US00RE46982E

(19) **United States**

(12) **Reissued Patent**

Ferguson et al.

(10) **Patent Number: US RE46,982 E**

(45) **Date of Reissued Patent: *Aug. 7, 2018**

(54) **CONTROLLING A VEHICLE HAVING INADEQUATE MAP DATA**

(71) Applicant: **Waymo LLC**, Mountain View, CA (US)

(72) Inventors: **David I. Ferguson**, San Francisco, CA (US); **Dmitri Dolgov**, Mountain View, CA (US)

(73) Assignee: **Waymo LLC**, Mountain View, CA (US)

(*) Notice: This patent is subject to a terminal disclaimer.

(21) Appl. No.: **15/367,115**

(22) Filed: **Dec. 1, 2016**

Related U.S. Patent Documents

Reissue of:

(64) Patent No.: **8,903,591**
Issued: **Dec. 2, 2014**
Appl. No.: **14/164,565**
Filed: **Jan. 27, 2014**

U.S. Applications:

(63) Continuation of application No. 13/943,867, filed on Jul. 17, 2013, now Pat. No. 8,676,430, which is a continuation of application No. 13/465,348, filed on May 7, 2012, now Pat. No. 8,521,352.

(51) **Int. Cl.**
G01C 22/00 (2006.01)
G05D 1/02 (2006.01)

(52) **U.S. Cl.**
CPC ***G05D 1/0272*** (2013.01)

(58) **Field of Classification Search**
CPC G05D 1/0272
USPC 701/25
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,036,935	A	8/1991	Kohara	
5,122,957	A	6/1992	Hattori	
5,307,419	A *	4/1994	Tsujino	G05D 1/0223 348/119
5,774,069	A *	6/1998	Tanaka et al.	340/903
5,875,412	A *	2/1999	Sulich	G01C 21/3415 340/988

(Continued)

OTHER PUBLICATIONS

Non-Final Office Action dated Sep. 12, 2017 for U.S. Appl. No. 15/367,112.

(Continued)

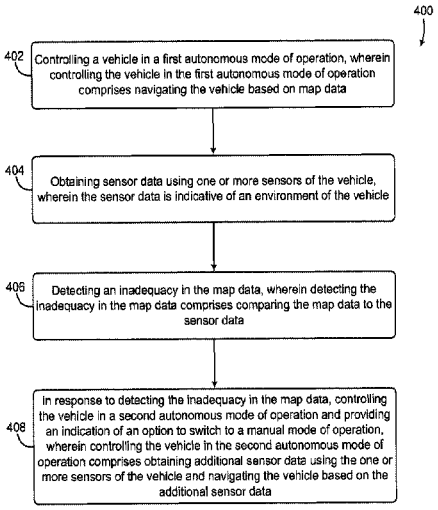
Primary Examiner — Michelle Tarae

(74) *Attorney, Agent, or Firm* — McDonnell Boehnen Hulbert & Berghoff LLP

(57) **ABSTRACT**

A vehicle can be controlled in a first autonomous mode of operation by at least navigating the vehicle based on map data. Sensor data can be obtained using one or more sensors of the vehicle. The sensor data can be indicative of an environment of the vehicle. An inadequacy in the map data can be detected by at least comparing the map data to the sensor data. In response to detecting the inadequacy in the map data, the vehicle can be controlled in a second autonomous mode of operation and a user can be prompted to switch to a manual mode of operation. The vehicle can be controlled in the second autonomous mode of operation by at least obtaining additional sensor data using the one or more sensors of the vehicle and navigating the vehicle based on the additional sensor data.

20 Claims, 7 Drawing Sheets



(56) **References Cited**

U.S. PATENT DOCUMENTS

6,151,539	A *	11/2000	Bergholz	G01S 13/931 340/435
6,292,752	B1 *	9/2001	Franke	G01S 13/931 340/435
7,268,700	B1	9/2007	Hoffberg	
7,510,038	B2 *	3/2009	Kaufmann	B62D 1/286 180/167
7,890,231	B2 *	2/2011	Saito	B62D 1/28 701/301
7,979,172	B2 *	7/2011	Breed	G08G 1/161 701/117
8,078,338	B2 *	12/2011	Pack et al.	701/1
8,108,092	B2 *	1/2012	Phillips et al.	701/23
8,618,922	B2 *	12/2013	Debouk	B60W 50/035 340/439
2003/0058444	A1 *	3/2003	Nara et al.	356/394
2003/0134648	A1 *	7/2003	Reed et al.	455/456
2009/0248231	A1 *	10/2009	Kamiya	701/23
2010/0098295	A1 *	4/2010	Zhang	G06K 9/00798 382/103
2010/0246889	A1 *	9/2010	Nara	G06K 9/00798 382/104
2010/0256836	A1 *	10/2010	Mudalige	701/2
2011/0118900	A1 *	5/2011	Uchida	G05D 1/0297 701/2
2011/0190972	A1 *	8/2011	Timmons	G01C 21/34 701/31.4

OTHER PUBLICATIONS

Non-Final Office Action dated Sep. 22, 2017 for U.S. Appl. No. 15/367,118.

Non-Final Office Action dated Sep. 22, 2017 for U.S. Appl. No. 15/367,122.

* cited by examiner

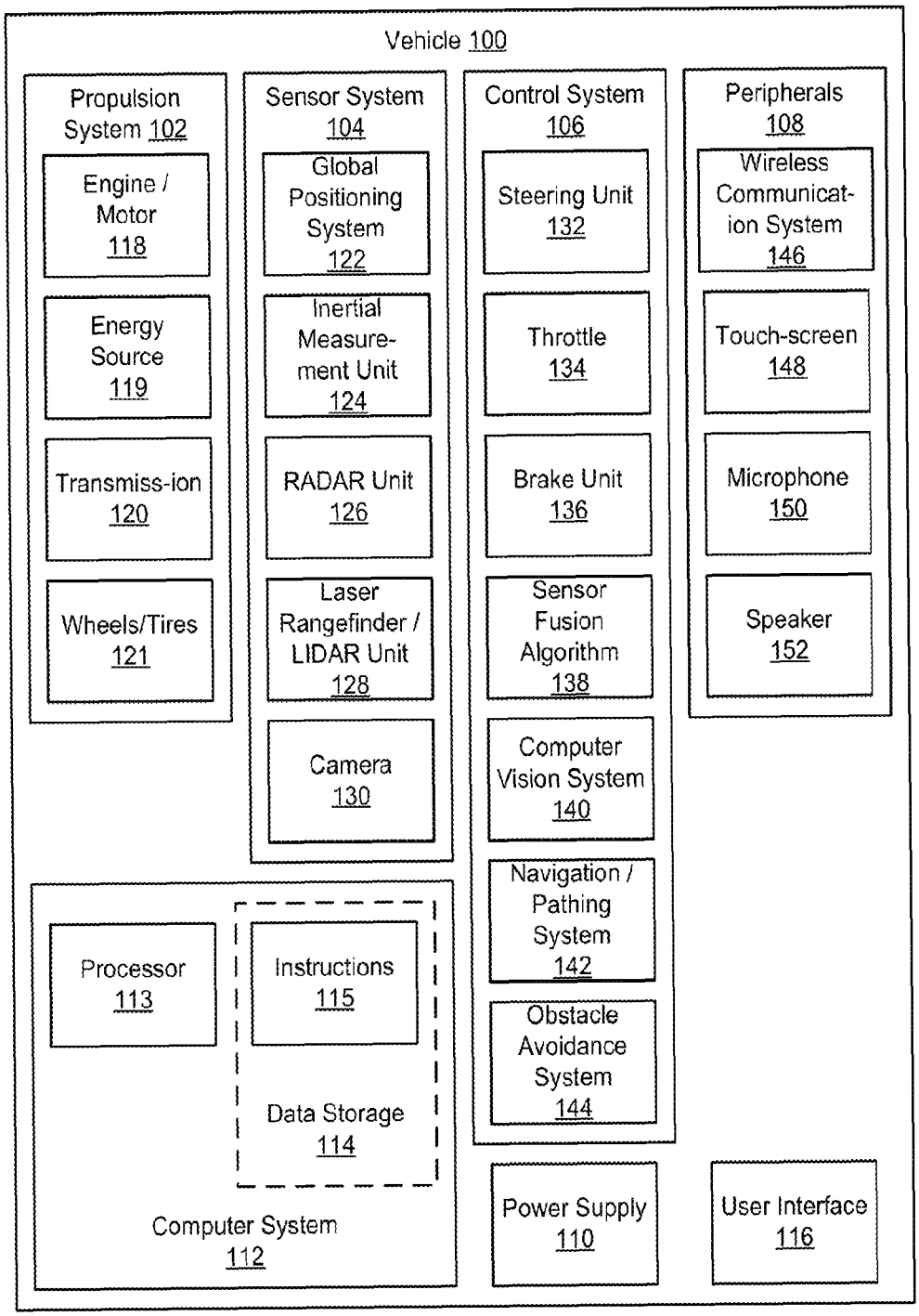

Vehicle 100
Propulsion System 102
Engine / Motor 118
Energy Source 119
Transmiss-ion 120
Wheels/Tires 121
Sensor System 104
Global Positioning System 122
Inertial Measure-ment Unit 124
RADAR Unit 126
Laser Rangefinder / LIDAR Unit 128
Camera 130
Control System 106
Steering Unit 132
Throttle 134
Brake Unit 136
Sensor Fusion Algorithm 138
Computer Vision System 140
Navigation / Pathing System 142
Obstacle Avoidance System 144
Peripherals 108
Wireless Communicat-ion System 146
Touch-screen 148
Microphone 150
Speaker 152
Processor 113
Instructions 115
Data Storage 114
Computer System 112
Power Supply 110
User Interface 116

Figure 1

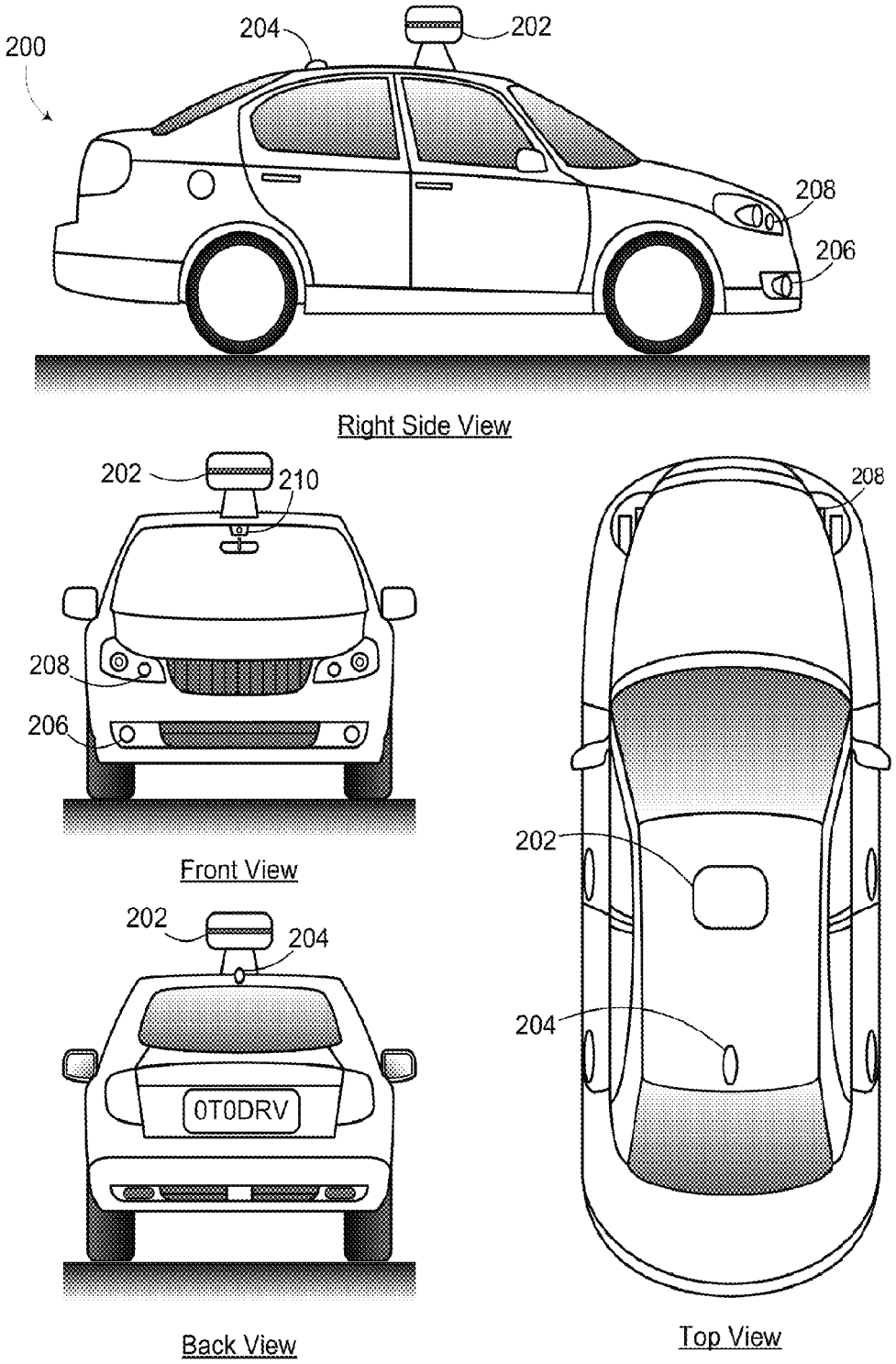

200
204
202
208
206
Right Side View
202
210
208
206
Front View
208
202
204
Top View
202
204
0T0DRV
Back View

Figure 2

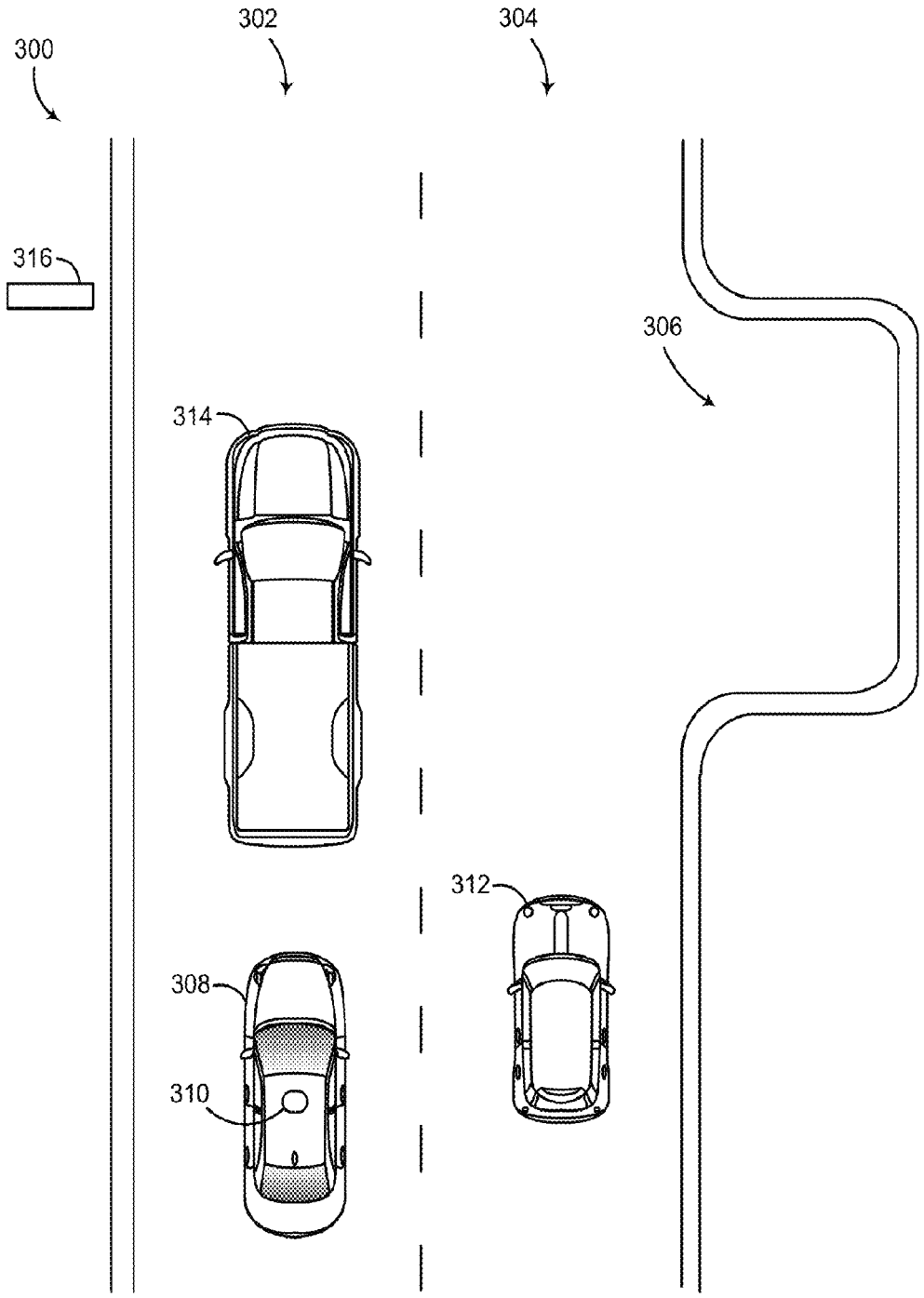


Figure 3A

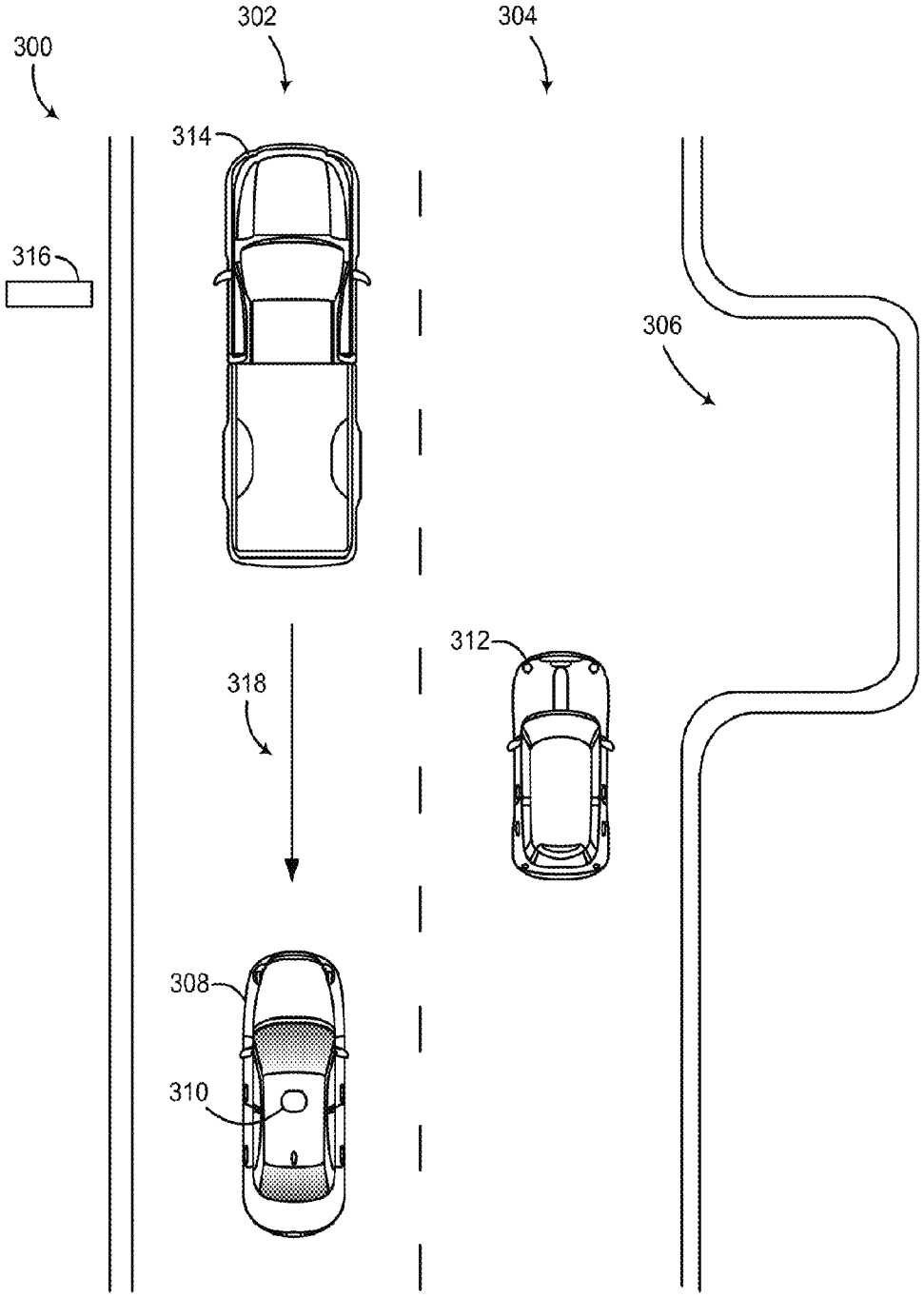


Figure 3B

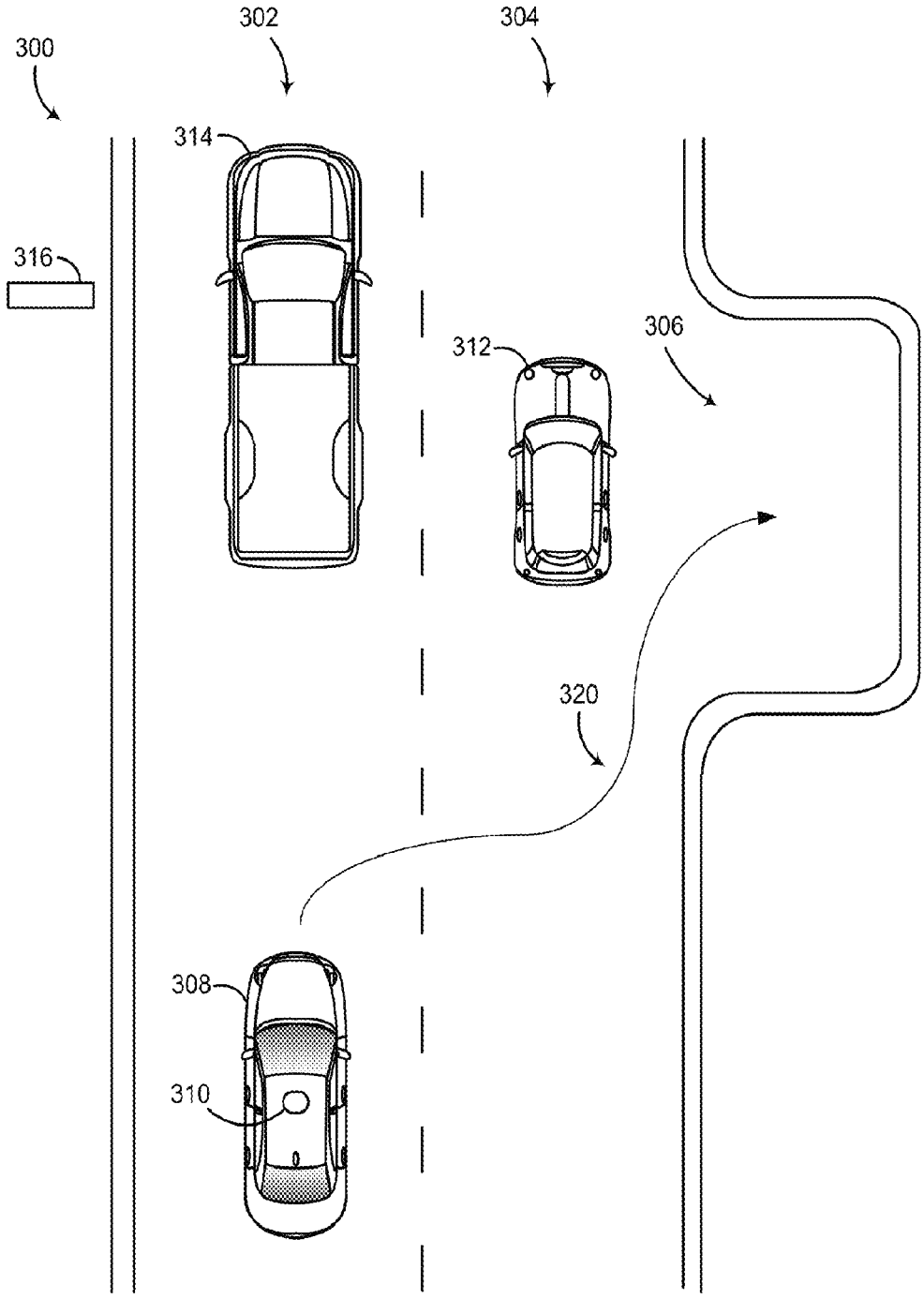


Figure 3C

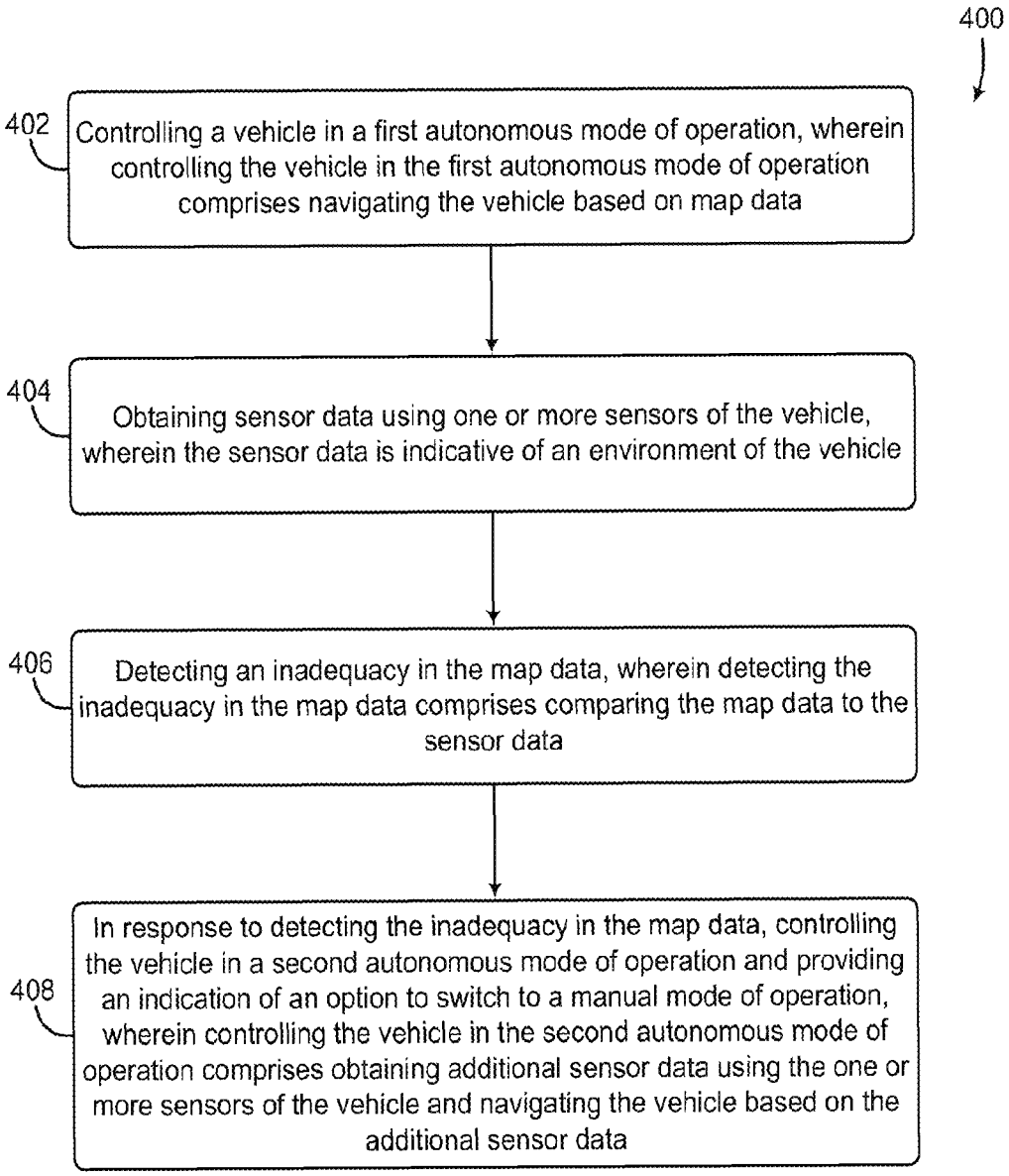

400
402
Controlling a vehicle in a first autonomous mode of operation, wherein controlling the vehicle in the first autonomous mode of operation comprises navigating the vehicle based on map data
404
Obtaining sensor data using one or more sensors of the vehicle, wherein the sensor data is indicative of an environment of the vehicle
406
Detecting an inadequacy in the map data, wherein detecting the inadequacy in the map data comprises comparing the map data to the sensor data
408
In response to detecting the inadequacy in the map data, controlling the vehicle in a second autonomous mode of operation and providing an indication of an option to switch to a manual mode of operation, wherein controlling the vehicle in the second autonomous mode of operation comprises obtaining additional sensor data using the one or more sensors of the vehicle and navigating the vehicle based on the additional sensor data

Figure 4

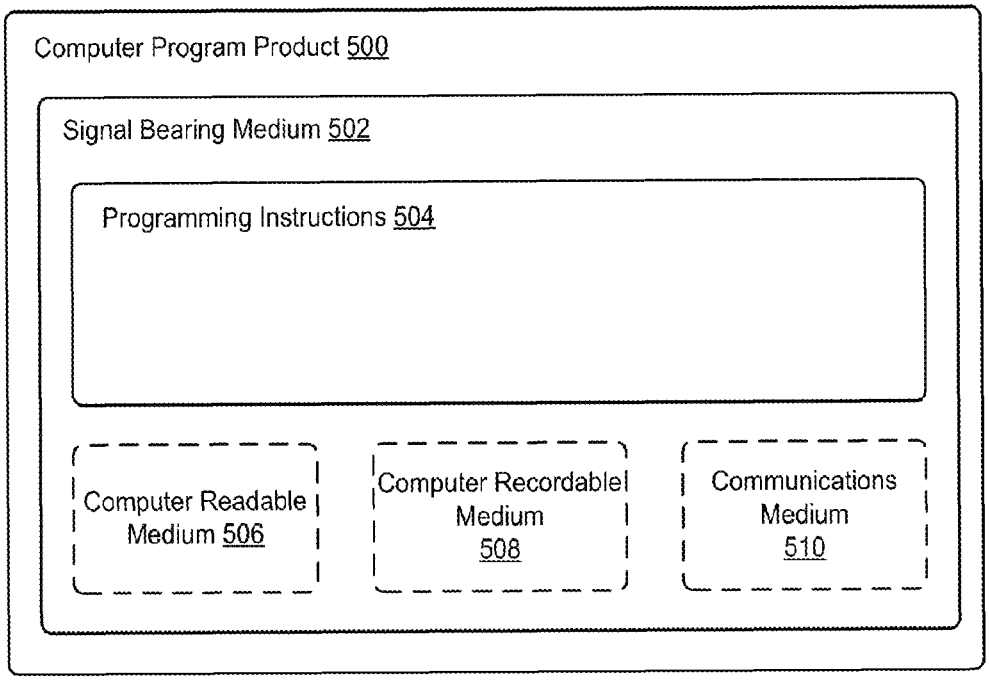

Computer Program Product 500
Signal Bearing Medium 502
Programming Instructions 504
Computer Readable Medium 506
Computer Recordable Medium 508
Communications Medium 510

Figure 5

CONTROLLING A VEHICLE HAVING INADEQUATE MAP DATA

Matter enclosed in heavy brackets [ ] appears in the original patent but forms no part of this reissue specification; matter printed in italics indicates the additions made by reissue; a claim printed with strikethrough indicates that the claim was canceled, disclaimed, or held invalid by a prior post-patent action or proceeding.

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation of U.S. patent application Ser. No. 13/943,867 filed on Jul. 17, 2013, and entitled "Controlling a Vehicle Having Inadequate Map Data," which is a continuation of U.S. patent application Ser. No. 13/465,348 (now U.S. Pat. No. 8,521,352), filed on May 7, 2012, and entitled "Controlling a Vehicle Having Inadequate Map Data," all of which are herein incorporated by reference as if fully set forth in this description.

BACKGROUND

Some vehicles are configured to operate in an autonomous mode in which the vehicle navigates through an environment with little or no input from a driver. Such a vehicle typically includes sensors that are configured to sense information about the environment. The vehicle can use the sensed information to navigate through the environment. For example, if the sensors sense that the vehicle is approaching an obstacle, the vehicle can navigate around the obstacle.

SUMMARY

In a first aspect, a method is provided. The method includes controlling a vehicle in a first autonomous mode of operation. Controlling the vehicle in the first autonomous mode of operation includes navigating the vehicle based on map data. The method includes obtaining sensor data using one or more sensors of the vehicle. The sensor data is indicative of an environment of the vehicle. The method includes detecting an inadequacy in the map data. Detecting the inadequacy in the map data includes comparing the map data to the sensor data. The method includes, in response to detecting the inadequacy in the map data, controlling the vehicle in a second autonomous mode of operation and prompting a user to switch to a manual mode of operation. Controlling the vehicle in the second autonomous mode of operation includes obtaining additional sensor data using the one or more sensors of the vehicle and navigating the vehicle based on the additional sensor data.

In a second aspect, a vehicle is provided. The vehicle includes at least one sensor and a computer system. The at least one sensor is configured to obtain first sensor data. The first sensor data is indicative of an environment of the vehicle when the vehicle is in a first autonomous mode of operation. The at least one sensor is configured to obtain second sensor data. The second sensor data is indicative of an environment of the vehicle when the vehicle is in a second autonomous mode of operation. The computer system is configured to control the vehicle in the first autonomous mode of operation by at least navigating the vehicle based on map data. The computer system is configured to detect an inadequacy in the map data by at least comparing the map data to the first sensor data. The computer system is configured to, in response to detecting the inadequacy in the map data, (i) control the vehicle in the second autonomous mode of operation by at least navigating the vehicle based on the second sensor data, and (ii) prompt a user to switch to a manual mode of operation.

In a third aspect, a non-transitory computer-readable medium is provided. The medium includes stored instructions that are executable by a computer system to cause the computer system to perform functions. The functions include controlling a vehicle in a first autonomous mode of operation. Controlling the vehicle in the first autonomous mode of operation includes navigating the vehicle based on map data. The functions include receiving sensor data from one or more sensors of the vehicle. The sensor data is indicative of an environment of the vehicle. The functions include detecting an inadequacy in the map data. Detecting the inadequacy in the map data includes comparing the map data to the sensor data. The functions include, in response to detecting the inadequacy in the map data, controlling the vehicle in a second autonomous mode of operation and prompting a user to switch to a manual mode of operation. Controlling the vehicle in the second autonomous mode of operation includes obtaining additional sensor data using the one or more sensors of the vehicle and navigating the vehicle based on the additional sensor data.

BRIEF DESCRIPTION OF THE FIGURES

FIG. **1** illustrates a functional block diagram of a vehicle, according to an example embodiment.

FIG. **2** illustrates a vehicle, according to an example embodiment.

FIGS. **3**A-**3**C illustrate a scenario showing a navigation of a vehicle having inadequate map data, according to an example embodiment.

FIG. **4** illustrates an example of a method for controlling a vehicle, according to an example embodiment.

FIG. **5** illustrates a conceptual view of a computer program product, according to an example embodiment.

DETAILED DESCRIPTION

Some vehicles can operate autonomously with the use of map data. For example, a person, such as an on-board passenger, can cause a vehicle to switch from manual operation to autonomous operation. In the autonomous mode, the vehicle can use map data to navigate the vehicle. Map data can be, for example, predetermined data that relates to the route of a vehicle or otherwise relates to the surroundings of the vehicle. For example, map data can relate to traffic conditions, road conditions, route information, positioning information, or combinations of these.

In some situations, map data can be inadequate for use in autonomously navigating a vehicle. For example, map data can become outdated over time due to changing road conditions, or the map data may not include sufficient detail about the present or future environment of the vehicle. If the vehicle determines that the map data is inadequate, the vehicle can rely on other sources of information to operate autonomously, or the vehicle can switch (or indicate an option to switch) to a manual mode.

This disclosure provides techniques for operating a vehicle when the map data has been determined to be inadequate. In some implementations, a computer system can control a vehicle in a first autonomous mode of operation (or simply "first autonomous mode"). In the first autonomous mode, the computer system can navigate the

vehicle based on map data. While the vehicle is in the first autonomous mode, the computer system can obtain sensor data using one or more sensors of the vehicle. The sensor data can be indicative of an environment of the vehicle. The sensor data can represent nearby objects, such as, for example, traffic signs, lane markers, other vehicles, or pedestrians. The sensor data can also, or instead, represent observations or calculations such as, for example, traffic patterns and geometries of one or more roads near the vehicle.

The computer system can compare the map data to the sensor data in order to detect an inadequacy in the map data. For example, the inadequacy in the map data can be an inconsistency between the sensor data and the map data. In response to detecting the inadequacy in the map data, the computer system can control the vehicle in a second autonomous mode of operation (or simply "second autonomous mode"), and provide an indication of an option to switch to a manual mode of operation (or simply "manual mode"). The indication can serve to notify a person, such as an on-board passenger, of the inadequacy in the map data, and to suggest that the person take control of the vehicle, such as by causing the vehicle to switch to the manual mode. In the second autonomous mode, the computer system can obtain additional sensor data using the one or more sensors, and can navigate the vehicle based on the additional sensor data.

In addition, in the second autonomous mode, the computer system can take precautions, such as, for example, reducing a speed of the vehicle, causing the vehicle to maintain a safer than usual distance from another vehicle, or the like. In this way, the computer system can take measures to enhance the safety of a person, such as an on-board passenger, while the computer system waits for the person to take control of the vehicle.

In the second autonomous mode, if the computer system detects an inactivity in relation to the option to switch to the manual mode, then the computer system can control the vehicle in a third autonomous mode of operation (or simply "third autonomous mode"). For example, if the computer system detects that a predetermined period has passed without the vehicle switching to the manual mode, then the computer system can control the vehicle in the third autonomous mode. In the third autonomous mode, the computer system can obtain further sensor data using the one or more sensors, and can navigate the vehicle based on the further sensor data. In addition, in the third autonomous mode, the computer system can navigate the vehicle with diminished or no use of the map data. In the third autonomous mode, the computer system can take further precautions, such as, for example, stopping the vehicle, navigating the vehicle to a shoulder of a road, following another vehicle at a safe distance, enabling the vehicle's hazard lights, or sending a message to alert appropriate authorities. In this way, when an on-board passenger does not take control of the vehicle in the second autonomous mode, the vehicle can be safely maneuvered and/or parked.

Also discussed are examples of systems that can be used in connection with some disclosed implementations. In some implementations, a system can take the form of an automobile or another suitable vehicle. Suitable vehicles include a car, truck, motorcycle, bus, boat, airplane, helicopter, lawn mower, earthmover, snowmobile, recreational vehicle, amusement park vehicle, farm equipment, construction equipment, tram, golf cart, train, or trolley. Other vehicles are possible as well.

FIG. **1** illustrates a functional block diagram of a vehicle **100**. The vehicle **100** can be configured to operate in one of several autonomous modes of operation or in a manual mode of operation. Depending on the desired implementation, the autonomous modes can include one or more of a first autonomous mode, a second autonomous mode, and a third autonomous mode. The first, second, and third autonomous modes are discussed below in further detail. While the vehicle **100** is in one of the autonomous modes, the vehicle **100** can be configured to operate without a need for human interaction. While the vehicle **100** is in the manual mode, the vehicle **100** can be configured to operate under the control of a person, such as an on-board passenger. Other implementations are possible. For example, the vehicle can be configured to operate in a semi-autonomous mode, in which the vehicle can be configured to perform some operations without a need for human interaction and to perform some operations under the control of a person, such as an on-board passenger.

With reference to FIG. **1**, the vehicle **100** can include various subsystems such as a propulsion system **102**, a sensor system **104**, a control system **106**, one or more peripherals **108**, as well as a power supply **110**, a computer system **112**, and a user interface **116**. The vehicle **100** can include more or fewer subsystems and each subsystem can include multiple elements. Further, each of the subsystems and elements of the vehicle **100** can be interconnected. Thus, one or more of the described functions of the vehicle **100** can be divided into additional functional or physical components, or combined into fewer functional or physical components. In some further examples, additional functional or physical components can be added to the illustration of FIG. **1**.

The propulsion system **102** can include components operable to provide powered motion for the vehicle **100**. Depending on the implementation, the propulsion system **102** can include an engine/motor **118**, an energy source **119**, a transmission **120**, and wheels/tires **121**. The engine/motor **118** can be any combination of an internal combustion engine, an electric motor, steam engine, Stirling engine, or another engines/motor. In some implementations, the engine/motor **118** can be configured to convert the energy source **119** into mechanical energy. In some implementations, the propulsion system **102** can include multiple types of engines and/or motors. For instance, a gas-electric hybrid car can include a gasoline engine and an electric motor. Other implementations are possible.

The energy source **119** can represent a source of energy that can, in full or in part, power the engine/motor **118**. That is, the engine/motor **118** can be configured to convert the energy source **119** into mechanical energy. Examples of energy sources **119** include gasoline, diesel, other petroleum-based fuels, propane, other compressed gas-based fuels, ethanol, solar panels, batteries, and other sources of electrical power. The energy source **119** can also, or instead, include any combination of fuel tanks, batteries, capacitors, and flywheels. The energy source **119** can also provide energy for other systems of the vehicle **100**.

The transmission **120** can include elements that are operable to transmit mechanical power from the engine/motor **118** to the wheels/tires **121**. To this end, the transmission **120** can include a gearbox, clutch, differential, and drive shafts. The transmission **120** can include other elements. The drive shafts can include one or more axles that can be coupled to the one or more wheels/tires **121**.

The wheels/tires **121** of the vehicle **100** can be of various forms, such as, for example, those of a unicycle, motorcycle,

tricycle, or car. Other wheel/tire forms are possible, such as those including six or more wheels. Any combination of the wheels/tires **121** of the vehicle **100** can be operable to rotate differentially with respect to other wheels/tires **121**. The wheels/tires **121** can represent at least one wheel that is attached to the transmission **120** and at least one tire coupled to a rim of the wheel that can make contact with the driving surface. The wheels/tires **121** can include any combination of metal and rubber, or another combination of materials.

The sensor system **104** can include a number of sensors configured to sense information about an environment of the vehicle **100**. For example, the sensor system **104** can include a Global Positioning System (GPS) **122**, an inertial measurement unit (IMU) **124**, a RADAR unit **126**, a laser rangefinder/LIDAR unit **128**, and a camera **130**, among other types of sensors. In addition, the sensor system **104** can include sensors that are configured to monitor internal systems of the vehicle **100**. Examples include an O_2 monitor, fuel gauge, and engine oil temperature. In addition, the sensor system **104** can include sensors that can sense conditions in a passenger cabin of the vehicle **100**, if the vehicle **100** is equipped with a passenger cabin. Examples include physiological sensors and cameras. Other sensors are possible as well.

The GPS **122** can include any number and combination of sensors, and can be configured to estimate a geographic location of the vehicle **100**. To this end, the GPS **122** can include a transceiver that is operable to provide information regarding the position of the vehicle **100** with respect to the Earth.

The IMU **124** can include any number and combination of sensors (for example, accelerometers and gyroscopes), and can be configured to sense position and orientation changes of the vehicle **100** based on inertial acceleration.

The RADAR unit **126** can represent a system that utilizes radio signals to sense objects within the environment of the vehicle **100**. In some implementations, in addition to sensing the objects, the RADAR unit **126** can additionally be configured to sense the speed of the objects, the heading of the objects, or both.

The laser rangefinder or LIDAR unit **128** can include any number and combination of sensors, and can be configured to sense objects in the environment of the vehicle **100** by using lasers. Depending on the implementation, the laser rangefinder/LIDAR unit **128** can include one or more laser sources, laser scanners, and detectors, among other components. The laser rangefinder/LIDAR unit **128** can be configured to operate in a coherent detection mode (for example, by using heterodyne detection) or an incoherent detection mode.

The camera **130** can include any number and combination of devices, and can be configured to capture images of the environment of the vehicle **100**. The camera **130** can be a still camera or a video camera.

The control system **106** can be configured to control operation of the vehicle **100** and its components. To this end, the control system **106** can include various elements, including a steering unit **132**, a throttle **134**, a brake unit **136**, a sensor fusion algorithm **138**, a computer vision system **140**, a navigation/pathing system **142**, and an obstacle avoidance system **144**.

The steering unit **132** can include any number and combination of devices, and can be configured to adjust the heading of the vehicle **100**.

The throttle **134** can be configured to control, for instance, the operating speed of the engine/motor **118** and, in turn, control the speed of the vehicle **100**.

The brake unit **136** can include any number and combination of devices, and can be configured to decelerate the vehicle **100**. The brake unit **136** can apply friction to slow the wheels/tires **121**. In some implementations, the brake unit **136** can convert the kinetic energy of the wheels/tires **121** to electric current. Other implementations are possible.

The sensor fusion algorithm **138** can be an algorithm or a computer program product storing an algorithm, and can be configured to receive data from the sensor system **104** as an input. The data can include, for example, data representing information sensed at the sensors of the sensor system **104**. The sensor fusion algorithm **138** can include, for instance, a Kalman filter, Bayesian network, or other algorithm. The sensor fusion algorithm **138** can further provide various assessments based on the data from the sensor system **104**. Depending on the implementation, the assessments can include evaluations of individual objects or features in the environment of the vehicle **100**, evaluation of a particular situation, or evaluations of possible impacts based on the particular situation. Other assessments are possible.

The computer vision system **140** can be any system that is operable to process and analyze images captured by the camera **130** in order to identify objects or features in the environment of the vehicle **100**. The objects or features can include, for example, traffic signals, traffic signs, roadway boundaries, and obstacles. The computer vision system **140** can use an object recognition algorithm, a Structure From Motion (SFM) algorithm, video tracking, and other computer vision techniques. In some implementations, the computer vision system **140** can be configured to map an environment, track objects, and estimate the speed of objects.

The navigation and pathing system **142** can be configured to determine a driving path for the vehicle **100**. The navigation and pathing system **142** can be configured to update the driving path dynamically while the vehicle **100** is in operation. In some implementations, the navigation and pathing system **142** can be configured to use map data to determine the driving path for the vehicle **100**. For example, the navigation and pathing system **142** can use data from the sensor fusion algorithm **138** or the GPS **122**, or from a different system or component of the vehicle **100**, to determine the driving path for the vehicle **100**.

The obstacle avoidance system **144** can represent a control system that is configured to identify, evaluate, and avoid or otherwise negotiate potential obstacles in the environment of the vehicle **100**.

The peripherals **108** can be configured to allow interaction between the vehicle **100** and external sensors, other vehicles, other computer systems, or a user. For example, the peripherals **108** can include a wireless communication system **146**, a touchscreen **148**, a microphone **150**, and a speaker **152**.

In some implementations, the peripherals **108** can enable a user of the vehicle **100** to interact with the user interface **116**. To this end, the touchscreen **148** can provide information to a user of vehicle **100**. For example, the touchscreen **148** can provide an indication of an option to switch from an autonomous mode of operation to a manual mode of operation. The user interface **116** can be operable to accept input from the user via the touchscreen **148**. The touchscreen **148** can be configured to sense at least one of a position and a movement of a user's finger via capacitive sensing, resistance sensing, or a surface acoustic wave process, among other possibilities. The touchscreen **148** can be capable of sensing finger movement in a direction parallel or planar to the touchscreen surface, in a direction normal to the touchscreen surface, or both, and can also be capable of sensing

a level of pressure applied to the touchscreen surface. The touchscreen **148** can be formed of one or more translucent or transparent insulating layers and one or more translucent or transparent conducting layers. The touchscreen **148** can take other forms as well.

In some implementations, the peripherals **108** can enable the vehicle **100** to communicate with devices in its environment. The microphone **150** can be configured to receive audio (for example, a voice command or other audio input) from a user of the vehicle **100**. Similarly, the speakers **152** can be configured to output audio to the user of the vehicle **100**. For example, the speakers **152** can provide an indication of an option to switch from an autonomous mode of operation to a manual mode of operation.

The wireless communication system **146** can be configured to wirelessly communicate with one or more devices directly or via a communication network. For example, the wireless communication system **146** can use 3G cellular communication, such as CDMA, EVDO, GSM/GPRS, or 4G cellular communication, such as WiMAX or LTE. In some implementations, the wireless communication system **146** can communicate with a wireless local area network (WLAN), for example, using WiFi. In some implementations, the wireless communication system **146** can communicate directly with a device, for example, using an infrared link, Bluetooth, or ZigBee. Other wireless protocols, such as various vehicular communication systems, are possible. For example, the wireless communication system **146** can include one or more dedicated short-range communications (DSRC) devices that can include public or private data communications between vehicles and roadside stations.

The power supply **110** can provide power to various components of the vehicle **100** and can represent, for example, a rechargeable lithium-ion or lead-acid battery. In some implementations, one or more banks of such batteries can be configured to provide electrical power. Other power supply materials and configurations are possible. In some implementations, the power supply **110** and energy source **119** can be implemented together, as in some all-electric cars.

Many or all of the functions of the vehicle **100** can be controlled by the computer system **112**. The computer system **112** can include at least one processor **113**, which can include at least one microprocessor. The at least one processor **113** can execute instructions **115** stored in a non-transitory computer-readable medium, such as the data storage **114**. The computer system **112** can also represent multiple computing devices that can control individual components or subsystems of the vehicle **100** in a distributed fashion.

In some implementations, the data storage **114** can contain instructions **115** (for example, program logic) that are executable by the processor **113** to execute various functions of vehicle **100**, including those described above in connection with FIG. **1** and those discussed below in connection with FIGS. **3**A-**3**C and **4**. The data storage **114** can contain additional instructions as well, including instructions to transmit data to, receive data from, interact with, and/or control one or more of the propulsion system **102**, the sensor system **104**, the control system **106**, and the peripherals **108**.

In addition to the instructions **115**, the data storage **114** can store map data, which can include roadway maps, path information, and road condition information, among other data. In some implementations, the map data can be used by the vehicle **100** and computer system **112** during the operation of the vehicle **100** in the autonomous, semi-autonomous, or manual modes. In some implementations, the map data can be selectively used by the vehicle **100** during the operation of the vehicle **100** in some of the autonomous modes, and can be used to a lesser extent during operation of the vehicle **100** in other autonomous modes.

The vehicle **100** can include a user interface **116** for providing information to or receiving input from a user of vehicle **100**. The user interface **116** can control or enable control of content and/or the layout of interactive images that can be displayed on the touchscreen **148**. Further, the user interface **116** can include one or more input/output devices within the set of peripherals **108**, such as the wireless communication system **146**, the touchscreen **148**, the microphone **150**, and the speaker **152**.

The computer system **112** can control functions of the vehicle **100** based on inputs received from various subsystems (for example, the propulsion system **102**, sensor system **104**, and control system **106**), as well as from the user interface **116**. For example, the computer system **112** can utilize input from the control system **106** in order to control the steering unit **132** to avoid an obstacle detected by the sensor system **104** and the obstacle avoidance system **144**. Depending upon the implementation, the computer system **112** can be operable to provide control over many aspects of the vehicle **100** and its subsystems.

The components of the vehicle **100** can be configured to work in an interconnected fashion with other components within or outside their respective systems. For instance, in some implementations, the camera **130** can capture a plurality of images that can represent information about a state of an environment of the vehicle **100** operating in an autonomous mode. The environment can include another vehicle, the road on which the vehicle **100** travels (including markings on the road), signs near the vehicle, pedestrians, and the like. The computer vision system **140** can recognize aspects of the environment based on object recognition models stored in data storage **114**.

In some implementations, the computer system **112** can control the vehicle **100** in one of several autonomous modes of operation, including first, second, and third autonomous modes. In the first autonomous mode, the computer system can navigate the vehicle based on map data, such as, for example, map data from the global positioning system **122**, map data that is stored to the data storage **114**, or map data that is received from the wireless communication system **146**. While the vehicle **100** is in the first autonomous mode, the computer system **112** can obtain sensor data using one or more sensors in the sensor system **104**. The sensor data can be indicative of an environment of the vehicle **100**. The sensor data can represent nearby objects, such as, for example, traffic signs, lane markers, other vehicles, or pedestrians. The sensor data can also, or instead, represent observations or calculations such as, for example, traffic patterns and road shapes near the vehicle **100**.

The computer system **112** can compare the map data to the sensor data in order to detect an inadequacy in the map data. For example, the inadequacy in the map data can be an inconsistency between the sensor data and the map data. In response to detecting the inadequacy in the map data, the computer system **112** can control the vehicle **100** in the second autonomous mode, and can provide an indication of an option to switch to the manual mode. For example, the indication can be provided by way of the touch screen **148**, the speaker **152**, and/or the user interface **116**. The indication can serve to notify a person, such as an on-board passenger, of the inadequacy in the map data, and to suggest that the person take control of the vehicle **100**, such as by causing the vehicle **100** to switch to the manual mode. In the second

autonomous mode, the computer system **112** can obtain additional sensor data using the sensor system **104**, and can navigate the vehicle **100** based on the additional sensor data.

Also, in the second autonomous mode, the computer system can take precautions, such as, for example, reducing a speed of the vehicle **100**, causing the vehicle **100** to maintain a safer than usual distance from other vehicles, or the like. In this way, the computer system **112** can take measures to enhance the safety of persons, such as on-board passengers, while the computer system **112** waits for a person to take control of the vehicle **100**.

In some implementations, in the second autonomous mode, if the computer system **112** detects an inactivity in relation to the option to switch to the manual mode, then the computer system **112** can control the vehicle **100** in the third autonomous mode. For example, if the computer system **112** detects that a predetermined period has passed without the vehicle **100** switching to the manual mode, then the computer system **112** can control the vehicle **100** in the third autonomous mode. In the third autonomous mode, the computer system **112** can obtain further sensor data using the one or more sensors, and can navigate the vehicle **100** based on the further sensor data. In addition, in the third autonomous mode, the computer system **112** can navigate the vehicle **100** with diminished or no use of the map data. In the third autonomous mode, the computer system **112** can take further precautions, such as, for example, stopping the vehicle **100** immediately, navigating the vehicle **100** to a shoulder of a road and then stopping the vehicle **100**, causing the vehicle **100** to follow another vehicle at a safe distance, enabling hazard lights of the vehicle **100**, or sending a message (for example, by way of the wireless communication system **146**) to alert appropriate authorities. In this way, when a person, such as an on-board passenger, does not take control of the vehicle **100**, the vehicle **100** can be safely maneuvered and/or parked.

Although FIG. **1** shows various components of the vehicle **100**, such as, for example, the wireless communication system **146**, the computer system **112**, the data storage **114**, and the user interface **116**, as being integrated into the vehicle **100**, one or more of these components can be mounted or associated separately from the vehicle **100**. For example, the data storage **114** can, in part or in full, exist separate from the vehicle **100**. Thus, the vehicle **100** can be provided in the form of device elements that can be located separately or together. The device elements that make up the vehicle **100** can be communicatively coupled together in a wired or wireless fashion.

FIG. **2** illustrates a vehicle **200**. The vehicle **200** can be similar or identical to the vehicle **100** discussed in reference to FIG. **1**. Although the vehicle **200** is illustrated in FIG. **2** as a car, other implementations are possible. For instance, the vehicle **200** can represent a truck, a van, a semi-trailer truck, a motorcycle, a golf cart, an off-road vehicle, or a farm vehicle, among other types of vehicles.

Depending on the implementation, the vehicle **200** can include a sensor unit **202**, a wireless communication system **204**, a LIDAR unit **206**, a laser rangefinder unit **208**, and a camera **210**. The elements of the vehicle **200** can include some or all of the elements described in connection with FIG. **1**.

The sensor unit **202** can include one or more different sensors configured to capture information about an environment of the vehicle **200**. For example, the sensor unit **202** can include any combination of cameras, RADARs, LIDARs, range finders, and acoustic sensors. Other types of sensors are possible. Depending on the implementation, the sensor unit **202** can include one or more movable mounts that can be operable to adjust the orientation of one or more sensors in the sensor unit **202**. In some implementations, the movable mount can include a rotating platform that can scan sensors so as to obtain information from each direction around the vehicle **200**. In another implementation, the movable mount of the sensor unit **202** can be moveable in a scanning fashion within a particular range of angles or azimuths. The sensor unit **202** can be mounted atop the roof of a car, for instance; however other mounting locations are possible. In addition, the sensors of sensor unit **202** can be distributed in different locations and need not be collocated in a single location. Some possible sensor types and mounting locations include the LIDAR unit **206** and the laser rangefinder unit **208**. In addition, each sensor of the sensor unit **202** can move or scan independently of other sensors of the sensor unit **202**.

The wireless communication system **204** can be located on a roof of the vehicle **200**, as depicted in FIG. **2**. In some implementations, the wireless communication system **204** can be located elsewhere. The wireless communication system **204** can include wireless transmitters and receivers that can be configured to communicate with devices external or internal to the vehicle **200**. In particular, the wireless communication system **204** can include transceivers that can be configured to communicate with other vehicles and/or computing devices, for instance, in a vehicular communication system or a roadway station. Examples of such vehicular communication systems include dedicated short-range communications (DSRC), radio frequency identification (RFID), and other proposed communication standards directed towards intelligent transport systems.

The camera **210** can be any camera (for example, a still camera or a video camera) that is configured to capture a plurality of images of the environment of the vehicle **200**. To this end, the camera **210** can be configured to detect visible light, or can be configured to detect light from other portions of the spectrum, such as infrared or ultraviolet light. Other types of cameras are possible as well.

The camera **210** can be a two-dimensional detector, or can have a three-dimensional spatial range. In some implementations, the camera **210** can be, for example, a range detector that is configured to generate a two-dimensional image indicating a distance from the camera **210** to a number of points in the environment. To this end, the camera **210** can use one or more range detecting techniques. For example, the camera **210** can use a structured light technique in which the vehicle **200** illuminates an object in the environment with a predetermined light pattern, such as a grid or checkerboard pattern and uses the camera **210** to detect a reflection of the predetermined light pattern from the object. Based on distortions in the reflected light pattern, the vehicle **200** can determine the distance to the points on the object. The predetermined light pattern can include infrared light or light of another wavelength. As another example, the camera **210** can use a laser scanning technique in which the vehicle **200** emits a laser and scans across a number of points on an object in the environment. While scanning the object, the vehicle **200** can use the camera **210** to detect a reflection of the laser from the object for each point. Based on a duration that it takes for the laser to reflect from the object at each point, the vehicle **200** can determine the distance to the points on the object. As yet another example, the camera **210** can use a time-of-flight technique in which the vehicle **200** emits a light pulse and uses the camera **210** to detect a reflection of the light pulse from an object at a number of points on the object. In particular, the camera **210** can

include a number of pixels, and each pixel can detect the reflection of the light pulse from a point on the object. Based on a duration it takes for the light pulse to reflect from the object at each point, the vehicle **200** can determine the distance to the points on the object. The light pulse can be a laser pulse. Other range detecting techniques are possible as well, including stereo triangulation, sheet-of-light triangulation, interferometry, and coded aperture techniques, among others. The camera **210** can take other forms as well.

The camera **210** can be mounted inside a front windshield of the vehicle **200**. Specifically, as illustrated, the camera **210** can capture images from a forward-looking view with respect to the vehicle **200**. Other mounting locations and viewing angles of the camera **210** are possible, either inside or outside the vehicle **200**.

The camera **210** can have associated optics that can be operable to provide an adjustable field of view. Further, the camera **210** can be mounted to the vehicle **200** with a movable mount that can be operable to vary a pointing angle of the camera **210**.

FIGS. **3**A-**3**C illustrate an example of a scenario **300** showing a navigation of a vehicle having inadequate map data. With reference to FIG. **3**A, the scenario **300** involves a roadway with a left lane **302**, a right lane **304**, and a shoulder **306**. In the left lane **302** is a vehicle **308**. Traveling in front of the vehicle **308** is a truck **314**, and traveling to the right of the vehicle **308** is a car **312**. Assume that in FIG. **3**A, the vehicle **308** is operating in a first autonomous mode. In the first autonomous mode, the vehicle **308** can be navigated based on map data. The map data can include, for example, roadway maps, path information, and road condition information, among other data. The map data can be received by the vehicle **308** while the vehicle is **308** is in motion or prior to the vehicle **308** being in motion. For example, the vehicle **308** can receive map data of a route in real-time, or can receive map data of the route in iterations as the vehicle **308** travels along the route. As another example, the vehicle **308** can receive map data prior to commencing the route. In other words, in some implementations, the map data can be generated and/or received prior to controlling the vehicle **308** in the first autonomous mode.

While the vehicle **308** is in the first autonomous mode, a computer system of the vehicle **308** can obtain sensor data using a sensor unit **310** of the vehicle **308** or any other sensor of the vehicle **308**. The sensor data can be indicative of the environment of the vehicle **308** and, accordingly, can represent such aspects of the environment as the roadway, the truck **314** or car **312**, and information on the road sign **316**. These examples are illustrative only; the sensor data can represent various other aspects of the environment of the vehicle **308**.

In addition, when the vehicle **308** is in the first autonomous mode, the vehicle's computer system can compare the map data to the sensor data in order to detect an inadequacy in the map data. In some implementations, the computer system can determine, based on the comparison, whether the difference between the map data and the sensor data exceeds a predetermined threshold. If the difference exceeds the threshold, then the computer system can determine that that the map data is inadequate. In some implementations, the map data can be compared to the sensor data in real-time. In some implementations, the map data can be compared to the sensor data outside real-time.

In response to detecting an inadequacy in the map data, the computer system of the vehicle **308** can control the vehicle **308** in a second autonomous mode, and can provide an indication of an option to switch to a manual mode. The indication can be any suitable indication, such as, for example, a notification by way of a display in a passenger cabin of the vehicle **308**, a speaker of the vehicle **308**, or a light indicator of the vehicle **308**.

Some of the examples above discuss an inadequacy in terms of inadequate map data. An inadequacy can also be found when there is simply no relevant map data for a given area. For example, the vehicle **308** may not receive map data for a given area, or may receive map data that does not include data for the given area.

FIG. **3**B shows the vehicle **308** operating in the second autonomous mode. In the second autonomous mode, the computer system of the vehicle **308** can obtain additional sensor data using the sensor unit **310** of the vehicle **308** or any other sensor of the vehicle **308**. The additional sensor data can be indicative of any aspect of the environment of the vehicle **308** and, accordingly, can represent such features of the environment as the truck **314**, the car **312**, the positions of the truck **314** and the car **314** relative to the vehicle **308**, the left lane **302** and the right lane **304** of the roadway, the boundary between the left and right lanes, and the information on the road sign **316**, for example. For example, in the second autonomous mode, the vehicle can continue to drive safely while transitioning control by estimating the shape and location of the current lane and road and using this information to stay within its lane. To do this lane/road estimation, the vehicle may incorporate several sources of information from sensors on the vehicle, such as features representing where the lane markers are, where other vehicles are traveling, and objects specific to road environments such as traffic signs, cones, and other markers. The vehicle can also take into account where other vehicles/objects are in its vicinity to maintain a safe distance from these vehicles/objects while transitioning control to the human driver. These examples are illustrative only; the additional sensor data can represent various other aspects of the environment of the vehicle **308**.

The vehicle **308** can be navigated based on the additional sensor data. In some implementations, the vehicle **308** can be navigated based on a message that conveys a condition of the environment of the vehicle **308**. For example, assume that the road sign **316** includes the message "Construction ahead: reduce speed to 20 MPH." The computer system of the vehicle **308** can accordingly reduce the speed of the vehicle **308** in accordance with the message on the road sign **316**. As another example, the computer system of the vehicle **308** can detect lane boundaries, such as, for example, the boundaries of the lane **302**, and can navigate the vehicle **308** to stay in the lane **302**. In some implementations, the computer system can navigate the vehicle **308** based on the additional sensor data and without using the map data. In some implementations, the computer system can navigate the vehicle **308** based on a combination of the additional sensor data and the map data. For example, the computer system of the vehicle **308** can use portions of the map data that are sufficiently consistent with the sensor data, and can use the sensor data to the exclusion of the map data when the sensor data and map data are sufficiently different from each other.

In some implementations, when the vehicle **308** is operating in the second autonomous mode, the computer system of the vehicle **308** can take precautions, such as, for example, reducing a speed of the vehicle **308**, causing the vehicle **308** to maintain a safer than usual distance from other vehicles, or the like. In this way, the computer system of the vehicle **308** can take measures to enhance the safety of persons, such as on-board passengers, while the computer

system waits for a person to respond to the indication of the option to switch to the manual mode. For example, as illustrated by arrow **318**, the vehicle **308** has slowed down and backed off from the truck **314**. Other implementations for taking precautions in the second autonomous mode are possible.

In some implementations, after the vehicle **308** begins to operate in the second autonomous mode, the computer system of the vehicle **308** can monitor for an inactivity in relation to the option to switch to the manual mode. If the computer system detects such an inactivity, then the computer system can control the vehicle **308** in a third autonomous mode. For example, if the computer system detects that a predetermined period has passed without the vehicle switching to the manual mode, then the computer system can control the vehicle in the third autonomous mode. As another example, the computer system can use sensors that are in or focused on the passenger cabin of the vehicle **308** to determine a condition of an on-board passenger. For instance, a camera in the passenger cabin can be used to determine whether an on-board passenger has moved (or has moved to a sufficient extent) after the indication was provided. In this way, the computer system of the vehicle **308** can detect the inactivity by detecting an inaction in the passenger cabin of the vehicle **308**. Other implementations are possible. For example, the computer system can use data from physiological sensors, such as, for example, heart rate monitors, to monitor for an inactivity.

FIG. **3**C shows the vehicle **308** operating in the third autonomous mode. In the third autonomous mode, the computer system of the vehicle **308** can obtain further sensor data using the sensor unit **310** or another sensor of the vehicle **308**, and can navigate the vehicle **308** based on the further sensor data. In some implementations, in the third autonomous mode, the computer system of the vehicle **308** can navigate the vehicle **308** with diminished or no use of the map data.

In some implementations, in the third autonomous mode, the computer system of the vehicle **308** can take or can cause the vehicle to take one or more precautious actions in addition to those taken, if any, in the second autonomous mode. As an example of a precautions action, the computer system of the vehicle **308** can immediately stop the vehicle **308**, assuming that the computer system determines that it is feasible and safe to do so. As another example of a precautions action, in the third autonomous mode, the computer system can determine a level of safety of parking the vehicle **308** at a location, such as, for example, the shoulder **306** of the roadway. If the computer system determines that the level of safety exceeds a target threshold, then the computer system can cause the vehicle **308** to navigate to the location and park the vehicle **308** at the location, as illustrated by arrow **320**. As yet another example of a precautions action, in the third autonomous mode, the computer system of the vehicle **308** can cause the vehicle **308** to follow another vehicle, such as the truck **314**, at a safe distance. In this way, the vehicle **308** can take advantage of the behavior of the other vehicle. The vehicle **308** can follow the other vehicle, for example, until the computer system determines that some condition or combination of conditions has been met. For example, the computer system of the vehicle **308** can cause the vehicle **308** to stop following the other vehicle upon a determination that it is no longer safe for the vehicle **308** to continue to follow the other vehicle, upon a determination that following the other vehicle has led or will lead the vehicle **308** sufficiently astray from a target path, or upon a determination of a safe location to park the vehicle **308**. As yet another example of a precautious action, in the third autonomous mode, the computer system of the vehicle **308** can enable hazard lights of the vehicle **308** and can reduce the speed of the vehicle **308**. As a further example of a precautions action, in the third autonomous mode, the computer system of the vehicle **308** can locate an area to park, for example, by way of a navigation system of the vehicle **308** or a navigation system that is accessible through a communication system of the vehicle **308**. The computer system of the vehicle **308** can navigate the vehicle **308** to the area and park the vehicle at the area. As still another example of a precautious action, in the third autonomous mode, the computer system of the vehicle **308** can cause the vehicle **308** to send a message to alert appropriate authorities.

As a further example of a precautious action, in the third autonomous mode, the computer system of the vehicle **308** can continue to navigate the vehicle **308** partially or entirely along a route. The route can be a predetermined route or a route that is generated upon (or after) the vehicle **308** entering the third autonomous mode. For instance, if the computer system is confident in its estimate of the current or future environment of the vehicle **308** based on the sensor data, then the computer system can continue to navigate the vehicle **308** along a route. In some implementations, the computer system can navigate the vehicle **308** partially along the predetermined route, for example, by navigating the vehicle **308** for a certain period of time or for a certain distance. In some implementations, the computer system can navigate the vehicle **308** until the vehicle **308** reaches the destination of the route.

Accordingly, when a person, such as an on-board passenger, does not cause the vehicle **308** to switch from the second autonomous mode to the manual mode, the vehicle **308** can be safely maneuvered and/or parked while the vehicle **308** is in the third autonomous mode. These examples of precautious actions can be implemented together in various combinations. For example, the computer system of the vehicle **308** can turn on hazard lights of the vehicle **308** while the computer system searches for a suitable location to park the vehicle **308**. Upon identifying a suitable location to park the vehicle **308**, the computer system can turn off the hazard lights and navigate the vehicle **308** to the location. These examples are illustratively only. The vehicle **308** can take (or be caused to take) various other precautious actions in the third autonomous mode; this disclosure contemplates the various other precautious actions.

FIG. **4** illustrates an example of a method **400** for controlling a vehicle. The method **400** can be performed using the vehicle **100** shown in FIG. **1**, the vehicle **200** shown in FIG. **2**, another suitable vehicle, or another suitable system or apparatus.

At block **402**, the method **400** includes controlling a vehicle in a first autonomous mode of operation. In the method **400**, controlling the vehicle in the first autonomous mode of operation includes navigating the vehicle based on map data. In some implementations, the method **400** can include receiving the map data prior to controlling the vehicle in the first autonomous mode of operation. In some implementations, the map data can be generated prior to controlling the vehicle in the first autonomous mode of operation.

At block **404**, the method **400** includes obtaining sensor data using one or more sensors of the vehicle. In the method **400**, the sensor data is indicative of an environment of the vehicle.

At block **406**, the method **400** includes detecting an inadequacy in the map data. In the method **400**, detecting the

inadequacy in the map data includes comparing the map data to the sensor data. In some implementations, detecting the inadequacy in the map data includes detecting a difference between the map data and the sensor data. In some implementations, comparing the map data to the sensor data comprises comparing the map data to the sensor data in real-time.

At block **408**, the method **400** includes controlling the vehicle in a second autonomous mode of operation and providing an indication of an option to switch to a manual mode of operation, in response to detecting the inadequacy in the map data. Providing the indication can serve to prompt a user to switch to the manual mode of operation. The indication can be provided in various ways. The indication can be provided, for example, by way of any device or system that is provided in connection with the vehicle, such as, for example, any combination of one or more displays (such as a touch-screen display), speakers, indicator lights, and navigation systems. These examples are merely illustrative; the indication can be provided in various other ways. For example, the indication can be provided by way of a mobile device, such as a mobile phone, that is in wireless communication with the vehicle.

In the method **400**, controlling the vehicle in the second autonomous mode of operation includes obtaining additional sensor data using the one or more sensors of the vehicle and navigating the vehicle based on the additional sensor data. In some implementations, navigating the vehicle based on the additional sensor data comprises navigating the vehicle without using the map data. In some implementations, the additional sensor data can be indicative of a lane boundary, and navigating the vehicle based on the additional sensor data can include navigating the vehicle based on the lane boundary. In some implementations, the additional sensor data can be indicative of a position of a second vehicle, and navigating the vehicle based on the additional sensor data can include navigating the vehicle based on the position of the second vehicle. In some implementations, the additional sensor data can be indicative of a traffic sign. The traffic sign can present a condition of an environment of the vehicle. Navigating the vehicle based on the additional sensor data can include navigating the vehicle based on the condition.

In some implementations, the method **400** can include detecting an inactivity when the vehicle is in the second autonomous mode of operation. The inactivity can relate to the option to switch to the manual mode of operation. In some implementations, detecting the inactivity can include receiving information that is indicative of a condition in a passenger cabin of the vehicle, and detecting the inactivity based on the information. In some implementations, detecting the inactivity can include detecting an inaction in a passenger cabin of the vehicle. The method **400** can include controlling the vehicle in a third autonomous mode of operation, in response to detecting the inadequacy in the map data. Controlling the vehicle in the third autonomous mode of operation can include obtaining further sensor data using the one or more sensors of the vehicle, and navigating the vehicle based on the further sensor data. In some implementations, navigating the vehicle based on the further sensor data can include determining a level of safety of parking the vehicle at a location, determining that the level of safety exceeds a target threshold, and in response to determining that the level of safety exceeds the target threshold, parking the vehicle at the location. In some implementations, navigating the vehicle based on the further sensor data can include navigating the vehicle without using the map data.

The method **400** of FIG. **4**, as well as other methods in the scope of this disclosure, can be carried out in whole or in part by a vehicle and its subsystems. In some implementations, the method **400** can be implemented in whole or in part by one or more computing devices. For example, the method **400** can be implemented in whole or in part by a server system, which receives data from a device that is associated with a vehicle. Other examples of computing devices or combinations of computing devices that can implement the method **400** are possible.

In some implementations, the method **400**, as well as other methods in the scope of this disclosure, can be implemented as computer program instructions encoded on a non-transitory computer-readable storage media in a machine-readable format, or on other non-transitory media or articles of manufacture.

FIG. **5** illustrates a conceptual view of a computer program product **500**. The computer program product **500** can be used to implement methods, such as the method **400**, that are in the scope of this disclosure. In some implementations, the computer program product **500** is provided using a signal bearing medium **502**. The signal bearing medium **502** can include one or more programming instructions **504** that, when executed by one or more processors can provide functionality or portions of the functionality described above with respect to FIGS. **1-4**. In some examples, the signal bearing medium **502** can encompass a computer-readable medium **506**, such as, but not limited to, a hard disk drive, a Compact Disc (CD), a Digital Video Disk (DVD), a digital tape, or memory. In some implementations, the signal bearing medium **502** can encompass a computer recordable medium **508**, such as, but not limited to, memory, read/write (R/W) CDs, or R/W DVDs. In some implementations, the signal bearing medium **502** can encompass a communications medium **510**, such as, but not limited to, a digital and/or an analog communication medium (for example, a fiber optic cable, a waveguide, a wired communications link, or a wireless communication link). Thus, for example, the signal bearing medium **502** can be conveyed by a wireless form of the communications medium **510**.

The one or more programming instructions **504** can be, for example, computer executable and/or logic implemented instructions. In some examples, a computing device such as the computer system **112** of FIG. **1** can be configured to provide various operations, functions, or actions in response to the programming instructions **504** conveyed to the computer system **112** by one or more of the computer readable medium **506**, the computer recordable medium **508**, and/or the communications medium **510**.

The non-transitory computer readable medium can also be distributed among multiple data storage elements, which can be remotely located from each other. The computing device that executes some or all of the stored instructions can be a vehicle, such as the vehicle **200** illustrated in FIG. **2**. Alternatively, the computing device that executes some or all of the stored instructions can be another computing device, such as a server.

The above detailed description describes various features and functions of the disclosed systems, devices, and methods with reference to the accompanying figures. While various aspects and implementations have been disclosed herein, other aspects and implementations are possible. The various aspects and implementations disclosed herein are for

purposes of illustration and are not intended to be limiting, with the true scope and spirit being indicated by the following claims.

What is claimed is:

[1. A method comprising:

controlling a vehicle in a first autonomous mode of operation, wherein controlling the vehicle in the first autonomous mode of operation comprises navigating the vehicle based on map data;

obtaining sensor data using one or more sensors of the vehicle, wherein the sensor data is indicative of an environment of the vehicle;

detecting an inadequacy in the map data, wherein detecting the inadequacy in the map data comprises comparing the map data to the sensor data; and

in response to detecting the inadequacy in the map data, controlling the vehicle in a second autonomous mode of operation, wherein controlling the vehicle in the second autonomous mode of operation comprises obtaining additional sensor data using the one or more sensors of the vehicle and navigating the vehicle based on the additional sensor data.]

[2. The method of claim 1, wherein the map data includes one or more of traffic conditions, road conditions, route information, and positioning information.]

[3. The method of claim 1, wherein detecting the inadequacy in the map data comprises comparing the map data and the sensor data to determine whether a difference between the map data and the sensor data exceeds a predetermined threshold.]

[4. The method of claim 1, wherein the additional sensor data is indicative of a lane boundary, and wherein navigating the vehicle based on the additional sensor data comprises navigating the vehicle based on the lane boundary.]

[5. The method of claim 1, wherein the additional sensor data is indicative of a position of a second vehicle, and wherein navigating the vehicle based on the additional sensor data comprises navigating the vehicle based on the position of the second vehicle.]

[6. The method of claim 5, wherein navigating the vehicle based on the further sensor data comprises increasing a distance between the vehicle and the second vehicle.]

[7. The method of claim 1, wherein the additional sensor data is indicative of a traffic sign, wherein the traffic sign presents a textual message, and wherein navigating the vehicle based on the additional sensor data comprises navigating the vehicle based on the textual message.]

[8. The method of claim 1, further comprising:

providing an indication of an option to switch to a manual mode of operation, wherein the indication of an option to switch to a manual mode of operation is provided by one or more of a display, a speaker, an indicator light and a mobile device in wireless communication with the vehicle;

detecting an inactivity when the vehicle is in the second autonomous mode of operation, wherein the inactivity relates to the option to switch to the manual mode of operation; and

in response to detecting the inactivity, controlling the vehicle in a third autonomous mode of operation.]

[9. The method of claim 8, wherein detecting the inactivity comprises:

receiving information that is indicative of a movement of an on-board passenger in the vehicle; and

detecting the inactivity based on the information.]

[10. The method of claim 8, wherein controlling the vehicle in the third autonomous mode of operation comprises:

obtaining further sensor data using the one or more sensors of the vehicle, and

navigating the vehicle based on the further sensor data.]

[11. The method of claim 10, wherein navigating the vehicle based on the further sensor data comprises:

determining a level of safety of parking the vehicle at a location;

determining that the level of safety exceeds a target threshold; and

in response to determining that the level of safety exceeds the target threshold, parking the vehicle at the location.]

[12. The method of claim 10, wherein navigating the vehicle based on the further sensor data comprises enabling hazard lights of the vehicle and reducing a speed of the vehicle.]

[13. A vehicle comprising:

one or more sensors; and

a controller configured to:

receive first sensor data from the one or more sensors, wherein the first sensor data is indicative of an environment of the vehicle when the vehicle is in a first autonomous mode of operation;

receive second sensor data from the one or more sensors, wherein the second sensor data is indicative of an environment of the vehicle when the vehicle is in a second autonomous mode of operation;

control the vehicle in the first autonomous mode of operation by at least navigating the vehicle based on map data;

detect an inadequacy in the map data by at least comparing the map data to the first sensor data; and

in response to detecting the inadequacy in the map data, control the vehicle in the second autonomous mode of operation by at least navigating the vehicle based on the second sensor data.]

[14. The vehicle of claim 13, wherein the additional sensor data is indicative of a traffic sign, wherein the traffic sign presents a textual message, and wherein navigating the vehicle based on the additional sensor data comprises navigating the vehicle based on the textual message.]

[15. The vehicle of claim 13, wherein the controller is further configured to:

provide an indication of an option to switch to a manual mode of operation, wherein the indication of an option to switch to a manual mode of operation is provided by one or more of a display, a speaker, an indicator light and a mobile device in wireless communication with the vehicle;

detect an inactivity when the vehicle is in the second autonomous mode of operation, wherein the inactivity relates to the option to switch to the manual mode of operation; and

in response to detecting the inactivity, control the vehicle in a third autonomous mode of operation by at least causing one or more precautious actions to be performed.]

[16. The vehicle of claim 15, wherein the one or more precautious actions comprises one or more of parking the vehicle, causing the vehicle to follow another vehicle, reducing a speed of the vehicle, navigating the vehicle along at least a part of a route, sending an alert message, and enabling one or more hazard lights of the vehicle.]

[17. The vehicle of claim 13, wherein the one or more sensors comprise one or more of a camera, a radar system, a LIDAR system, a global positioning system, and an inertial measurement unit.]

[18. A non-transitory computer-readable storage medium having stored thereon instructions, that when executed by a computing device, cause the computing device to carry out functions comprising:

controlling a vehicle in a first autonomous mode of operation, wherein controlling the vehicle in the first autonomous mode of operation comprises navigating the vehicle based on map data;

obtaining sensor data using one or more sensors of the vehicle, wherein the sensor data is indicative of an environment of the vehicle;

detecting an inadequacy in the map data, wherein detecting the inadequacy in the map data comprises comparing the map data to the sensor data; and

in response to detecting the inadequacy in the map data, controlling the vehicle in a second autonomous mode of operation, wherein controlling the vehicle in the second autonomous mode of operation comprises obtaining additional sensor data using the one or more sensors of the vehicle and navigating the vehicle based on the additional sensor data.]

[19. The non-transitory computer-readable storage medium of claim 18, wherein the functions further comprise:

providing an indication of an option to switch to a manual mode of operation, wherein the indication of an option to switch to a manual mode of operation is provided by one or more of a display, a speaker, an indicator light and a mobile device in wireless communication with the vehicle;

detecting an inactivity when the vehicle is in the second autonomous mode of operation, wherein the inactivity relates to the option to switch to the manual mode of operation; and

in response to detecting the inactivity, controlling the vehicle in a third autonomous mode of operation.]

[20. The non-transitory computer-readable storage medium of claim 18, wherein the additional sensor data is indicative of a traffic sign, wherein the traffic sign presents a textual message, and wherein navigating the vehicle based on the additional sensor data comprises navigating the vehicle based on the textual message.]

21. A method comprising:

controlling a vehicle in a first autonomous mode, wherein controlling the vehicle in the first autonomous mode comprises navigating the vehicle based on map data;

obtaining sensor data indicative of an environment of the vehicle;

detecting an inadequacy in the map data based on a comparison of the map data and the sensor data; and

in response to the inadequacy, controlling the vehicle in a second autonomous mode, wherein controlling the vehicle in the second autonomous mode comprises controlling the vehicle based on lane indications provided by the sensor data.

22. The method of claim 21, wherein the lane indications provided by the sensor data comprise an estimated shape and location of a current lane of the vehicle.

23. The method of claim 21, wherein controlling the vehicle in the second autonomous mode comprises remaining in a current lane of the vehicle.

24. The method of claim 21, wherein controlling the vehicle in the second autonomous mode further comprises transitioning control of the vehicle to a human driver.

25. The method of claim 21, wherein controlling the vehicle in the second autonomous mode further comprises controlling the vehicle based on trajectories of other vehicles, and objects specific to road environments.

26. The method of claim 21 wherein detecting the inadequacy in the map data comprises comparing the map data and the sensor data to determine whether a difference between the map data and the sensor data exceeds a predetermined threshold.

27. The method of claim 21, wherein controlling the vehicle in the second autonomous mode comprises maintaining a safe distance from other vehicles/objects in a vicinity of the vehicle.

28. The method of claim 21, further comprising:

providing an indication of an option to switch to a manual mode of operation, wherein the indication of an option to switch to a manual mode of operation is provided by one or more of a display, a speaker, an indicator light and a mobile device in wireless communication with the vehicle;

detecting an inactivity when the vehicle is in the second autonomous mode of operation, wherein the inactivity relates to the option to switch to the manual mode of operation; and

in response to detecting the inactivity, controlling the vehicle in a third autonomous mode of operation.

29. The method of claim 28, wherein detecting the inactivity comprises:

receiving information that is indicative of a movement of an on-board passenger in the vehicle; and

detecting the inactivity based on the information.

30. The method of claim 28, wherein controlling the vehicle in the third autonomous mode of operation comprises:

obtaining further sensor data using the one or more sensors of the vehicle, and

navigating the vehicle based on the further sensor data.

31. The method of claim 30, wherein navigating the vehicle based on the further sensor data comprises:

determining a level of safety of parking the vehicle at a location;

determining that the level of safety exceeds a target threshold; and

in response to determining that the level of safety exceeds the target threshold, parking the vehicle at the location.

32. The method of claim 21, wherein the map data is selectively used in the first autonomous mode, wherein controlling the vehicle in the second autonomous mode further comprises controlling the vehicle based on the map data, and wherein the map data is used to a lesser extent in the second autonomous mode than in the first autonomous mode.

33. A vehicle comprising:

one or more sensors; and

a controller configured to:

control the vehicle in the first autonomous mode of operation by at least navigating the vehicle based on map data;

receive sensor data from the one or more sensors, wherein the sensor data is indicative of an environment of the vehicle;

detect an inadequacy in the map data by at least comparing the map data to the sensor data; and

in response to the inadequacy in the map data, control the vehicle in a second autonomous mode, wherein controlling the vehicle in the second autonomous mode comprises controlling the vehicle based on lane indications provided by the sensor data.

34. The vehicle of claim 33, wherein the lane indications provided by the sensor data comprise an estimated shape and location of a current lane of the vehicle.

35. The vehicle of claim 33, wherein controlling the vehicle in the second autonomous mode comprises remaining in a current lane of the vehicle.

36. The vehicle of claim 33, wherein controlling the vehicle in the second autonomous mode further comprises transitioning control of the vehicle to a human driver.

37. The vehicle of claim 33, wherein the one or more sensors comprise one or more of a camera, a radar system, a LIDAR system, a global positioning system, and an inertial measurement unit.

38. The vehicle of claim 33, wherein the lane indications provided by the sensor data comprise features representing lane marker locations, trajectories of other vehicles, and objects specific to road environments.

39. A non-transitory computer-readable storage medium having stored thereon instructions, that when executed by a computing device, cause the computing device to carry out functions comprising:

controlling a vehicle in a first autonomous mode, wherein controlling the vehicle in the first autonomous mode comprises navigating the vehicle based on map data;

obtaining sensor data indicative of an environment of the vehicle;

detecting an inadequacy in the map data based on a comparison of the map data and the sensor data; and

in response to the inadequacy, controlling the vehicle in a second autonomous mode, wherein controlling the vehicle in the second autonomous mode comprises controlling the vehicle based on lane indications provided by the sensor data.

40. The non-transitory computer-readable storage medium of claim 39, wherein the functions further comprise:

providing an indication of an option to switch to a manual mode of operation, wherein the indication of an option to switch to a manual mode of operation is provided by one or more of a display, a speaker, an indicator light and a mobile device in wireless communication with the vehicle;

detecting an inactivity when the vehicle is in the second autonomous mode of operation, wherein the inactivity relates to the option to switch to the manual mode of operation; and

in response to detecting the inactivity, controlling the vehicle in a third autonomous mode of operation.

* * * * *