and/or the personal electronic device **189** cannot operate fully autonomously to travel to the service location. The on-board computer **114**, the smart home **187** and/or the personal electronic device **189** may further cause the alert to be presented to the owner, occupant, or operator by a display of the vehicle **108**, the smart home controller **185**, the personal electronic device **189**, mobile device **110**, or other computing device associated with the owner, occupant, or operator. The alert may include information regarding the one or more malfunctions associated with the components of the vehicle **108**, the smart home **187** and/or the personal electronic device **189**, such as a summary of malfunctions or causes of the malfunctions. The alert may further include one or more repair recommendations. In some embodiments, information regarding the recommended repairs may be included in the alert, such as typical costs, time, or parts associated with such repairs. In further embodiments, information regarding one or more repair service providers may be provided, and one or more proposed appointments may be recommended. In yet further embodiments, the alert may include a request to the owner, occupant, or operator to confirm, reschedule, or cancel an automatically scheduled appointment with a repair service provider.

At block **920**, in some embodiments, the on-board computer **114**, the smart home **187** and/or the personal electronic

device **189** may schedule an appointment to repair the one or more malfunctioning components at a service location not associated with the repair service provider. Such service location may include a current location of the vehicle **108**, the smart home **187** and/or the personal electronic device **189** or a usual parking or garaging location of the vehicle **108**. Thus, the vehicle **108**, the smart home **187** and/or the personal electronic device **189** may be repaired without traveling to the repair service provider, which may be of particular value when the vehicle **108** is incapable of fully autonomous operation because of the one or more malfunctions. This may include automatically rescheduling the appointment with the repair service provider, or this may include changing the service location before scheduling the appointment (or before finalizing or confirming the appointment).

At block **922**, in some embodiments, the on-board computer **114**, the smart home **187** and/or the personal electronic device **189** or server **140** may determine an insurance policy coverage or other coverage for the one or more repairs. Such coverage may be determined based at least in part upon a determined cause of each malfunction. For example, a coverage for weather-related damage may be determined to apply to the one or more repairs when the one or more malfunctions are determined to have been caused by freezing temperatures or hail damage. In further embodiments, a payment may be automatically made to the repair service provider for the repair work based upon the determined coverage. This may be facilitated by one or more servers **140**, which may cause a transfer of funds to be made to an account associated with the repair service provider. Such transfers may be made following completion of the repairs. The one or more server **140** may further cause a deduction to be made from an account associated with the vehicle **108**, the smart home **187** and/or the personal electronic device **189** for a copayment or deductible payment associated with the coverage in yet further embodiments.

Exemplary Malfunction Detection Methods

FIG. **10** illustrates a flow diagram of an exemplary autonomous environment control software evaluation method **1000** for testing the quality of control decisions generated by autonomous operation feature of an autonomous vehicle **108**, a smart home **187**, and/or a personal electronic device **189**. Such method **1000** may be implemented to assess the operation of software components used in autonomous operation outside of a vehicle, a smart home, and/or a personal electronic device. Such testing may allow new software or software version updates to be evaluated in a realistic computing environment without the hazards associated with testing in a vehicle, a smart home, and/or a personal electronic device. In some embodiments, the test environment may include emulation of an autonomous operating system, such as the on-board computer architecture **114** and/or the smart home controller **185**, operating at an artificially accelerated system clock speed to facilitate faster testing of control software under a variety of conditions.

Although the method **1000** is described below as being performed by one server **140** for simplicity, it should be understood that one or more mobile devices **110**, on-board computers **114**, smart home controllers **185**, personal electronic device **189**, or servers **140** may alternatively, or additionally, be used to perform part or all of the process. For example, multiple test scenarios representing a plurality of test conditions may be simultaneously run using a plurality of servers **140** (or a plurality of processors **162**) to reduce the total time required to evaluate the software features.

The exemplary method **1000** may begin with selection of one or more autonomous operation features to test (block **1002**). Based upon the selection of autonomous operation features, computer instructions associated with such autonomous operation features may be retrieved from a memory storage (block **1004**). The computer instructions may include one or more software routines associated with the selected autonomous operation features. A further selection of test conditions to be used in testing the autonomous operation features may be received (block **1006**), which may be associated with types of vehicles, smart homes, and/or personal electronic devices, other software features, or environmental conditions of a virtual operating environment mimicking a vehicle operating environment. Simulated input data may then be generated based upon the selected autonomous operation features and test conditions (block **1008**). An emulation of an autonomous environment operating system may be started to test the software routines (block **1010**), and the software routines may be implemented within the emulated operating system (block **1012**).

Once the software environment is prepared, the test may be performed by presenting the simulated input data to the software routines (block **1014**), processing the simulated input data by the software routines (block **1016**), and recording output data received from the software routines (block **1018**). Such output data may include control commands generated by the software routines configured to directly or indirectly control autonomous operation when executed within an autonomous environment during autonomous operation using the associated autonomous operation feature. One or more quality metrics indicative of effectiveness of the evaluated autonomous operation features may be calculated for the software routines based upon the recorded output data (block **1024**). In some embodiments, baseline output values may be retrieved (block **1022**) and used in generating and/or determining the one or more quality metrics by comparison with the recorded output data (block **1024**).

At block **1002**, a user may select one or more autonomous operation features to evaluate. The selection may be made from a list of autonomous operation features or groups of autonomous operation features. In some embodiments, the user may select the features via a user interface of a display **202**, which selection may be communicated to the server **140**. In further embodiments, the user may implicitly select one or more features to evaluate by storing or loading the features in a memory of the server **140** for testing. This may include storing computer-readable instructions associated with the autonomous operation features in a directory location that may be accessed for testing. In yet further embodiments, the user may select a directory location to select the computer-readable instructions stored at such location.

At block **1004**, the server **140** may access computer-readable instructions associated with the selected one or more autonomous operation features in response to receiving the user selection. Such computer-readable instructions may comprise one or more software routines that may be implemented within an autonomous environment operating system, such as one running on an on-board computer **114** of an autonomous vehicle **108** and/or one running on a smart home controller **185** of a smart home **187**, to perform control, monitoring, assessment, communication, and/or similar operations in support of autonomous operation. Although referred to as software routines for simplicity, such computer-readable instructions may include subroutines, programs, applications, scripts, or similar executable or callable code segments. Accessing the software routines

may include retrieving the computer-readable instructions stored in one or more directory locations. In some embodiments, the software routines may be accessed from a remote storage device, such as another server connected to the server **140** via the network **130**.

At block **1006**, the server **140** may receive a selection of test conditions for evaluating the one or more autonomous operation features. The user may select the test conditions by selecting one or more indicators representing the test conditions, or the server **140** may automatically select the test conditions based upon a configuration file or other stored information. The test conditions may indicate parameters, scope, or duration of testing of the autonomous operation features. In some embodiments, the selection of test conditions may include selection of a make and/or model of an autonomous vehicle, an on-board computer, a smart home controller, or an autonomous environment operating system (or version thereof). This may include information regarding sensors or sensor data available for use by the autonomous operation features (e.g., number and type of sensors, operating status of sensors, or configuration of sensors within a simulated environment).

In further embodiments, the selection of test conditions may include indicating one or more types of environmental conditions to mimic in the simulated input data to be presented to the software routines during testing. Such environmental conditions may include conditions relating to time of day (e.g., daylight levels, glare, or headlights of other vehicles), weather (e.g., wind, precipitation, visibility, temperature, or other weather conditions), road type (e.g., highway, residential, urban, or rural), road integrity (e.g., road material, ice, pooling water, or potholes), traffic (e.g., congestion, mean or median speed, or average vehicle spacing), neighborhood (e.g., urban, suburban, apartment complex, or agricultural) construction (e.g., lane closures, temporary traffic patterns, or active construction work), and/or other similar conditions that affect effectiveness of autonomous operation features in controlling a vehicle and/or smart home. The environmental conditions may be specified at various levels of detail or in groupings, such as urban rush hour conditions or rural winter storm conditions.

At block **1008**, the server **140** may generate simulated input data based upon the selected test conditions. The simulated input data may be generated as one or more sets of test data associated with test conditions. The test data may include simulated sensor data, such as a plurality of simulated sensor data points to be presented to the software routines as inputs during testing. The test data may further include simulated control data from one or more other autonomous operation features that may be provided to the software routines as inputs during testing, as well as simulated communication data from one or more communication components. In some embodiments, the set of test data may include a plurality of subsets of test data, each such subset representing a combination of conditions (e.g., daylight urban driving in moderate congestion during clear weather, daylight urban driving in moderate congestion during rain, daylight urban household during snow, etc.). In this manner, the selected autonomous operation features may be tested in a range of environments in an efficient manner, without requiring the user to specify each potential environmental condition. Similarly, the subsets of test data may be used to present a variety of scenarios with the same combination of conditions. For example, normal operation may be tested by one subset of test data, while response to the simulated vehicle being cut off by another vehicle within the simulation may be tested using another subset of test data.

The test data may include one or more sequences of simulated data signals, such as sensor data signals. Each sequence of simulated data signals may simulate a time series of continuous or discrete data over a time period during vehicle operation. For example, a sequence may be associated with a time series of data points over a time interval representing sensor readings from an accelerometer within the vehicle. Another sequence may be associated with a time series of data points over the same time interval of a proximity sensor at a location within the vehicle and/or smart home. The sequences may be standardized sequences generated in advance and stored in a database **146**, to be retrieved by the server **140** to generate the set of test data. Such retrieved sequences may include recorded sequences of sensor data from actual autonomous operation that has previously occurred and been recorded by on-board computers **114** of a plurality of vehicles **108** and/or a plurality of smart home controller **185** from a plurality of smart homes **187**. Such recorded sensor data may be associated with ordinary autonomous operation or incidents involving the vehicles and/or smart homes (e.g., loss of control situations, collisions, loss-events, etc.).

In some embodiments, the sequences may be generated by the server **140** based upon the received selections of autonomous operation features and test conditions, such as by generating expected sensor data based upon a simulation of an autonomous operation in a virtual environment meeting the criteria indicated by the selected test conditions. The set of test data may be generated by combining a plurality of sequences of simulated data signals, which sequences may be matched in time to be concurrent within the simulated test environment. In some embodiments, the combination of sequences may include a simple aggregation of such signal sequences. In further embodiments, combining the sequences may include generating one or more summary sequences or signals from two or more of the retrieved sequences, or combining the sequences may include modifying one or more of the sequences based upon other retrieved sequences.

At block **1010**, the server **140** may start an emulator program to mimic an autonomous environment operating system. The emulator may be configured to mimic a specific version of an autonomous environment operating system running on a particular make and model of a smart home controller **185** and/or an on-board computer **114**, which may be associated with a particular make, model, and year of an autonomous vehicle. The emulator may perform operations to execute the computer-readable instructions of the software routines on the hardware architecture of the server **140**. This may include translating signals from the sets of test data into a format usable by the software routines and translating the output of the software routines for storage in the program memory **160** or database **146**. Such translation may include interpolation or sampling of data points. In some embodiments, the emulator program may be configured to operate at an accelerated speed in order to process the test data faster than real-time. This may include keeping a separate internal system clock within the emulator program that is used by the software routines. Such internal system clock may progress faster than an external clock of the server **140**. By operating at an accelerated speed, the emulator program may enable the software routines to process the simulated input data in less time than the time interval nominally associated with the data.

At block **1012**, the emulator may implement the one or more software routines associated with the selected autonomous operation features. This may include accessing a

directory location where the computer-readable instructions specifying the software routines are stored to load the software routines in the emulated environment. The software routines may be executed within the emulator to process the simulated input data in a manner similar to operation within an on-board computer **114** of an autonomous vehicle **108** and/or a smart home controller **185** of a smart home **187**.

At block **1014**, the emulator may present the simulated input data as inputs to the one or more software routines within the emulated environment. In some embodiments, the emulator may receive the set of test data from another program or routine running on the server **140**. As noted above, the simulated input data may include simulated or prerecorded values of sensor data, control data, communication data, or a combination of such data. The emulator may parse the set of test data to separate the types of simulated input data for separate presentation to the software routines. For example, the sensor data may include data sequences with different periodicity from the update period of control data signals with in the data set. The emulator may then align the presentation of such various simulated input data to the software routines to represent a coherent set of inputs.

In some embodiments, the emulator may further implement one or more additional software routines to generate control data as further inputs to the software routines. Such additional software routines may be presented with part or all of the simulated input data as inputs, and the outputs generated by such additional software routines may be presented as inputs to the one or more software routines.

At block **1016**, the one or more software routines may process the received inputs to generate output data within the emulator environment. The output data generated by the software routines may include output signals indicative of conditions determined by the software routines, control signals configured for controlling autonomous components, and/or other data generated by the software routines as inputs into further software or hardware components configured for controlling autonomous components. The one or more software routines may run within the emulator program on the server **140** to produce such output data in the same manner that the software routines would run within the autonomous environment operating system, such as on an on-board computer **114** during vehicle operation and/or a smart home controller **185** during smart home operation. In some embodiments, the emulator program may control one or more settings of the autonomous operation features associated with the software routines by adjusting parameter variable values stored within the emulated environment and accessed by the software routines during data processing.

At block **1018**, the emulator may cause the output data or indications associated with the output data to be stored by the server **140**. This may include sampling or translating the output data from the software routines to prepare the output data for storage by the server **140**. The server **140** may receive the prepared output data or indications associated therewith and store such received data in the program memory **160** or database **146** for further analysis. The output data may be time-stamped or otherwise associated with sequences of simulated data signals in the set of test data. In some embodiments, the indications associated with the output data may include indications of errors or failures of the software routines. For example, the indications could including information regarding stack overflow, infinite looping, out-of-range values, or other events associated with failures of the software routines to operate properly or perform vehicle control functions in an effective manner.

In some embodiments, at block **1020**, the emulator (or other application running on the server **140**) may further use the output data generated by the one or more software routines in determining or adjusting the simulated input data to present to the software routines as inputs. This may include providing previously generated output data as input data (e.g., prior period control data generated by a software routine may be used as an input for generating current period control data). This may likewise include adjusting simulated sensor data or control data from additional software routines based upon output data generated by the software routines. For example, the server **140** may run a virtual vehicle environment simulation application that interfaces with the emulator to provide simulated input data to the emulator and to model movement of a virtual vehicle within a virtual environment based upon the output data generated within the emulator. Thus, output generated by the software routines may be used to control a virtual position of the virtual vehicle relative to other objects within the virtual environment, which updated position may then be used to generate further simulated input data. Similarly, the server **140** may run a virtual smart home environment simulation application that interfaces with the emulator to provide simulated input data to the emulator to model movement of objects within the virtual environment proximate to or within a smart home. For example, the virtual smart home environment simulation application may simulate and/or model a virtual fire on a neighboring property. The adjusted or updated simulated input data may then be presented to the one or more software routines running within the emulator program (block **1014**).

In further embodiments, at block **1022**, the server **140** may access baseline output values associated with the selected test conditions from the database **146**. The baseline output values may be indicative of ordinary or acceptable functioning of the selected one or more autonomous operation features under the selected conditions. The baseline output values may be determined based upon calculated output values required for safe autonomous operation of a vehicle, smart home, and/or personal electronic device, or the baseline output values may be determined from analysis of data indicating actual output values from actual operation of a plurality of autonomous vehicles, smart homes, and/or personal electronic devices. In some embodiments, the baseline output values may be associated with test or actual output values from another version of a related software routine associated with an autonomous operation feature. For example, output values for a current version of control software routines associated with an autonomous operation feature that had been determined by previous testing (i.e., using the method described herein) may be used as baseline output values for comparison against output data generated by testing a new version or update to the control software routines associated with the same autonomous operation feature.

At block **1024**, the server **140** may generate and/or determine one or more quality metrics indicative of effectiveness of the evaluated autonomous operation features in controlling an autonomous vehicle. The quality metrics may be generated and/or determined based upon the output data recorded during evaluation of the software routines associated with the autonomous operation features. In some embodiments, such quality metrics may be indicative of risks associated with the autonomous operation features. The quality metrics may be generated and/or determined by

comparison of the recorded output data with output values indicative of effective control of an autonomous vehicle, smart home, and/or personal electronic device by the autonomous operation features. As discussed above, some embodiments may generate and/or determine the quality metrics by comparing the recorded output data with baseline output values.

Such comparison may include determining one or more measures of differences between record output and baseline output values, which may then be used to determine the one or more quality metrics. For example, the quality metric may be determined as a measure of magnitude of the differences between the record output and baseline output values. The differences may be indicative of improvement or deterioration of the operation of the tested software routines relative to the baseline performance indicated by the baseline output values. The determined quality metrics may be stored or presented to the user for review. Once the quality metrics have been generated, the method **1000** may terminate.

Exemplary Methods of Determining Risk Using Telematics Data

As described herein, telematics data may be collected and used in monitoring, controlling, evaluating, and assessing risks associated with autonomous or semi-autonomous operation of a vehicle **108**. In some embodiments, the Data Application installed on the mobile computing device **110** and/or on-board computer **114** may be used to collect and transmit data regarding vehicle operation. This data may include operating data regarding operation of the vehicle **108**, autonomous operation feature settings or configurations, sensor data (including location data), data regarding the type or condition of the sensors **120**, telematics data regarding vehicle regarding operation of the vehicle **108**, environmental data regarding the environment in which the vehicle **108** is operating (e.g., weather, road, traffic, construction, or other conditions). Such data may be transmitted from the vehicle **108** or the mobile computing device **110** via radio links **183** (and/or via the network **130**) to the server **140**. The server **140** may receive the data directly or indirectly (i.e., via a wired or wireless link **183***e* to the network **130**) from one or more vehicles **182** or mobile computing devices **184**. Upon receiving the data, the server **140** may process the data to determine one or more risk levels associated with the vehicle **108**.

In some embodiments, a plurality of risk levels associated with operation of the vehicle **108** may be determined based upon the received data, using methods similar to those discussed elsewhere herein, and a total risk level associated with the vehicle **108** may be determined based upon the plurality of risk levels. In other embodiments, the server **140** may directly determine a total risk level based upon the received data. Such risk levels may be used for vehicle navigation, vehicle control, control hand-offs between the vehicle and driver, settings adjustments, driver alerts, accident avoidance, insurance policy generation or adjustment, and/or other processes as described elsewhere herein.

In some aspects, computer-implemented methods for monitoring the use of a vehicle **108** having one or more autonomous operation features and/or adjusting an insurance policy associated with the vehicle **108** may be provided. In some embodiments, the mobile computing device **110** and/or on-board computer **114** may have a Data Application installed thereon, as described above. Such Data Application may be executed by one or more processors of the mobile computing device **110** and/or on-board computer **114** to, with the customer's permission or affirmative consent, collect the sensor data, determine the telematics data, receive the feature use levels, and transmit the information to the remote server **140**. The Data Application may similarly perform or cause to be performed any other functions or operations described herein as being controlled by the mobile computing device **110** and/or on-board computer **114**.

The telematics data may include data regarding one or more of the following regarding the vehicle **108**: acceleration, braking, speed, heading, and/or location. The telematics data may further include information regarding one or more of the following: time of day of vehicle operation, road conditions in a vehicle environment in which the vehicle is operating, weather conditions in the vehicle environment, and/or traffic conditions in the vehicle environment. In some embodiments, the one or more sensors **120** of the mobile computing device **110** may include one or more of the following sensors disposed within the mobile computing device **110**: an accelerometer array, a camera, a microphone, and/or a geolocation unit (e.g., a GPS receiver). In further embodiments, one or more of the sensors **120** may be communicatively connected to the mobile computing device **110** (such as through a wireless communication link).

The feature use levels may be received by the mobile computing device **110** from the on-board computer **114** via yet another radio link **183** between the mobile computing device **110** and the on-board computer **114**, such as link **116**. The feature use levels may include data indicating adjustable settings for at least one of the one or more autonomous operation features. Such adjustable settings may affect operation of the at least one of the one or more autonomous operation features in controlling an aspect of vehicle operation, as described elsewhere herein.

In some embodiments, the method may further including receiving environmental information regarding the vehicle's environment at the mobile computing device **110** and/or on-board computer **114** via another radio link **183** or wireless communication channel. Such environmental information may also be transmitted to the remote server **140** via the radio link **183** and may be used by the remote server **140** in determining the total risk level. In some embodiments, the remote server **140** may receive part or all of the environmental information through the network **130** from sources other than the mobile computing device **110** and/or on-board computer **114**. Such sources may include third-party data sources, such as weather or traffic information services. The environmental data may include one or more of the following: road conditions, weather conditions, nearby traffic conditions, type of road, construction conditions, location of pedestrians, movement of pedestrians, movement of other obstacles, signs, traffic signals, or availability of autonomous communications from external sources. The environmental data may similarly include any other data regarding a vehicle environment described elsewhere herein.

In further embodiments, the method may include collecting addition telematics data and/or information regarding feature use levels at a plurality of additional mobile computing devices **184** associated with a plurality of additional vehicles **182**. Such additional telematics data and/or information regarding feature use levels may be transmitted from the plurality of additional mobile computing devices **184** to the remote server **140** via a plurality of radio links **183** and received at one or more processors of the remote server **140**. The remote server **140** may further base the determination of the total risk level at least in part upon the additional telematics data and/or feature use levels. Some embodiments of the methods described herein may include determining, adjusting, generating, rating, or otherwise perform-

ing actions necessary for creating or updating an insurance policy associated with the vehicle **108**.

Autonomous Vehicle Insurance Policies

The disclosure herein relates in part to insurance policies for vehicles with autonomous operation features. Accordingly, as used herein, the term "vehicle" may refer to any of a number of motorized transportation devices. A vehicle may be a car, truck, bus, train, boat, plane, motorcycle, snowmobile, other personal transport devices, etc. Also as used herein, an "autonomous operation feature" of a vehicle means a hardware or software component or system operating within the vehicle to control an aspect of vehicle operation without direct input from a vehicle operator once the autonomous operation feature is enabled or engaged. Autonomous operation features may include semi-autonomous operation features configured to control a part of the operation of the vehicle while the vehicle operator control other aspects of the operation of the vehicle.

The term "autonomous vehicle" means a vehicle including at least one autonomous operation feature, including semi-autonomous vehicles. A "fully autonomous vehicle" means a vehicle with one or more autonomous operation features capable of operating the vehicle in the absence of or without operating input from a vehicle operator. Operating input from a vehicle operator excludes selection of a destination or selection of settings relating to the one or more autonomous operation features. Autonomous and semi-autonomous vehicles and operation features may be classified using the five degrees of automation described by the National Highway Traffic Safety Administration's.

Additionally, the term "insurance policy" or "vehicle insurance policy," as used herein, generally refers to a contract between an insurer and an insured. In exchange for payments from the insured, the insurer pays for damages to the insured which are caused by covered perils, acts, or events as specified by the language of the insurance policy. The payments from the insured are generally referred to as "premiums," and typically are paid by or on behalf of the insured upon purchase of the insurance policy or over time at periodic intervals.

Although the exemplary embodiments discussed herein relate to automobile insurance policies, it should be appreciated that an insurance provider may offer or provide one or more different types of insurance policies. Other types of insurance policies may include, for example, commercial automobile insurance, inland marine and mobile property insurance, ocean marine insurance, boat insurance, motorcycle insurance, farm vehicle insurance, aircraft or aviation insurance, and other types of insurance products.

Autonomous Automobile Insurance

Some aspects of some embodiments described herein may relate to assessing and pricing insurance based upon autonomous (or semi-autonomous) operation of the vehicle **108**. Risk levels and/or insurance policies may be assessed, generated, or revised based upon the use of autonomous operation features or the availability of autonomous operation features in the vehicle **108**. Additionally, risk levels and/or insurance policies may be assessed, generated, or revised based upon the effectiveness or operating status of the autonomous operation features (i.e., degree to which the features are operating as intended or are impaired, damaged, or otherwise prevented from full and ordinary operation). Thus, information regarding the capabilities or effectiveness of the autonomous operation features available to be used or actually used in operation of the vehicle **108** may be used in risk assessment and insurance policy determinations.

Insurance providers currently develop a set of rating factors based upon the make, model, and model year of a vehicle. Models with better loss experience receive lower factors, and thus lower rates. One reason that this current rating system cannot be used to assess risk for vehicles using autonomous technologies is that many autonomous operation features vary for the same vehicle model. For example, two vehicles of the same model may have different hardware features for automatic braking, different computer instructions for automatic steering, and/or different artificial intelligence system versions. The current make and model rating may also not account for the extent to which another "driver," in this case the vehicle itself, is controlling the vehicle. The present embodiments may assess and price insurance risks at least in part based upon autonomous operation features that replace actions of the driver. In a way, the vehicle-related computer instructions and artificial intelligence may be viewed as a "driver."

Insurance policies, including insurance premiums, discounts, and rewards, may be updated, adjusted, and/or determined based upon hardware or software functionality, and/or hardware or software upgrades, associated with autonomous operation features. Insurance policies, including insurance premiums, discounts, etc. may also be updated, adjusted, and/or determined based upon the amount of usage and/or the type(s) of the autonomous or semi-autonomous technology employed by the vehicle. In one embodiment, performance of autonomous driving software and/or sophistication of artificial intelligence utilized in the autonomous operation features may be analyzed for each vehicle. An automobile insurance premium may be determined by evaluating how effectively the vehicle may be able to avoid and/or mitigate crashes and/or the extent to which the driver's control of the vehicle is enhanced or replaced by the vehicle's software and artificial intelligence.

When pricing a vehicle with autonomous operation features, artificial intelligence capabilities, rather than human decision making, may be evaluated to determine the relative risk of the insurance policy. This evaluation may be conducted using multiple techniques. Autonomous operation feature technology may be assessed in a test environment, in which the ability of the artificial intelligence to detect and avoid potential crashes may be demonstrated experimentally. For example, this may include a vehicle's ability to detect a slow-moving vehicle ahead and/or automatically apply the brakes to prevent a collision. Additionally, actual loss experience of the software in question may be analyzed. Vehicles with superior artificial intelligence and crash avoidance capabilities may experience lower insurance losses in real driving situations. Results from both the test environment and/or actual insurance losses may be compared to the results of other autonomous software packages and/or vehicles lacking autonomous operation features to determine relative risk levels or risk factors for one or more autonomous operation features. To determine such risk levels or factors, the control decisions generated by autonomous operation features may be assessed to determine the degree to which actual or shadow control decisions are expected to succeed in avoiding or mitigating vehicle accidents. This risk levels or factors may be applicable to other vehicles that utilize the same or similar autonomous operation features and may, in some embodiments, be applied to vehicle utilizing similar features (such as other software versions), which may require adjustment for differences between the features.

Emerging technology, such as new iterations of artificial intelligence systems or other autonomous operation features,

may be priced by combining an individual test environment assessment with actual losses corresponding to vehicles with similar autonomous operation features. The entire vehicle software and artificial intelligence evaluation process may be conducted with respect to each of various autonomous operation features. A risk level or risk factor associated with the one or more autonomous operation features of the vehicle could then be determined and applied when pricing insurance for the vehicle. In some embodiments, the driver's past loss experience and/or other driver risk characteristics may not be considered for fully autonomous vehicles, in which all driving decisions are made by the vehicle's artificial intelligence. Risks associated with the driver's operation of the vehicle may, however, be included in embodiments in which the driver controls some portion of vehicle operation in at least some circumstances.

In one embodiment, a separate portion of the automobile insurance premium may be based explicitly on the effectiveness of the autonomous operation features. An analysis of how the artificial intelligence of autonomous operation features facilitates avoiding accidents and/or mitigates the severity of accidents in order to build a database and/or model of risk assessment. After which, automobile insurance risk and/or premiums (as well as insurance discounts, rewards, and/or points) may be adjusted based upon autonomous or semi-autonomous vehicle functionality, such as by individual autonomous operation features or groups thereof. In one aspect, an evaluation may be performed of how artificial intelligence, and the usage thereof, impacts automobile accidents and/or automobile insurance claims. Such analysis may be based upon data from a plurality of autonomous vehicles operating in ordinary use, or the analysis may be based upon tests performed upon autonomous vehicles and/or autonomous operation feature test units.

The adjustments to automobile insurance rates or premiums based upon the autonomous or semi-autonomous vehicle-related functionality or technology may take into account the impact of such functionality or technology on the likelihood of a vehicle accident or collision occurring or upon the likely severity of such accident or collision. For instance, a processor may analyze historical accident information and/or test data involving vehicles having autonomous or semi-autonomous functionality. Factors that may be analyzed and/or accounted for that are related to insurance risk, accident information, or test data may include the following: (1) point of impact; (2) type of road; (3) time of day; (4) weather conditions; (5) road construction; (6) type/length of trip; (7) vehicle style; (8) level of pedestrian traffic; (9) level of vehicle congestion; (10) atypical situations (such as manual traffic signaling); (11) availability of internet connection for the vehicle; and/or other factors. These types of factors may also be weighted according to historical accident information, predicted accidents, vehicle trends, test data, and/or other considerations.

Automobile insurance premiums, rates, discounts, rewards, refunds, points, etc. may be adjusted based upon the percentage of time or vehicle usage that the vehicle is the driver, i.e., the amount of time a specific driver uses each type of autonomous operation feature. In other words, insurance premiums, discounts, rewards, etc. may be adjusted based upon the percentage of vehicle usage during which the autonomous or semi-autonomous functionality is in use. For example, automobile insurance risks, premiums, discounts, etc. for an automobile having one or more autonomous operation features may be adjusted and/or set based upon the percentage of vehicle usage that the one or more individual autonomous operation features are in use, which may include an assessment of settings used for the autonomous operation features. In some embodiments, such automobile insurance risks, premiums, discounts, etc. may be further set or adjusted based upon availability, use, or quality of Vehicle-to-Vehicle (V2V) wireless communication to a nearby vehicle also employing the same or other type(s) of autonomous communication features.

Insurance premiums, rates, ratings, discounts, rewards, special offers, points, programs, refunds, claims, claim amounts, etc. may be adjusted for, or may otherwise take into account, the foregoing functionalities, technologies, or aspects of the autonomous operation features of vehicles, as described elsewhere herein. For instance, insurance policies may be updated based upon autonomous or semi-autonomous vehicle functionality; V2V wireless communication-based autonomous or semi-autonomous vehicle functionality; and/or vehicle-to-infrastructure or infrastructure-to-vehicle wireless communication-based autonomous or semi-autonomous vehicle functionality.

Machine Learning

Machine learning techniques have been developed that allow parametric or nonparametric statistical analysis of large quantities of data. Such machine learning techniques may be used to automatically identify relevant variables (i.e., variables having statistical significance or a sufficient degree of explanatory power) from data sets. This may include identifying relevant variables or estimating the effect of such variables that indicate actual observations in the data set. This may also include identifying latent variables not directly observed in the data, viz. variables inferred from the observed data points. In some embodiments, the methods and systems described herein may use machine learning techniques to identify and estimate the effects of observed or latent variables such as time of day, weather conditions, traffic congestion, interaction between autonomous operation features, or other such variables that influence the risks associated with autonomous or semi-autonomous vehicle operation.

Some embodiments described herein may include automated machine learning to determine risk levels, identify relevant risk factors, optimize autonomous or semi-autonomous operation, optimize routes, determine autonomous operation feature effectiveness, predict user demand for a vehicle, determine vehicle operator or passenger illness or injury, evaluate sensor operating status, predict sensor failure, evaluate damage to a vehicle, predict repairs to a vehicle, predict risks associated with manual vehicle operation based upon the driver and environmental conditions, recommend optimal or preferred autonomous operation feature usage, estimate risk reduction or cost savings from feature usage changes, determine when autonomous operation features should be engaged or disengaged, determine whether a driver is prepared to resume control of some or all vehicle operations, and/or determine other events, conditions, risks, or actions as described elsewhere herein. Although the methods described elsewhere herein may not directly mention machine learning techniques, such methods may be read to include such machine learning for any determination or processing of data that may be accomplished using such techniques. In some embodiments, such machine-learning techniques may be implemented automatically upon occurrence of certain events or upon certain conditions being met. Use of machine learning techniques, as described herein, may begin with training a machine learning program, or such techniques may begin with a previously trained machine learning program.

A processor or a processing element may be trained using supervised or unsupervised machine learning, and the machine learning program may employ a neural network, which may be a convolutional neural network, a deep learning neural network, or a combined learning module or program that learns in two or more fields or areas of interest. Machine learning may involve identifying and recognizing patterns in existing data (such as autonomous vehicle system, feature, or sensor data, autonomous vehicle system control signal data, vehicle-mounted sensor data, mobile device sensor data, and/or telematics, image, or radar data) in order to facilitate making predictions for subsequent data (again, such as autonomous vehicle system, feature, or sensor data, autonomous vehicle system control signal data, vehicle-mounted sensor data, mobile device sensor data, and/or telematics, image, or radar data). Models may be created based upon example inputs of data in order to make valid and reliable predictions for novel inputs.

Additionally or alternatively, the machine learning programs may be trained by inputting sample data sets or certain data into the programs, such as autonomous system sensor and/or control signal data, and other data discuss herein. The machine learning programs may utilize deep learning algorithms primarily focused on pattern recognition, and may be trained after processing multiple examples. The machine learning programs may include Bayesian program learning (BPL), voice recognition and synthesis, image or object recognition, optical character recognition, and/or natural language processing—either individually or in combination. The machine learning programs may also include natural language processing, semantic analysis, automatic reasoning, and/or machine learning.

In supervised machine learning, a processing element may be provided with example inputs and their associated outputs, and may seek to discover a general rule that maps inputs to outputs, so that when subsequent novel inputs are provided the processing element may, based upon the discovered rule, accurately predict the correct or a preferred output. In unsupervised machine learning, the processing element may be required to find its own structure in unlabeled example inputs. In one embodiment, machine learning techniques may be used to extract the control signals generated by the autonomous systems or sensors, and under what conditions those control signals were generated by the autonomous systems or sensors.

The machine learning programs may be trained with autonomous system data, autonomous sensor data, and/or vehicle-mounted or mobile device sensor data to identify actions taken by the autonomous vehicle before, during, and/or after vehicle collisions; identify who was behind the wheel of the vehicle (whether actively driving, or riding along as the autonomous vehicle autonomously drove); identify actions taken by the human driver and/or autonomous system, and under what (road, traffic, congestion, or weather) conditions those actions were directed by the autonomous vehicle or the human driver; identify damage (or the extent of damage) to insurable vehicles after an insurance-related event or vehicle collision; and/or generate proposed insurance claims for insured parties after an insurance-related event.

The machine learning programs may be trained with autonomous system data, autonomous vehicle sensor data, and/or vehicle-mounted or mobile device sensor data to identify preferred (or recommended) and actual control signals relating to or associated with, for example, whether to apply the brakes; how quickly to apply the brakes; an amount of force or pressure to apply the brakes; how much to increase or decrease speed; how quickly to increase or decrease speed; how quickly to accelerate or decelerate; how quickly to change lanes or exit; the speed to take while traversing an exit or entrance ramp; at what speed to approach a stop sign or light; how quickly to come to a complete stop; and/or how quickly to accelerate from a complete stop.

After training, machine learning programs (or information generated by such machine learning programs) may be used to evaluate additional data. Such data may be related to tests of new autonomous operation feature or versions thereof, actual operation of an autonomous vehicle, or other similar data to be analyzed or processed. The trained machine learning programs (or programs utilizing models, parameters, or other data produced through the training process) may then be used for determining, assessing, analyzing, predicting, estimating, evaluating, or otherwise processing new data not included in the training data. Such trained machine learning programs may, thus, be used to perform part or all of the analytical functions of the methods described elsewhere herein.

Other Matters

In some aspect, customers may opt-in to a rewards, loyalty, or other program. The customers may allow a remote server to collect sensor, telematics, vehicle, mobile device, and other types of data discussed herein. With customer permission or affirmative consent, the data collected may be analyzed to provide certain benefits to customers. For instance, insurance cost savings may be provided to lower risk or risk averse customers. Recommendations that lower risk or provide cost savings to customers may also be generated and provided to customers based upon data analysis. The other functionality discussed herein may also be provided to customers in return for them allowing collection and analysis of the types of data discussed herein.

Although the text herein sets forth a detailed description of numerous different embodiments, it should be understood that the legal scope of the invention is defined by the words of the claims set forth at the end of this patent. The detailed description is to be construed as exemplary only and does not describe every possible embodiment, as describing every possible embodiment would be impractical, if not impossible. One could implement numerous alternate embodiments, using either current technology or technology developed after the filing date of this patent, which would still fall within the scope of the claims.

It should also be understood that, unless a term is expressly defined in this patent using the sentence "As used herein, the term '_____' is hereby defined to mean . . . " or a similar sentence, there is no intent to limit the meaning of that term, either expressly or by implication, beyond its plain or ordinary meaning, and such term should not be interpreted to be limited in scope based upon any statement made in any section of this patent (other than the language of the claims). To the extent that any term recited in the claims at the end of this disclosure is referred to in this disclosure in a manner consistent with a single meaning, that is done for sake of clarity only so as to not confuse the reader, and it is not intended that such claim term be limited, by implication or otherwise, to that single meaning. Finally, unless a claim element is defined by reciting the word "means" and a function without the recital of any structure, it is not intended that the scope of any claim element be interpreted based upon the application of 35 U.S.C. § 112(f).

Throughout this specification, plural instances may implement components, operations, or structures described as a

single instance. Although individual operations of one or more methods are illustrated and described as separate operations, one or more of the individual operations may be performed concurrently, and nothing requires that the operations be performed in the order illustrated. Structures and functionality presented as separate components in example configurations may be implemented as a combined structure or component. Similarly, structures and functionality presented as a single component may be implemented as separate components. These and other variations, modifications, additions, and improvements fall within the scope of the subject matter herein.

Additionally, certain embodiments are described herein as including logic or a number of routines, subroutines, applications, or instructions. These may constitute either software (code embodied on a non-transitory, tangible machine-readable medium) or hardware. In hardware, the routines, etc., are tangible units capable of performing certain operations and may be configured or arranged in a certain manner. In example embodiments, one or more computer systems (e.g., a standalone, client or server computer system) or one or more modules of a computer system (e.g., a processor or a group of processors) may be configured by software (e.g., an application or application portion) as a module that operates to perform certain operations as described herein.

In various embodiments, a module may be implemented mechanically or electronically. Accordingly, the term "module" should be understood to encompass a tangible entity, be that an entity that is physically constructed, permanently configured (e.g., hardwired), or temporarily configured (e.g., programmed) to operate in a certain manner or to perform certain operations described herein. Considering embodiments in which modules are temporarily configured (e.g., programmed), each of the modules need not be configured or instantiated at any one instance in time. For example, where the modules comprise a general-purpose processor configured using software, the general-purpose processor may be configured as respective different modules at different times. Software may accordingly configure a processor, for example, to constitute a particular module at one instance of time and to constitute a different module at a different instance of time.

Modules can provide information to, and receive information from, other modules. Accordingly, the described modules may be regarded as being communicatively coupled. Where multiple of such modules exist contemporaneously, communications may be achieved through signal transmission (e.g., over appropriate circuits and buses) that connect the modules. In embodiments in which multiple modules are configured or instantiated at different times, communications between such modules may be achieved, for example, through the storage and retrieval of information in memory structures to which the multiple modules have access. For example, one module may perform an operation and store the output of that operation in a memory device to which it is communicatively coupled. A further module may then, at a later time, access the memory device to retrieve and process the stored output. Modules may also initiate communications with input or output devices, and can operate on a resource (e.g., a collection of information).

The various operations of example methods described herein may be performed, at least partially, by one or more processors that are temporarily configured (e.g., by software) or permanently configured to perform the relevant operations. Whether temporarily or permanently configured, such processors may constitute processor-implemented modules that operate to perform one or more operations or functions. The modules referred to herein may, in some example embodiments, comprise processor-implemented modules.

Similarly, the methods or routines described herein may be at least partially processor-implemented. For example, at least some of the operations of a method may be performed by one or more processors or processor-implemented modules. The performance of certain of the operations may be distributed among the one or more processors, not only residing within a single machine, but deployed across a number of machines. In some example embodiments, the processor or processors may be located in a single location (e.g., within a home environment, an office environment or as a server farm), while in other embodiments the processors may be distributed across a number of locations.

The performance of certain of the operations may be distributed among the one or more processors, not only residing within a single machine, but deployed across a number of machines. In some example embodiments, the one or more processors or processor-implemented modules may be located in a single geographic location (e.g., within a home environment, an office environment, or a server farm). In other example embodiments, the one or more processors or processor-implemented modules may be distributed across a number of geographic locations.

Unless specifically stated otherwise, discussions herein using words such as "processing," "computing," "calculating," "determining," "presenting," "displaying," or the like may refer to actions or processes of a machine (e.g., a computer) that manipulates or transforms data represented as physical (e.g., electronic, magnetic, or optical) quantities within one or more memories (e.g., volatile memory, non-volatile memory, or a combination thereof), registers, or other machine components that receive, store, transmit, or display information. Some embodiments may be described using the expression "coupled" and "connected" along with their derivatives. For example, some embodiments may be described using the term "coupled" to indicate that two or more elements are in direct physical or electrical contact. The term "coupled," however, may also mean that two or more elements are not in direct contact with each other, but yet still co-operate or interact with each other.

As used herein any reference to "one embodiment" or "an embodiment" means that a particular element, feature, structure, or characteristic described in connection with the embodiment may be included in at least one embodiment. The appearances of the phrase "in one embodiment" in various places in the specification are not necessarily all referring to the same embodiment. In addition, use of the "a" or "an" are employed to describe elements and components of the embodiments herein. This is done merely for convenience and to give a general sense of the description. This description, and the claims that follow, should be read to include one or at least one and the singular also includes the plural unless it is obvious that it is meant otherwise.

As used herein, the terms "comprises," "comprising," "includes," "including," "has," "having" or any other variation thereof, are intended to cover a non-exclusive inclusion. For example, a process, method, article, or apparatus that comprises a list of elements is not necessarily limited to only those elements but may include other elements not expressly listed or inherent to such process, method, article, or apparatus.

This detailed description is to be construed as exemplary only and does not describe every possible embodiment, as describing every possible embodiment would be impractical, if not impossible. One could implement numerous

alternate embodiments, using either current technology or technology developed after the filing date of this application. Upon reading this disclosure, those of skill in the art will appreciate still additional alternative structural and functional designs for system and a method for assigning mobile device data to a vehicle through the disclosed principles herein. Thus, while particular embodiments and applications have been illustrated and described, it is to be understood that the disclosed embodiments are not limited to the precise construction and components disclosed herein. Various modifications, changes and variations, which will be apparent to those skilled in the art, may be made in the arrangement, operation and details of the method and apparatus disclosed herein without departing from the spirit and scope defined in the appended claims.

The particular features, structures, or characteristics of any specific embodiment may be combined in any suitable manner and in any suitable combination with one or more other embodiments, including the use of selected features without corresponding use of other features. In addition, many modifications may be made to adapt a particular application, situation or material to the essential scope and spirit of the present invention. It is to be understood that other variations and modifications of the embodiments of the present invention described and illustrated herein are possible in light of the teachings herein and are to be considered part of the spirit and scope of the present invention.

While the preferred embodiments of the invention have been described, it should be understood that the invention is not so limited and modifications may be made without departing from the invention. The scope of the invention is defined by the appended claims, and all devices that come within the meaning of the claims, either literally or by equivalence, are intended to be embraced therein. It is therefore intended that the foregoing detailed description be regarded as illustrative rather than limiting, and that it be understood that it is the following claims, including all equivalents, that are intended to define the spirit and scope of this invention. By way of example, and not limitation, the disclosure herein contemplates at least the following aspects:

In one aspect, a computer-implemented method for detecting sensor malfunctions in an autonomous vehicle may be provided. The method may include (1) receiving, from a plurality of sensors of the autonomous vehicle, sensor data including a plurality of signals from the plurality of sensors during operation of the autonomous vehicle; (2) selecting, by one or more processors, a first sensor from the plurality of sensors; obtaining, by one or more processors, a first set of signals associated with the first sensor from the plurality of signals; (3) determining, by one or more processors, a first sensor range indicative of a range of signal values associated with proper functioning of the first sensor; (4) determining, by one or more processors, that the first sensor is malfunctioning when at least one signal in the first set of signals associated with the first sensors is outside the first sensor range; and/or (5) performing, by one or more processors, an action in response to determining that the first sensor is malfunctioning. The method may include additional, less, or alternate actions, including those discussed elsewhere herein.

For instance, the first sensor range may be determined based upon a baseline plurality of signals received from the first sensor during a plurality of previous operation sessions of the autonomous vehicle. Additionally or alternatively, the first sensor range may be determined by predicting values of signals associated with the first sensor based upon a second set of signals from the plurality of signals, wherein the second set of signals may be received from at least one second sensor of the plurality of sensors other than the first sensor during operation of the autonomous vehicle.

Determining that the first sensor is malfunctioning may be based upon a determination of an inconsistency between the first set of signals and the second set of signals. Additionally or alternatively, the first sensor may be selected in response to additional sensor data indicating a collision involving the autonomous vehicle. The first sensor may be disposed within an area of the autonomous vehicle involved in the collision. That said, the first sensor may be determined to be malfunctioning without any indication of a vehicle collision.

The method may include determining, by one or more processors, a cause of the first sensor's malfunction based upon the received sensor data. The received sensor data may include a plurality of signals at different times from each of the plurality of sensors, each signal being associated with a timestamp indicating a time associated with the signal. Based upon the received sensor data, the method may include determining, via the one or more processors, an apportionment of liability for a cost of repair or replacement of the first sensor between one or more of: a manufacturer of the first sensor, a manufacturer of the autonomous vehicle, an installer of the first sensor, an insurer of the autonomous vehicle, an owner of the autonomous vehicle, or an owner, operator, or insurer of a second vehicle. The performed action may include automatically scheduling, via the one or more processors, repair or replacement of the first sensor by a third party based upon the determined apportionment of liability.

The method may include receiving additional information associated with a plurality of other vehicles regarding a plurality of sensor malfunctions; and determining, via the one or more processors, one or more repairs to correct the first sensor's malfunctioning based upon the received sensor data and additional information. Determining that the first sensor is malfunctioning may include determining a probability of malfunctioning based upon the sensor data. The probability of malfunctioning may indicate a probability of future failure of the first sensor based upon comparison with data from a plurality of other vehicles. Additionally or alternatively, the first set of signals is outside the first sensor range when the first set of signals includes one or more indications that data from the first sensor is unavailable.

Performing the action may include generating, via the one or more processors, an alert regarding the first sensor's malfunctioning; and/or presenting the alert to one or more of the following: an operator of the autonomous vehicle or an owner of the autonomous vehicle. The alert may include a recommendation to take one or more of the following actions: repair the first sensor, replace the first sensor, avoid using one or more autonomous operation features of the autonomous vehicle, and/or avoid using one or more settings associated with the one or more autonomous operation features. The alert may, additionally or alternatively, include an indication of an adjustment to a cost or coverage associated with an insurance policy covering operation of the autonomous vehicle based upon the determination that the first sensor is malfunctioning. The adjustment to the cost or coverage associated with the insurance policy may be based upon a determination of an increase in a risk based upon the first sensor's malfunctioning. Additionally or alternatively, the adjustment may be contingent upon usage of one or more autonomous operation features of the autonomous vehicle that utilize data from the first sensor to control the autonomous vehicle.

Performing the action further may further include (1) identifying, via the one or more processors, one or more autonomous operation features of the autonomous vehicle that utilize data from the first sensor to control the autonomous vehicle; (2) determining, via the one or more processors, a risk level for each of the identified autonomous operation features, wherein each risk level indicates a risk associated with operation of the autonomous operation feature when the first sensor is malfunctioning; and/or (3) limiting, via the one or more processors, operation of at least one of the identified one or more autonomous operation features based upon the associated risk level exceeding a safety threshold level. Limiting operation of the at least one of the identified one or more autonomous operation features may include disabling operation of the at least one of the identified one or more autonomous operation features. Additionally or alternatively the plurality of sensors may include a sensor of a smart infrastructure component.

In another aspect, a computer system configured to detect sensor malfunctions in an autonomous vehicle may be provided. The system may comprise (i) one or more processors; (ii) a communication module adapted to communicate with a plurality of sensors of the autonomous vehicle; and (iii) a non-transitory program memory coupled to the one or more processors and storing executable instructions. The instructions, when executed by the one or more processors, may cause the computer system to (1) receive sensor data including a plurality of signals from the plurality of sensors during operation of the autonomous vehicle; (2) select a first sensor from the plurality of sensors; (3) obtain a first set of signals associated with the first sensor from the plurality of signals; (4) determine a first sensor range indicative of a range of signal values associated with proper functioning of the first sensor; (5) determine that the first sensor is malfunctioning when at least one signal in the first set of signals associated with the first sensors is outside the first sensor range; and/or (6) perform an action in response to determining that the first sensor is malfunctioning. The system may include additional, less, or alternate components that perform additional, less, or alternate actions, including those discussed elsewhere herein.

For instance, the first sensor range may be determined based upon a baseline plurality of signals received from the first sensor during a plurality of previous operation sessions of the autonomous vehicle. Additionally or alternatively, the first sensor range may be determined by predicting values of signals associated with the first sensor based upon a second set of signals from the plurality of signals, wherein the second set of signals is received from at least one second sensor of the plurality of sensors other than the first sensor during operation of the autonomous vehicle. The determination that the first sensor is malfunctioning may be based upon a determination of an inconsistency between the first set of signals and the second set of signals.

The instructions, when executed by the one or more processors, may cause the computer system to receive additional information associated with a plurality of other vehicles regarding a plurality of sensor malfunctions; and/or determine one or more repairs to correct the first sensor's malfunctioning based upon the received sensor data and additional information.

To perform the action, the instructions, when executed by the one or more processors, may cause the computer system to (1) identify one or more autonomous operation features of the autonomous vehicle that utilize data from the first sensor to control the autonomous vehicle; (2) determine a risk level for each of the identified autonomous operation features, wherein each risk level indicates a risk associated with operation of the autonomous operation feature when the first sensor is malfunctioning; and/or (3) limit operation of at least one of the identified one or more autonomous operation features based upon the associated risk level exceeding a safety threshold level. Limiting operation of the at least one of the identified one or more autonomous operation features may include disabling operation of the at least one of the identified one or more autonomous operation features.

What is claimed is:

1. A computer-implemented method for detecting sensor malfunctions in a smart home, comprising:

receiving, from a plurality of sensors of the smart home, sensor data including a plurality of signals from the plurality of sensors during operation of the smart home;

analyzing, by one or more processors, the sensor data to detect an event impacting the smart home;

selecting, by the one or more processors, a first sensor from one or more higher-level sensors based upon a hierarchy of sensors in order to test the one or more higher-level sensors for malfunctioning before lower-level sensors;

obtaining, by one or more processors, a first set of signals of the plurality of signals from the first sensor of the plurality of sensors;

determining, by one or more processors, a first sensor range indicative of a range of signal values associated with proper functioning of the first sensor, wherein the first sensor range is based upon specifications for the first sensor, historical data from the first sensor, or estimates of what the signal values should be for the first sensor;

determining, by one or more processors, that the first sensor is malfunctioning when at least one signal in the first set of signals associated with the first sensors is outside the first sensor range; and

performing, by one or more processors, an action in response to determining that the first sensor is malfunctioning.

2. The computer-implemented method of claim **1**, wherein the estimates of what the signal values should be for the first sensor is determined by predicting values of signals associated with the first sensor based upon a second set of signals from the plurality of signals, wherein the second set of signals is received from at least one second sensor of the plurality of sensors other than the first sensor during operation of the smart home.

3. The computer-implemented method of claim **2**, wherein the determination that the first sensor is malfunctioning is based upon a determination of an inconsistency between the first set of signals and the second set of signals.

4. The computer-implemented method of claim **1**, wherein performing the action further comprises:

generating, via the one or more processors, an alert regarding the first sensor's malfunctioning; and

at least one of (i) presenting the alert on a display of a smart home controller or (ii) transmitting the alert to a personal electronic device.

5. A computer system configured to detect sensor malfunctions in a smart home, comprising:

one or more processors; and

a non-transitory program memory coupled to the one or more processors and storing executable instructions that, when executed by the one or more processors, cause the computer system to:

receive sensor data including a plurality of signals from the plurality of sensors during operation of the smart home;

analyze the sensor data to detect an event impacting the smart home;

analyze a hierarchy of sensors;

select a first sensor from one or more higher-level sensors based upon the hierarchy of sensors so the one or more higher-level sensors are tested for malfunctioning before lower-level sensors;

obtain a first set of signals of the plurality of signals from the first sensor of the plurality of sensors;

determine a first sensor range indicative of a range of signal values associated with proper functioning of the first sensor, wherein the first sensor range is based upon historical data from the first sensor;

determine that the first sensor is malfunctioning when at least one signal in the first set of signals associated with the first sensors is outside the first sensor range; and

perform an action in response to determining that the first sensor is malfunctioning.

6. The computer system of claim **5**, the non-transitory program memory coupled to the one or more processors and storing executable instructions that, when executed by the one or more processors, cause the computer system to select the first sensor.

7. The computer system of claim **5**, wherein to perform the action, the non-transitory program memory coupled to the one or more processors and storing executable instructions that, when executed by the one or more processors, cause the computer system to:

generate an alert regarding the first sensor's malfunctioning; and

present the alert on a display of a smart home controller, transmit the alert to a personal electronic device, or both.

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