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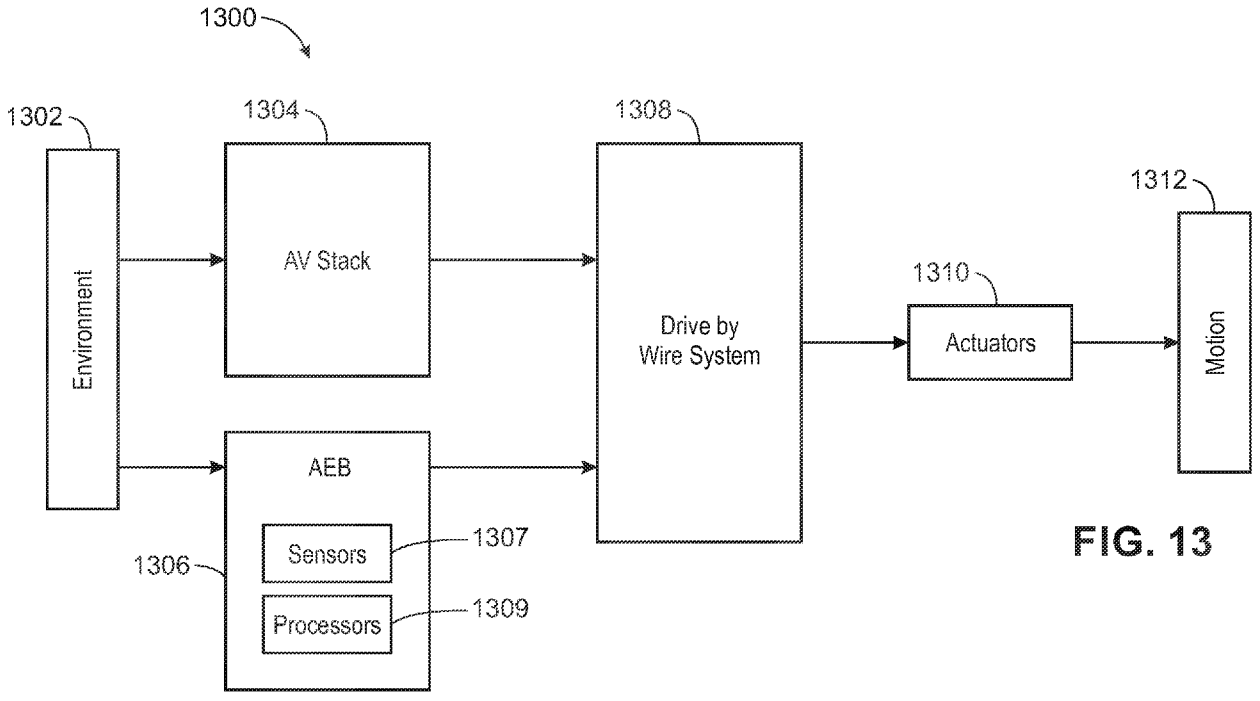


FIG. 13

(57) Abstract: Among other things, systems and methods are described for brake arbitration. Safe stop requests are obtained. A safe stop request is associated with a deceleration value of a vehicle in motion. Safe stop activations associated with the safe stop request are determined, wherein the safe stop activations are associated with predetermined deceleration values. An automated emergency (AEB) system deceleration command is calculated. Arbitration is performed between the deceleration values associated with the safe stop request, predetermined deceleration values associated with the safe stop activations, and the deceleration value calculated from data captured by the AEB system to determine a final deceleration output.

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BRAKE ARBITRATION

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority to U.S. Provisional Patent Application Serial No. 63/161,315, filed March 15, 2021, now pending, the entirety of which is incorporated by reference.

FIELD OF THE INVENTION

[0002] This description relates to brake arbitration.

BACKGROUND

[0003] A vehicle (e.g., an autonomous vehicle) is operable along a path in an environment from a starting location to a final location while avoiding objects and obeying rules of the road. While traversing the path, events can occur that require emergency braking. For example, an object may enter the vehicle's path such that without braking, the vehicle would collide with the object. Emergency braking decelerates the vehicle to prevent a collision or unsafe scenario.

BRIEF DESCRIPTION OF THE DRAWINGS

[0004] FIG. 1 shows an example of an autonomous vehicle (AV) having autonomous capability.

[0005] FIG. 2 shows an example "cloud" computing environment.

[0006] FIG. 3 shows a computer system.

[0007] FIG. 4 shows an example architecture for an AV.

[0008] FIG. 5 shows an example of inputs and outputs that can be used by a perception system.

[0009] FIG. 6 shows an example of a LiDAR system.

[0010] FIG. 7 shows the LiDAR system in operation.

[0011] FIG. 8 shows the operation of the LiDAR system in additional detail.

[0012] FIG. 9 shows a block diagram of the relationships between inputs and outputs of a planning system.

[0013] FIG. 10 shows a directed graph used in path planning.

[0014] FIG. 11 shows a block diagram of the inputs and outputs of a control system.

[0015] FIG. 12 shows a block diagram of the inputs, outputs, and components of a controller.

[0016] FIG. 13 is a block diagram of a braking sub-system.

[0017] FIG. 14 is a block diagram of AEB arbitration.

[0018] FIG. 15 is a process flow diagram of a process for brake arbitration.

DETAILED DESCRIPTION

[0019] In the following description, for the purposes of explanation, numerous specific details are set forth in order to provide a thorough understanding of the present disclosure. It will be apparent, however, that the present disclosure can be practiced without these specific details. In other instances, well-known structures and devices are shown in block diagram form in order to avoid unnecessarily obscuring the present disclosure.

[0020] In the drawings, specific arrangements or orderings of schematic elements, such as those representing devices, modules, systems, instruction blocks, and data elements, are shown for ease of description. However, it should be understood by those skilled in the art that the specific ordering or arrangement of the schematic elements in the drawings is not meant to imply that a particular order or sequence of processing, or separation of processes, is required. Further, the inclusion of a schematic element in a drawing is not meant to imply that such element is required in all embodiments or that the features represented by such element may not be included in or combined with other elements in some embodiments.

[0021] Further, in the drawings, where connecting elements, such as solid or dashed lines or arrows, are used to illustrate a connection, relationship, or association between or among two or more other schematic elements, the absence of any such connecting elements is not meant to imply that no connection, relationship, or association can exist. In other words, some connections, relationships, or associations between elements are not shown in the drawings so as not to obscure the disclosure. In addition, for ease of illustration, a single connecting element is used to represent multiple connections, relationships or associations between elements. For example, where a connecting element represents a communication of signals, data, or instructions, it should be understood by those skilled in the art that such element represents one or multiple signal paths (e.g., a bus), as may be needed, to affect the communication.

[0022] Reference will now be made in detail to embodiments, examples of which are illustrated in the accompanying drawings. In the following detailed description, numerous

specific details are set forth in order to provide a thorough understanding of the various described embodiments. However, it will be apparent to one of ordinary skill in the art that the various described embodiments may be practiced without these specific details. In other instances, well-known methods, procedures, components, circuits, and networks have not been described in detail so as not to unnecessarily obscure aspects of the embodiments.

[0023] Several features are described hereafter that can each be used independently of one another or with any combination of other features. However, any individual feature may not address any of the problems discussed above or might only address one of the problems discussed above. Some of the problems discussed above might not be fully addressed by any of the features described herein. Although headings are provided, information related to a particular heading, but not found in the section having that heading, may also be found elsewhere in this description. Embodiments are described herein according to the following outline:

1. General Overview
2. System Overview
3. AV Architecture
4. AV Inputs
5. AV Planning
6. AV Control
7. Automated Emergency Braking
8. AEB Arbitration
9. AEB Calibration
10. Safe Stop Activation and Safe Handling Deceleration

General Overview

[0024] In some aspects and/or embodiments, systems, methods, and computer program products described herein include and/or implement brake arbitration. Safe stop requests are obtained. A safe stop request is associated with a deceleration value of a vehicle in motion. Safe stop activations associated with the safe stop request are determined. The safe stop activations are associated with predetermined deceleration values. An automated emergency (AEB) system deceleration command is calculated. Arbitration is performed between the deceleration values associated with the safe stop request, predetermined deceleration values associated with the safe

stop activations, and the deceleration value calculated from data captured by the AEB system to determine a final deceleration output.

[0025] By virtue of the implementation of systems, methods, and computer program products described herein, techniques for brake arbitration enables an improved automated emergency braking system that operates in both manual and auto mode creating a highly effective system. The safe stop activations and safe handling according to the present techniques provide predetermined levels of deceleration, enabling a consistent and improved response of the AEB system.

System Overview

[0026] FIG. 1 shows an example of an AV 100 having autonomous capability.

[0027] As used herein, the term "autonomous capability" refers to a function, feature, or facility that enables a vehicle to be partially or fully operated without real-time human intervention, including without limitation fully AVs, highly AVs, and conditionally AVs.

[0028] As used herein, an autonomous vehicle (AV) is a vehicle that possesses autonomous capability.

[0029] As used herein, "vehicle" includes means of transportation of goods or people. For example, cars, buses, trains, airplanes, drones, trucks, boats, ships, submersibles, dirigibles, etc. A driverless car is an example of a vehicle.

[0030] As used herein, "trajectory" refers to a path or route to navigate an AV from a first spatiotemporal location to second spatiotemporal location. In an embodiment, the first spatiotemporal location is referred to as the initial or starting location and the second spatiotemporal location is referred to as the destination, final location, goal, goal position, or goal location. In some examples, a trajectory is made up of one or more segments (e.g., sections of road) and each segment is made up of one or more blocks (e.g., portions of a lane or intersection). In an embodiment, the spatiotemporal locations correspond to real world locations. For example, the spatiotemporal locations are pick up or drop-off locations to pick up or drop-off persons or goods.

[0031] As used herein, "sensor(s)" includes one or more hardware components that detect information about the environment surrounding the sensor. Some of the hardware components can include sensing components (e.g., image sensors, biometric sensors), transmitting and/or

receiving components (e.g., laser or radio frequency wave transmitters and receivers), electronic components such as analog-to-digital converters, a data storage device (such as a RAM and/or a nonvolatile storage), software or firmware components and data processing components such as an ASIC (application-specific integrated circuit), a microprocessor and/or a microcontroller.

[0032] As used herein, a "scene description" is a data structure (e.g., list) or data stream that includes one or more classified or labeled objects detected by one or more sensors on the AV vehicle or provided by a source external to the AV.

[0033] As used herein, a "road" is a physical area that can be traversed by a vehicle, and may correspond to a named thoroughfare (e.g., city street, interstate freeway, etc.) or may correspond to an unnamed thoroughfare (e.g., a driveway in a house or office building, a section of a parking lot, a section of a vacant lot, a dirt path in a rural area, etc.). Because some vehicles (e.g., 4-wheel-drive pickup trucks, sport utility vehicles, etc.) are capable of traversing a variety of physical areas not specifically adapted for vehicle travel, a "road" may be a physical area not formally defined as a thoroughfare by any municipality or other governmental or administrative body.

[0034] As used herein, a "lane" is a portion of a road that can be traversed by a vehicle. A lane is sometimes identified based on lane markings. For example, a lane may correspond to most or all of the space between lane markings, or may correspond to only some (e.g., less than 50%) of the space between lane markings. For example, a road having lane markings spaced far apart might accommodate two or more vehicles between the markings, such that one vehicle can pass the other without traversing the lane markings, and thus could be interpreted as having a lane narrower than the space between the lane markings, or having two lanes between the lane markings. A lane could also be interpreted in the absence of lane markings. For example, a lane may be defined based on physical features of an environment, e.g., rocks and trees along a thoroughfare in a rural area or, e.g., natural obstructions to be avoided in an undeveloped area. A lane could also be interpreted independent of lane markings or physical features. For example, a lane could be interpreted based on an arbitrary path free of obstructions in an area that otherwise lacks features that would be interpreted as lane boundaries. In an example scenario, an AV could interpret a lane through an obstruction-free portion of a field or empty lot. In another example scenario, an AV could interpret a lane through a wide (e.g., wide enough for two or more lanes) road that does not have lane markings. In this scenario, the AV could communicate information

about the lane to other AVs so that the other AVs can use the same lane information to coordinate path planning among themselves.

[0035] The term "over-the-air (OTA) client" includes any AV, or any electronic device (e.g., computer, controller, IoT device, electronic control unit (ECU)) that is embedded in, coupled to, or in communication with an AV.

[0036] The term "over-the-air (OTA) update" means any update, change, deletion or addition to software, firmware, data or configuration settings, or any combination thereof, that is delivered to an OTA client using proprietary and/or standardized wireless communications technology, including but not limited to: cellular mobile communications (e.g., 2G, 3G, 4G, 5G), radio wireless area networks (e.g., WiFi) and/or satellite Internet.

[0037] The term "edge node" means one or more edge devices coupled to a network that provide a portal for communication with AVs and can communicate with other edge nodes and a cloud based computing platform, for scheduling and delivering OTA updates to OTA clients.

[0038] The term "edge device" means a device that implements an edge node and provides a physical wireless access point (AP) into enterprise or service provider (e.g., VERIZON, AT&T) core networks. Examples of edge devices include but are not limited to: computers, controllers, transmitters, routers, routing switches, integrated access devices (IADs), multiplexers, metropolitan area network (MAN) and wide area network (WAN) access devices.

[0039] "One or more" includes a function being performed by one element, a function being performed by more than one element, *e.g.*, in a distributed fashion, several functions being performed by one element, several functions being performed by several elements, or any combination of the above.

[0040] It will also be understood that, although the terms first, second, etc. are, in some instances, used herein to describe various elements, these elements should not be limited by these terms. These terms are only used to distinguish one element from another. For example, a first contact could be termed a second contact, and, similarly, a second contact could be termed a first contact, without departing from the scope of the various described embodiments. The first contact and the second contact are both contacts, but they are not the same contact.

[0041] The terminology used in the description of the various described embodiments herein is for the purpose of describing particular embodiments only and is not intended to be limiting. As used in the description of the various described embodiments and the appended claims, the

singular forms “a,” “an” and “the” are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will also be understood that the term “and/or” as used herein refers to and encompasses any and all possible combinations of one or more of the associated listed items. It will be further understood that the terms “includes,” “including,” “comprises,” and/or “comprising,” when used in this description, specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components, and/or groups thereof.

[0042] As used herein, the term “if” is, optionally, construed to mean “when” or “upon” or “in response to determining” or “in response to detecting,” depending on the context. Similarly, the phrase “if it is determined” or “if [a stated condition or event] is detected” is, optionally, construed to mean “upon determining” or “in response to determining” or “upon detecting [the stated condition or event]” or “in response to detecting [the stated condition or event],” depending on the context.

[0043] As used herein, an AV system refers to the AV along with the array of hardware, software, stored data, and data generated in real-time that supports the operation of the AV. In an embodiment, the AV system is incorporated within the AV. In an embodiment, the AV system is spread across several locations. For example, some of the software of the AV system is implemented on a cloud computing environment similar to cloud computing environment 200 described below with respect to FIG. 2.

[0044] In general, this document describes technologies applicable to any vehicles that have one or more autonomous capabilities including fully AVs, highly AVs, and conditionally AVs, such as so-called Level 5, Level 4 and Level 3 vehicles, respectively (see SAE International's standard J3016: Taxonomy and Definitions for Terms Related to On-Road Motor Vehicle Automated Driving Systems, which is incorporated by reference in its entirety, for more details on the classification of levels of autonomy in vehicles). The technologies described in this document are also applicable to partially AVs and driver assisted vehicles, such as so-called Level 2 and Level 1 vehicles (see SAE International's standard J3016: Taxonomy and Definitions for Terms Related to On-Road Motor Vehicle Automated Driving Systems). In an embodiment, one or more of the Level 1, 2, 3, 4 and 5 vehicle systems can automate certain vehicle operations (e.g., steering, braking, and using maps) under certain operating conditions

based on processing of sensor inputs. The technologies described in this document can benefit vehicles in any levels, ranging from fully AVs to human-operated vehicles.

[0045] AVs have advantages over vehicles that require a human driver. One advantage is safety. For example, in 2016, the United States experienced 6 million automobile accidents, 2.4 million injuries, 40,000 fatalities, and 13 million vehicles in crashes, estimated at a societal cost of $910+ billion. U.S. traffic fatalities per 100 million miles traveled have been reduced from about six to about one from 1965 to 2015, in part due to additional safety measures deployed in vehicles. For example, an additional half second of warning that a crash is about to occur is believed to mitigate 60% of front-to-rear crashes. However, passive safety features (e.g., seat belts, airbags) have likely reached their limit in improving this number. Thus, active safety measures, such as automated control of a vehicle, are the likely next step in improving these statistics. Because human drivers are believed to be responsible for a critical pre-crash event in 95% of crashes, automated driving systems are likely to achieve better safety outcomes, e.g., by reliably recognizing and avoiding critical situations better than humans; making better decisions, obeying traffic laws, and predicting future events better than humans; and reliably controlling a vehicle better than a human.

[0046] Referring to FIG. 1, an AV system 120 operates the vehicle 100 along a trajectory 198 through an environment 190 to a destination 199 (sometimes referred to as a final location) while avoiding objects (e.g., natural obstructions 191, vehicles 193, pedestrians 192, cyclists, and other obstacles) and obeying rules of the road (e.g., rules of operation or driving preferences).

[0047] In an embodiment, the AV system 120 includes devices 101 that are instrumented to receive and act on operational commands from the computer processors 146. We use the term "operational command" to mean an executable instruction (or set of instructions) that causes a vehicle to perform an action (e.g., a driving maneuver). Operational commands can, without limitation, including instructions for a vehicle to start moving forward, stop moving forward, start moving backward, stop moving backward, accelerate, decelerate, perform a left turn, and perform a right turn. In an embodiment, computing processors 146 are similar to the processor 304 described below in reference to FIG. 3. Examples of devices 101 include a steering control 102, brakes 103, gears, accelerator pedal or other acceleration control mechanisms, windshield wipers, side-door locks, window controls, and turn-indicators.

[0048] In an embodiment, the AV system 120 includes sensors 121 for measuring or inferring properties of state or condition of the vehicle 100, such as the AV's position, linear and angular velocity and acceleration, and heading (e.g., an orientation of the leading end of vehicle 100). Example of sensors 121 are GPS, inertial measurement units (IMU) that measure both vehicle linear accelerations and angular rates, wheel speed sensors for measuring or estimating wheel slip ratios, wheel brake pressure or braking torque sensors, engine torque or wheel torque sensors, and steering angle and angular rate sensors.

[0049] In an embodiment, the sensors 121 also include sensors for sensing or measuring properties of the AV's environment. For example, monocular or stereo video cameras 122 in the visible light, infrared or thermal (or both) spectra, LiDAR 123, RADAR, ultrasonic sensors, time-of-flight (TOF) depth sensors, speed sensors, temperature sensors, humidity sensors, and precipitation sensors.

[0050] In an embodiment, the AV system 120 includes a data storage unit 142 and memory 144 for storing machine instructions associated with computer processors 146 or data collected by sensors 121. In an embodiment, the data storage unit 142 is similar to the ROM 308 or storage device 310 described below in relation to FIG. 3. In an embodiment, memory 144 is similar to the main memory 306 described below. In an embodiment, the data storage unit 142 and memory 144 store historical, real-time, and/or predictive information about the environment 190. In an embodiment, the stored information includes maps, driving performance, traffic congestion updates or weather conditions. In an embodiment, data relating to the environment 190 is transmitted to the vehicle 100 via a communications channel from a remotely located database 134.

[0051] In an embodiment, the AV system 120 includes communications devices 140 for communicating measured or inferred properties of other vehicles' states and conditions, such as positions, linear and angular velocities, linear and angular accelerations, and linear and angular headings to the vehicle 100. These devices include Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communication devices and devices for wireless communications over point-to-point or ad hoc networks or both. In an embodiment, the communications devices 140 communicate across the electromagnetic spectrum (including radio and optical communications) or other media (e.g., air and acoustic media). A combination of Vehicle-to-Vehicle (V2V) Vehicle-to-Infrastructure (V2I) communication (and, in some embodiments, one or more other

types of communication) is sometimes referred to as Vehicle-to-Everything (V2X) communication. V2X communication typically conforms to one or more communications standards for communication with, between, and among AVs.

[0052] In an embodiment, the communication devices 140 include communication interfaces. For example, wired, wireless, WiMAX, Wi-Fi, Bluetooth, satellite, cellular, optical, near field, infrared, or radio interfaces. The communication interfaces transmit data from a remotely located database 134 to AV system 120. In an embodiment, the remotely located database 134 is embedded in a cloud computing environment 200 as described in FIG. 2. The communication devices 140 transmit data collected from sensors 121 or other data related to the operation of vehicle 100 to the remotely located database 134. In an embodiment, communication devices 140 transmit information that relates to teleoperations to the vehicle 100. In some embodiments, the vehicle 100 communicates with other remote (e.g., "cloud") servers 136.

[0053] In an embodiment, the remotely located database 134 also stores and transmits digital data (e.g., storing data such as road and street locations). Such data is stored on the memory 144 on the vehicle 100, or transmitted to the vehicle 100 via a communications channel from the remotely located database 134.

[0054] In an embodiment, the remotely located database 134 stores and transmits historical information about driving properties (e.g., speed and acceleration profiles) of vehicles that have previously traveled along trajectory 198 at similar times of day. In one implementation, such data can be stored on the memory 144 on the vehicle 100, or transmitted to the vehicle 100 via a communications channel from the remotely located database 134.

[0055] Computer processors 146 located on the vehicle 100 algorithmically generate control actions based on both real-time sensor data and prior information, allowing the AV system 120 to execute its autonomous driving capabilities.

[0056] In an embodiment, the AV system 120 includes computer peripherals 132 coupled to computer processors 146 for providing information and alerts to, and receiving input from, a user (e.g., an occupant or a remote user) of the vehicle 100. In an embodiment, peripherals 132 are similar to the display 312, input device 314, and cursor controller 316 discussed below in reference to FIG. 3. The coupling is wireless or wired. Any two or more of the interface devices can be integrated into a single device.

[0057] In an embodiment, the AV system 120 receives and enforces a privacy level of a passenger, e.g., specified by the passenger or stored in a profile associated with the passenger. The privacy level of the passenger determines how particular information associated with the passenger (e.g., passenger comfort data, biometric data, etc.) is permitted to be used, stored in the passenger profile, and/or stored on the cloud server 136 and associated with the passenger profile. In an embodiment, the privacy level specifies particular information associated with a passenger that is deleted once the ride is completed. In an embodiment, the privacy level specifies particular information associated with a passenger and identifies one or more entities that are authorized to access the information. Examples of specified entities that are authorized to access information can include other AVs, third party AV systems, or any entity that could potentially access the information.

[0058] A privacy level of a passenger can be specified at one or more levels of granularity. In an embodiment, a privacy level identifies specific information to be stored or shared. In an embodiment, the privacy level applies to all the information associated with the passenger such that the passenger can specify that none of her personal information is stored or shared. Specification of the entities that are permitted to access particular information can also be specified at various levels of granularity. Various sets of entities that are permitted to access particular information can include, for example, other AVs, cloud servers 136, specific third party AV systems, etc.

[0059] In an embodiment, the AV system 120 or the cloud server 136 determines if certain information associated with a passenger can be accessed by the AV 100 or another entity. For example, a third-party AV system that attempts to access passenger input related to a particular spatiotemporal location must obtain authorization, e.g., from the AV system 120 or the cloud server 136, to access the information associated with the passenger. For example, the AV system 120 uses the passenger's specified privacy level to determine whether the passenger input related to the spatiotemporal location can be presented to the third-party AV system, the AV 100, or to another AV. This enables the passenger's privacy level to specify which other entities are allowed to receive data about the passenger's actions or other data associated with the passenger.

[0060] FIG. 2 shows an example “cloud” computing environment. Cloud computing is a model of service delivery for enabling convenient, on-demand network access to a shared pool of configurable computing resources (e.g. networks, network bandwidth, servers, processing,

memory, storage, applications, virtual machines, and services). In typical cloud computing systems, one or more large cloud data centers house the machines used to deliver the services provided by the cloud. Referring now to FIG. 2, the cloud computing environment 200 includes cloud data centers 204a, 204b, and 204c that are interconnected through the cloud 202. Data centers 204a, 204b, and 204c provide cloud computing services to computer systems 206a, 206b, 206c, 206d, 206e, and 206f connected to cloud 202.

[0061] The cloud computing environment 200 includes one or more cloud data centers. In general, a cloud data center, for example the cloud data center 204a shown in FIG. 2, refers to the physical arrangement of servers that make up a cloud, for example the cloud 202 shown in FIG. 2, or a particular portion of a cloud. For example, servers are physically arranged in the cloud datacenter into rooms, groups, rows, and racks. A cloud datacenter has one or more zones, which include one or more rooms of servers. Each room has one or more rows of servers, and each row includes one or more racks. Each rack includes one or more individual server nodes. In some implementation, servers in zones, rooms, racks, and/or rows are arranged into groups based on physical infrastructure requirements of the datacenter facility, which include power, energy, thermal, heat, and/or other requirements. In an embodiment, the server nodes are similar to the computer system described in FIG. 3. The data center 204a has many computing systems distributed through many racks.

[0062] The cloud 202 includes cloud data centers 204a, 204b, and 204c along with the network and networking resources (for example, networking equipment, nodes, routers, switches, and networking cables) that interconnect the cloud data centers 204a, 204b, and 204c and help facilitate the computing systems' 206a-f access to cloud computing services. In an embodiment, the network represents any combination of one or more local networks, wide area networks, or internetworks coupled using wired or wireless links deployed using terrestrial or satellite connections. Data exchanged over the network, is transferred using any number of network layer protocols, such as Internet Protocol (IP), Multiprotocol Label Switching (MPLS), Asynchronous Transfer Mode (ATM), Frame Relay, etc. Furthermore, in embodiments where the network represents a combination of multiple sub-networks, different network layer protocols are used at each of the underlying sub-networks. In some embodiments, the network represents one or more interconnected internetworks, such as the public Internet.

[0063] The computing systems 206a-f or cloud computing services consumers are connected to the cloud 202 through network links and network adapters. In an embodiment, the computing systems 206a-f are implemented as various computing devices, for example servers, desktops, laptops, tablet, smartphones, Internet of Things (IoT) devices, AVs (including, cars, drones, shuttles, trains, buses, etc.) and consumer electronics. In an embodiment, the computing systems 206a-f are implemented in or as a part of other systems.

[0064] FIG. 3 shows a computer system 300. In an implementation, the computer system 300 is a special purpose computing device. The special-purpose computing device is hard-wired to perform the techniques or includes digital electronic devices such as one or more application-specific integrated circuits (ASICs) or field programmable gate arrays (FPGAs) that are persistently programmed to perform the techniques, or can include one or more general purpose hardware processors programmed to perform the techniques pursuant to program instructions in firmware, memory, other storage, or a combination. Such special-purpose computing devices can also combine custom hard-wired logic, ASICs, or FPGAs with custom programming to accomplish the techniques. In various embodiments, the special-purpose computing devices are desktop computer systems, portable computer systems, handheld devices, network devices or any other device that incorporates hard-wired and/or program logic to implement the techniques.

[0065] In an embodiment, the computer system 300 includes a bus 302 or other communication mechanism for communicating information, and a processor 304 coupled with a bus 302 for processing information. The processor 304 is, for example, a general-purpose microprocessor. The computer system 300 also includes a main memory 306, such as a random-access memory (RAM) or other dynamic storage device, coupled to the bus 302 for storing information and instructions to be executed by processor 304. In one implementation, the main memory 306 is used for storing temporary variables or other intermediate information during execution of instructions to be executed by the processor 304. Such instructions, when stored in non-transitory storage media accessible to the processor 304, render the computer system 300 into a special-purpose machine that is customized to perform the operations specified in the instructions.

[0066] In an embodiment, the computer system 300 further includes a read only memory (ROM) 308 or other static storage device coupled to the bus 302 for storing static information and instructions for the processor 304. A storage device 310, such as a magnetic disk, optical

disk, solid-state drive, or three-dimensional cross point memory is provided and coupled to the bus 302 for storing information and instructions.

[0067] In an embodiment, the computer system 300 is coupled via the bus 302 to a display 312, such as a cathode ray tube (CRT), a liquid crystal display (LCD), plasma display, light emitting diode (LED) display, or an organic light emitting diode (OLED) display for displaying information to a computer user. An input device 314, including alphanumeric and other keys, is coupled to bus 302 for communicating information and command selections to the processor 304. Another type of user input device is a cursor controller 316, such as a mouse, a trackball, a touch-enabled display, or cursor direction keys for communicating direction information and command selections to the processor 304 and for controlling cursor movement on the display 312. This input device typically has two degrees of freedom in two axes, a first axis (e.g., x-axis) and a second axis (e.g., y-axis), that allows the device to specify positions in a plane.

[0068] According to one embodiment, the techniques herein are performed by the computer system 300 in response to the processor 304 executing one or more sequences of one or more instructions contained in the main memory 306. Such instructions are read into the main memory 306 from another storage medium, such as the storage device 310. Execution of the sequences of instructions contained in the main memory 306 causes the processor 304 to perform the process steps described herein. In alternative embodiments, hard-wired circuitry is used in place of or in combination with software instructions.

[0069] The term “storage media” as used herein refers to any non-transitory media that store data and/or instructions that cause a machine to operate in a specific fashion. Such storage media includes non-volatile media and/or volatile media. Non-volatile media includes, for example, optical disks, magnetic disks, solid-state drives, or three-dimensional cross point memory, such as the storage device 310. Volatile media includes dynamic memory, such as the main memory 306. Common forms of storage media include, for example, a floppy disk, a flexible disk, hard disk, solid-state drive, magnetic tape, or any other magnetic data storage medium, a CD-ROM, any other optical data storage medium, any physical medium with patterns of holes, a RAM, a PROM, and EPROM, a FLASH-EPROM, NV-RAM, or any other memory chip or cartridge.

[0070] Storage media is distinct from but may be used in conjunction with transmission media. Transmission media participates in transferring information between storage media. For example, transmission media includes coaxial cables, copper wire and fiber optics, including the

wires that comprise the bus 302. Transmission media can also take the form of acoustic or light waves, such as those generated during radio-wave and infrared data communications.

[0071] In an embodiment, various forms of media are involved in carrying one or more sequences of one or more instructions to the processor 304 for execution. For example, the instructions are initially carried on a magnetic disk or solid-state drive of a remote computer. The remote computer loads the instructions into its dynamic memory and send the instructions over a telephone line using a modem. A modem local to the computer system 300 receives the data on the telephone line and use an infrared transmitter to convert the data to an infrared signal. An infrared detector receives the data carried in the infrared signal and appropriate circuitry places the data on the bus 302. The bus 302 carries the data to the main memory 306, from which processor 304 retrieves and executes the instructions. The instructions received by the main memory 306 can optionally be stored on the storage device 310 either before or after execution by processor 304.

[0072] The computer system 300 also includes a communication interface 318 coupled to the bus 302. The communication interface 318 provides a two-way data communication coupling to a network link 320 that is connected to a local network 322. For example, the communication interface 318 is an integrated service digital network (ISDN) card, cable modem, satellite modem, or a modem to provide a data communication connection to a corresponding type of telephone line. As another example, the communication interface 318 is a local area network (LAN) card to provide a data communication connection to a compatible LAN. In some implementations, wireless links are also implemented. In any such implementation, the communication interface 318 sends and receives electrical, electromagnetic, or optical signals that carry digital data streams representing various types of information.

[0073] The network link 320 typically provides data communication through one or more networks to other data devices. For example, the network link 320 provides a connection through the local network 322 to a host computer 324 or to a cloud data center or equipment operated by an Internet Service Provider (ISP) 326. The ISP 326 in turn provides data communication services through the world-wide packet data communication network now commonly referred to as the “Internet” 328. The local network 322 and Internet 328 both use electrical, electromagnetic or optical signals that carry digital data streams. The signals through the various networks and the signals on the network link 320 and through the communication interface 318,

which carry the digital data to and from the computer system 300, are example forms of transmission media. In an embodiment, the network 320 contains the cloud 202 or a part of the cloud 202 described above.

[0074] The computer system 300 sends messages and receives data, including program code, through the network(s), the network link 320, and the communication interface 318. In an embodiment, the computer system 300 receives code for processing. The received code is executed by the processor 304 as it is received, and/or stored in storage device 310, or other non-volatile storage for later execution.

AV Architecture

[0075] FIG. 4 shows an example architecture 400 for an AV (e.g., the vehicle 100 shown in FIG. 1). The architecture 400 includes a perception system 402 (sometimes referred to as a perception circuit), a planning system 404 (sometimes referred to as a planning circuit), a control system 406 (sometimes referred to as a control circuit), a localization system 408 (sometimes referred to as a localization circuit), and a database system 410 (sometimes referred to as a database circuit). Each system plays a role in the operation of the vehicle 100. Together, the systems 402, 404, 406, 408, and 410 can be part of the AV system 120 shown in FIG. 1. In some embodiments, any of the systems 402, 404, 406, 408, and 410 is a combination of computer software (e.g., executable code stored on a computer-readable medium) and computer hardware (e.g., one or more microprocessors, microcontrollers, application-specific integrated circuits [ASICs]), hardware memory devices, other types of integrated circuits, other types of computer hardware, or a combination of any or all of these things). Each of the systems 402, 404, 406, 408, and 410 is sometimes referred to as a processing circuit (e.g., computer hardware, computer software, or a combination of the two). A combination of any or all of the systems 402, 404, 406, 408, and 410 is also an example of a processing circuit.

[0076] In use, the planning system 404 receives data representing a destination 412 and determines data representing a trajectory 414 (sometimes referred to as a route) that can be traveled by the vehicle 100 to reach (e.g., arrive at) the destination 412. In order for the planning system 404 to determine the data representing the trajectory 414, the planning system 404 receives data from the perception system 402, the localization system 408, and the database system 410.

[0077] The perception system 402 identifies nearby physical objects using one or more sensors 121, e.g., as also shown in FIG. 1. The objects are classified (e.g., grouped into types such as pedestrian, bicycle, automobile, traffic sign, etc.) and a scene description including the classified objects 416 is provided to the planning system 404.

[0078] The planning system 404 also receives data representing the AV position 418 from the localization system 408. The localization system 408 determines the AV position by using data from the sensors 121 and data from the database system 410 (e.g., a geographic data) to calculate a position. For example, the localization system 408 uses data from a GNSS (Global Navigation Satellite System) sensor and geographic data to calculate a longitude and latitude of the AV. In an embodiment, data used by the localization system 408 includes high-precision maps of the roadway geometric properties, maps describing road network connectivity properties, maps describing roadway physical properties (such as traffic speed, traffic volume, the number of vehicular and cyclist traffic lanes, lane width, lane traffic directions, or lane marker types and locations, or combinations of them), and maps describing the spatial locations of road features such as crosswalks, traffic signs or other travel signals of various types. In an embodiment, the high-precision maps are constructed by adding data through automatic or manual annotation to low-precision maps.

[0079] The control system 406 receives the data representing the trajectory 414 and the data representing the AV position 418 and operates the control functions 420a-c (e.g., steering, throttling, braking, ignition) of the AV in a manner that will cause the vehicle 100 to travel the trajectory 414 to the destination 412. For example, if the trajectory 414 includes a left turn, the control system 406 will operate the control functions 420a-c in a manner such that the steering angle of the steering function will cause the vehicle 100 to turn left and the throttling and braking will cause the vehicle 100 to pause and wait for passing pedestrians or vehicles before the turn is made.

AV Inputs

[0080] FIG. 5 shows an example of inputs 502a-d (e.g., sensors 121 shown in FIG. 1) and outputs 504a-d (e.g., sensor data) that is used by the perception system 402 (FIG. 4). One input 502a is a LiDAR (Light Detection and Ranging) system (e.g., LiDAR 123 shown in FIG. 1). LiDAR is a technology that uses light (e.g., bursts of light such as infrared light) to obtain data

about physical objects in its line of sight. A LiDAR system produces LiDAR data as output 504a. For example, LiDAR data is collections of 3D or 2D points (also known as a point clouds) that are used to construct a representation of the environment 190.

[0081] Another input 502b is a RADAR system. RADAR is a technology that uses radio waves to obtain data about nearby physical objects. RADARs can obtain data about objects not within the line of sight of a LiDAR system. A RADAR system produces RADAR data as output 504b. For example, RADAR data are one or more radio frequency electromagnetic signals that are used to construct a representation of the environment 190.

[0082] Another input 502c is a camera system. A camera system uses one or more cameras (e.g., digital cameras using a light sensor such as a charge-coupled device [CCD]) to obtain information about nearby physical objects. A camera system produces camera data as output 504c. Camera data often takes the form of image data (e.g., data in an image data format such as RAW, JPEG, PNG, etc.). In some examples, the camera system has multiple independent cameras, e.g., for the purpose of stereopsis (stereo vision), which enables the camera system to perceive depth. Although the objects perceived by the camera system are described here as "nearby," this is relative to the AV. In some embodiments, the camera system is configured to "see" objects far, e.g., up to a kilometer or more ahead of the AV. Accordingly, in some embodiments, the camera system has features such as sensors and lenses that are optimized for perceiving objects that are far away.

[0083] Another input 502d is a traffic light detection (TLD) system. A TLD system uses one or more cameras to obtain information about traffic lights, street signs, and other physical objects that provide visual navigation information. A TLD system produces TLD data as output 504d. TLD data often takes the form of image data (e.g., data in an image data format such as RAW, JPEG, PNG, etc.). A TLD system differs from a system incorporating a camera in that a TLD system uses a camera with a wide field of view (e.g., using a wide-angle lens or a fish-eye lens) in order to obtain information about as many physical objects providing visual navigation information as possible, so that the vehicle 100 has access to all relevant navigation information provided by these objects. For example, the viewing angle of the TLD system is about 120 degrees or more.

[0084] In some embodiments, outputs 504a-d are combined using a sensor fusion technique. Thus, either the individual outputs 504a-d are provided to other systems of the vehicle 100 (e.g.,

provided to a planning system 404 as shown in FIG. 4), or the combined output can be provided to the other systems, either in the form of a single combined output or multiple combined outputs of the same type (e.g., using the same combination technique or combining the same outputs or both) or different types type (e.g., using different respective combination techniques or combining different respective outputs or both). In some embodiments, an early fusion technique is used. An early fusion technique is characterized by combining outputs before one or more data processing steps are applied to the combined output. In some embodiments, a late fusion technique is used. A late fusion technique is characterized by combining outputs after one or more data processing steps are applied to the individual outputs.

[0085] FIG. 6 shows an example of a LiDAR system 602 (e.g., the input 502a shown in FIG. 5). The LiDAR system 602 emits light 604a-c from a light emitter 606 (e.g., a laser transmitter). Light emitted by a LiDAR system is typically not in the visible spectrum; for example, infrared light is often used. Some of the light 604b emitted encounters a physical object 608 (e.g., a vehicle) and reflects back to the LiDAR system 602. (Light emitted from a LiDAR system typically does not penetrate physical objects, e.g., physical objects in solid form.) The LiDAR system 602 also has one or more light detectors 610, which detect the reflected light. In an embodiment, one or more data processing systems associated with the LiDAR system generates an image 612 representing the field of view 614 of the LiDAR system. The image 612 includes information that represents the boundaries 616 of a physical object 608. In this way, the image 612 is used to determine the boundaries 616 of one or more physical objects near an AV.

[0086] FIG. 7 shows the LiDAR system 602 in operation. In the scenario shown in this figure, the vehicle 100 receives both camera system output 504c in the form of an image 702 and LiDAR system output 504a in the form of LiDAR data points 704. In use, the data processing systems of the vehicle 100 compares the image 702 to the data points 704. In particular, a physical object 706 identified in the image 702 is also identified among the data points 704. In this way, the vehicle 100 perceives the boundaries of the physical object based on the contour and density of the data points 704.

[0087] FIG. 8 shows the operation of the LiDAR system 602 in additional detail. As described above, the vehicle 100 detects the boundary of a physical object based on characteristics of the data points detected by the LiDAR system 602. As shown in FIG. 8, a flat object, such as the ground 802, will reflect light 804a-d emitted from a LiDAR system 602 in a

consistent manner. Put another way, because the LiDAR system 602 emits light using consistent spacing, the ground 802 will reflect light back to the LiDAR system 602 with the same consistent spacing. As the vehicle 100 travels over the ground 802, the LiDAR system 602 will continue to detect light reflected by the next valid ground point 806 if nothing is obstructing the road. However, if an object 808 obstructs the road, light 804e-f emitted by the LiDAR system 602 will be reflected from points 810a-b in a manner inconsistent with the expected consistent manner. From this information, the vehicle 100 can determine that the object 808 is present.

Path Planning

[0088] FIG. 9 shows a block diagram 900 of the relationships between inputs and outputs of a planning system 404 (e.g., as shown in FIG. 4). In general, the output of a planning system 404 is a route 902 from a start point 904 (e.g., source location or initial location), and an end point 906 (e.g., destination or final location). The route 902 is typically defined by one or more segments. For example, a segment is a distance to be traveled over at least a portion of a street, road, highway, driveway, or other physical area appropriate for automobile travel. In some examples, e.g., if the vehicle 100 is an off-road capable vehicle such as a four-wheel-drive (4WD) or all-wheel-drive (AWD) car, SUV, pick-up truck, or the like, the route 902 includes "off-road" segments such as unpaved paths or open fields.

[0089] In addition to the route 902, a planning system also outputs lane-level route planning data 908. The lane-level route planning data 908 is used to traverse segments of the route 902 based on conditions of the segment at a particular time. For example, if the route 902 includes a multi-lane highway, the lane-level route planning data 908 includes trajectory planning data 910 that the vehicle 100 can use to choose a lane among the multiple lanes, e.g., based on whether an exit is approaching, whether one or more of the lanes have other vehicles, or other factors that vary over the course of a few minutes or less. Similarly, in some implementations, the lane-level route planning data 908 includes speed constraints 912 specific to a segment of the route 902. For example, if the segment includes pedestrians or un-expected traffic, the speed constraints 912 may limit the vehicle 100 to a travel speed slower than an expected speed, e.g., a speed based on speed limit data for the segment.

[0090] In an embodiment, the inputs to the planning system 404 includes database data 914 (e.g., from the database system 410 shown in FIG. 4), current location data 916 (e.g., the AV

position 418 shown in FIG. 4), destination data 918 (e.g., for the destination 412 shown in FIG. 4), and object data 920 (e.g., the classified objects 416 as perceived by the perception system 402 as shown in FIG. 4). In some embodiments, the database data 914 includes rules used in planning. Rules are specified using a formal language, e.g., using Boolean logic. In any given situation encountered by the vehicle 100, at least some of the rules will apply to the situation. A rule applies to a given situation if the rule has conditions that are met based on information available to the vehicle 100, e.g., information about the surrounding environment. Rules can have priority. For example, a rule that says, "if the road is a freeway, move to the leftmost lane" can have a lower priority than "if the exit is approaching within a mile, move to the rightmost lane."

[0091] FIG. 10 shows a directed graph 1000 used in path planning, e.g., by the planning system 404 (FIG. 4). In general, a directed graph 1000 like the one shown in FIG. 10 is used to determine a path between any start point 1002 and end point 1004. In real-world terms, the distance separating the start point 1002 and end point 1004 may be relatively large (e.g., in two different metropolitan areas) or may be relatively small (e.g., two intersections abutting a city block or two lanes of a multi-lane road).

[0092] In an embodiment, the directed graph 1000 has nodes 1006a-d representing different locations between the start point 1002 and the end point 1004 that could be occupied by a vehicle 100. In some examples, e.g., when the start point 1002 and end point 1004 represent different metropolitan areas, the nodes 1006a-d represent segments of roads. In some examples, e.g., when the start point 1002 and the end point 1004 represent different locations on the same road, the nodes 1006a-d represent different positions on that road. In this way, the directed graph 1000 includes information at varying levels of granularity. In an embodiment, a directed graph having high granularity is also a subgraph of another directed graph having a larger scale. For example, a directed graph in which the start point 1002 and the end point 1004 are far away (e.g., many miles apart) has most of its information at a low granularity and is based on stored data, but also includes some high granularity information for the portion of the graph that represents physical locations in the field of view of the vehicle 100.

[0093] The nodes 1006a-d are distinct from objects 1008a-b which cannot overlap with a node. In an embodiment, when granularity is low, the objects 1008a-b represent regions that cannot be traversed by automobile, e.g., areas that have no streets or roads. When granularity is

high, the objects 1008a-b represent physical objects in the field of view of the vehicle 100, e.g., other automobiles, pedestrians, or other entities with which the vehicle 100 cannot share physical space. In an embodiment, some or all of the objects 1008a-b are a static objects (e.g., an object that does not change position such as a street lamp or utility pole) or dynamic objects (e.g., an object that is capable of changing position such as a pedestrian or other car).

[0094] The nodes 1006a-d are connected by edges 1010a-c. If two nodes 1006a-b are connected by an edge 1010a, it is possible for a vehicle 100 to travel between one node 1006a and the other node 1006b, e.g., without having to travel to an intermediate node before arriving at the other node 1006b. (When we refer to a vehicle 100 traveling between nodes, we mean that the vehicle 100 travels between the two physical positions represented by the respective nodes.) The edges 1010a-c are often bidirectional, in the sense that a vehicle 100 travels from a first node to a second node, or from the second node to the first node. In an embodiment, edges 1010a-c are unidirectional, in the sense that an vehicle 100 can travel from a first node to a second node, however the vehicle 100 cannot travel from the second node to the first node. Edges 1010a-c are unidirectional when they represent, for example, one-way streets, individual lanes of a street, road, or highway, or other features that can only be traversed in one direction due to legal or physical constraints.

[0095] In an embodiment, the planning system 404 uses the directed graph 1000 to identify a path 1012 made up of nodes and edges between the start point 1002 and end point 1004.

[0096] An edge 1010a-c has an associated cost 1014a-b. The cost 1014a-b is a value that represents the resources that will be expended if the vehicle 100 chooses that edge. A typical resource is time. For example, if one edge 1010a represents a physical distance that is twice that as another edge 1010b, then the associated cost 1014a of the first edge 1010a may be twice the associated cost 1014b of the second edge 1010b. Other factors that affect time include expected traffic, number of intersections, speed limit, etc. Another typical resource is fuel economy. Two edges 1010a-b may represent the same physical distance, but one edge 1010a may require more fuel than another edge 1010b, e.g., because of road conditions, expected weather, etc.

[0097] When the planning system 404 identifies a path 1012 between the start point 1002 and end point 1004, the planning system 404 typically chooses a path optimized for cost, e.g., the path that has the least total cost when the individual costs of the edges are added together.

AV Control

[0098] FIG. 11 shows a block diagram 1100 of the inputs and outputs of a control system 406 (e.g., as shown in FIG. 4). A control system operates in accordance with a controller 1102 which includes, for example, one or more processors (e.g., one or more computer processors such as microprocessors or microcontrollers or both) similar to processor 304, short-term and/or long-term data storage (e.g., memory random-access memory or flash memory or both) similar to main memory 306, ROM 308, and storage device 310, and instructions stored in memory that carry out operations of the controller 1102 when the instructions are executed (e.g., by the one or more processors).

[0099] In an embodiment, the controller 1102 receives data representing a desired output 1104. The desired output 1104 typically includes a velocity, e.g., a speed and a heading. The desired output 1104 can be based on, for example, data received from a planning system 404 (e.g., as shown in FIG. 4). In accordance with the desired output 1104, the controller 1102 produces data usable as a throttle input 1106 and a steering input 1108. The throttle input 1106 represents the magnitude in which to engage the throttle (e.g., acceleration control) of an vehicle 100, e.g., by engaging the steering pedal, or engaging another throttle control, to achieve the desired output 1104. In some examples, the throttle input 1106 also includes data usable to engage the brake (e.g., deceleration control) of the vehicle 100. The steering input 1108 represents a steering angle, e.g., the angle at which the steering control (e.g., steering wheel, steering angle actuator, or other functionality for controlling steering angle) of the AV should be positioned to achieve the desired output 1104.

[0100] In an embodiment, the controller 1102 receives feedback that is used in adjusting the inputs provided to the throttle and steering. For example, if the vehicle 100 encounters a disturbance 1110, such as a hill, the measured speed 1112 of the vehicle 100 is lowered below the desired output speed. In an embodiment, any measured output 1114 is provided to the controller 1102 so that the necessary adjustments are performed, e.g., based on the differential 1113 between the measured speed and desired output. The measured output 1114 includes a measured position 1116, a measured velocity 1118 (including speed and heading), a measured acceleration 1120, and other outputs measurable by sensors of the vehicle 100.

[0101] In an embodiment, information about the disturbance 1110 is detected in advance, e.g., by a sensor such as a camera or LiDAR sensor, and provided to a predictive feedback

system 1122. The predictive feedback system 1122 then provides information to the controller 1102 that the controller 1102 can use to adjust accordingly. For example, if the sensors of the vehicle 100 detect ("see") a hill, this information can be used by the controller 1102 to prepare to engage the throttle at the appropriate time to avoid significant deceleration.

[0102] FIG. 12 shows a block diagram 1200 of the inputs, outputs, and components of the controller 1102. The controller 1102 has a speed profiler 1202 which affects the operation of a throttle/brake controller 1204. For example, the speed profiler 1202 instructs the throttle/brake controller 1204 to engage acceleration or engage deceleration using the throttle/brake 1206 depending on, e.g., feedback received by the controller 1102 and processed by the speed profiler 1202.

[0103] The controller 1102 also has a lateral tracking controller 1208 which affects the operation of a steering controller 1210. For example, the lateral tracking controller 1208 instructs the steering controller 1210 to adjust the position of the steering angle actuator 1212 depending on, e.g., feedback received by the controller 1102 and processed by the lateral tracking controller 1208.

[0104] The controller 1102 receives several inputs used to determine how to control the throttle/brake 1206 and steering angle actuator 1212. A planning system 404 provides information used by the controller 1102, for example, to choose a heading when the vehicle 100 begins operation and to determine which road segment to traverse when the vehicle 100 reaches an intersection. A localization system 408 provides information to the controller 1102 describing the current location of the vehicle 100, for example, so that the controller 1102 can determine if the vehicle 100 is at a location expected based on the manner in which the throttle/brake 1206 and steering angle actuator 1212 are being controlled. In an embodiment, the controller 1102 receives information from other inputs 1214, e.g., information received from databases, computer networks, etc.

Automated Emergency Braking

[0105] FIG. 13 is a block diagram of a braking sub-system 1300. In the example of FIG. 13, the braking subsystem 1300 obtains inputs from the environment 1302 (e.g., environment 190 of FIG. 1). An AV stack 1304 captures and processes sensor data (e.g., outputs 504a-d) from the environment 1302. In embodiments, the AV stack 1304 refers to an architecture of the AV, such

as the architecture 400 of FIG. 4. Additionally, in embodiments the AV stack 1304 is the AV system 120 including sensors 121 of FIG 1. In examples, the AV stack 1304 includes a perception system 402 (sometimes referred to as a perception circuit), planning system 404 (sometimes referred to as a planning circuit), a control system 406 (sometimes referred to as a control circuit), a localization system 408 (sometimes referred to as a localization circuit), and a database system 410 (sometimes referred to as a database circuit). In some embodiments, perception system 402, planning system 404, control system 406, localization system 408, and database 410 are included and/or implemented in an autonomous navigation system of a vehicle (e.g., an autonomous vehicle compute).

[0106] The AV stack 1304 outputs data that is obtained by a drive by wire system 1308. In embodiments, the AV stack 1304 outputs trajectory data. The trajectory data is, for example, generated by a planning system 404 (FIG. 4) of the AV stack 1304. In embodiments, the planning system outputs trajectory planning data (e.g., trajectory planning data 910 of FIG. 9). The AV stack 1304 outputs a trajectory that includes data associated with a trajectory such as speed, waypoint information (x,y), speed at each waypoint, and the like. In examples, the waypoints are separated by time. For example, between each waypoint a time value of .5 seconds may elapse. The outputs of the AV stack can include one or more commands or diagnostics for input to the drive by wire system 1308. For example, the data output by the AV stack 1304 includes fault diagnostics detected by the AV stack. Fault diagnostics include data identifying an error or abnormal condition of the vehicle. For example, a brake fault diagnostic indicates an error or abnormal condition in the brake system.

[0107] The AEB system 1306 captures and processes sensor data from the environment 1302. The AEB system 1306 includes sensors 1307 and processors 1309. In embodiments, the sensors 1307 and processors 1309 are independent and separate from the AV stack 1304. For example, the sensors 1307 and the processors 1309 capture and process data without the use of compute resources from the AV stack 1304. In embodiments, the sensors 1307 are sensors for measuring or inferring properties of state or condition of the AV, such as the AV's position, linear and angular velocity and acceleration, and heading (e.g., an orientation of the leading end of the vehicle).The sensors 1307 also include sensors for sensing or measuring properties of the AV's environment. Exemplary sensors 1307 include monocular or stereo video cameras, LiDAR, RADAR, ultrasonic sensors, time-of-flight (TOF) depth sensors, speed sensors, temperature

sensors, humidity sensors, precipitation sensors, GPS, IMU, wheel speed sensors, wheel brake pressure or braking torque sensors, engine torque or wheel torque sensors, steering angle and angular rate sensors. In embodiments, the sensors 1307 are redundant or overlap sensors of the AV stack 1304.

[0108] In examples, the AEB system 1306 is provided in the vehicle 100. For example, referring to FIG. 1, an AV system 120 (e.g., AV stack 1304) operates the vehicle 100 along a trajectory 198 through an environment 190 to a destination 199 (sometimes referred to as a final location) while avoiding objects (e.g., natural obstructions 191, vehicles 193, pedestrians 192, cyclists, and other obstacles) and obeying rules of the road (e.g., rules of operation or driving preferences). The AEB system 1306 detects potential collisions in the environment 190 while the vehicle 100 traverses the trajectory 198 the destination 199. For example, the AEB system 1306 generates deceleration commands to cause actuation of the brakes 103 of the vehicle 100, or otherwise cause deceleration of the vehicle 100 in response to imminent collision. In embodiments, a deceleration command includes a rate of deceleration (e.g., deceleration value). In embodiments, the deceleration command includes data used to calculate the rate of deceleration.

[0109] In embodiments, the AEB generates deceleration commands with values calculated by the AEB system 1306. Generally, the AV stack 1304 and the AEB system 1306 are independent and separate systems. The AEB system 1306 has its own sensors, has its own logic, has its own processing, has its own assessment of the external world, and its own path to braking actuation which passes through the drive by wire system 1308. In examples, the AEB system 1306 includes a controller, camera, and radar. In embodiments, AEB is a fused camera and radar system that enables automated emergency braking using fused camera and radar data.

[0110] A drive by wire system 1308 determines commands to cause operation of the AV. In embodiments, the drive by wire system 1308 is a safety controller. The drive by wire system 1308 enables vehicle functions traditionally achieved by mechanical linkages in a vehicle. For example, the drive by wire system 1308 replaces the traditional mechanical control systems with electronic control systems using electromechanical actuators and human-machine interfaces, such as pedal and steering feel emulators.

[0111] Inputs to the drive by wire system 1308 include, for example, data output by the AV stack 1304 and data output by the AEB system 1306. In examples, inputs to the drive by wire

system 1308 include driver brake pedal data, such as when the vehicle operates in manual mode and a human driver presses the brake pedal. Additional inputs to the drive by wire system 1308 include data from stability control systems, engine braking systems, and the like.

[0112] Commands output by the drive by wire system 1308 include, for example, steering commands, acceleration/deceleration commands (e.g., braking commands), speed commands, and the like. In examples, determining the commands for output includes performing a safety evaluation of the commands. For example, an estimated likelihood of the commands resulting in a collision or dangerous/illegal maneuver is determined. If this likelihood is less than a predetermined threshold, the command is output to actuators 1310. In embodiments, drive by wire system 1308 receives deceleration commands from the AV stack 1304 and the AEB system 1306. Actuators 1310 receive commands from the drive by wire system 1308 that cause motion 1312 of the vehicle. In embodiments, the drive by wire system 1308 calculates a deceleration value from trajectory data output by the AV stack 1304, and outputs commands based on the trajectory data. One or more actuators 1310 obtains the commands output by the drive by wire system 1308. The actuators 1310 output signals that cause vehicle motion 1312.

[0113] In embodiments, the drive by wire system 1308 performs brake arbitration when the AV is operating in an automated mode. In examples, drive by wire system calculates a deceleration command for output based on the data received from the AV stack 1304. In brake arbitration at the drive by wire system 1308, the drive by wire system 1308 selects between the deceleration command based on data output by the AV stack and a deceleration command output by the AEB system 1306. The AEB system 1306 performs brake arbitration, wherein the brake arbitration is modified at the AEB system 1306 based on the operational mode of the AV. In examples, the AEB 1306 provides perception during a fall back to a secondary trajectory data in the event of primary perception failure of the AV stack 1304. In embodiments, a primary system (e.g., the AV stack 1304) that handles more corner cases is a sharp system with lower technical risk. In embodiments, the backup secondary system (e.g., the AEB system 1306) is a safety system that assists drivers.

[0114] The block diagram of FIG. 13 is not intended to indicate that the AV system 1300 is to include all of the components shown in FIG. 13. Rather, the system can include fewer or additional components not illustrated in FIG. 13 (e.g., additional braking components, hardware, software, etc.). The system 1300 may include any number of additional components not shown,

depending on the details of the specific implementation. Furthermore, any of the AV stack 1304, AEB system 1306, drive by wire 1308, actuators 1310 and other described functionalities may be partially, or entirely, implemented in hardware and/or in a processor. For example, the functionality may be implemented with an application specific integrated circuit, in logic implemented in a processor, in logic implemented in a specialized graphics processing unit, or in any other device.

[0115] In embodiments, the automated emergency braking system as described herein takes as input vehicle platform dynamics, driver awareness inputs, perception data, and the like. In an example, vehicle platform dynamics include, but are not limited to, vehicle speed, an acceleration/deceleration rate, and steering data. In embodiments, vehicle platform dynamics are used to forecast a vehicle path. Driver awareness inputs include, but are not limited to, throttle pedal state, brake pedal states, steering rate, and the like. Perception data includes data captured by sensors of the AEB system (e.g., sensors 1307). In embodiments, the automated emergency braking system as described herein provides a number of outputs. For example, the outputs include throttle off, recharge, decelerate commands, and driver awareness inputs and the like. In embodiments, throttle of is used to initiate power torque drop-off. In embodiments, pre-charge is initiated to reduce hydraulic pressure by approximately 200ms. In examples, a decelerate command output by the AEB system is provided as discrete levels of deceleration. For example, the discrete levels of deceleration may be four, six, or ten meters per second squared (m/s2). In embodiments, the driver awareness inputs are utilized to assess human control of the vehicle.

[0116] In embodiments, the AEB system is a back-up system for the AV stack. Accordingly, the AEB system contains its own sensing, perception, trajectory forecast, and control systems. In embodiments, arbitration is implemented at the AEB system, and acceleration/deceleration selection is performed. In embodiments, an AEB arbiter determines a final deceleration output based on the arbitration among safety high, safe stop active (SSA) and longitudinal control outputs to ensure the highest level of deceleration is achieved. In an embodiment, AEB arbiter uses input from a brake system monitor (BSM) to arbitrate when a brake control system of the vehicle is actively braking, where "SH_Decel_Request.sts_SH1State = Safe-Stop Activated." In an embodiment, the AEB Arbiter uses the DOG input to arbitrate when DOG is actively braking, where "SH_Decel_Request.sts_SH2State = Safe-Stop Activated."

AEB Arbitration

[0117] FIG. 14 is a block diagram of AEB arbitration 1400. In the example of FIG. 14, an arbiter 1402 is illustrated. In embodiments, the arbiter 1402 is an AEB arbiter that is a software block executing via at least one power train chassis control unit (PCCU). In an embodiment, PCCUs are used for drive by wire control. In an embodiment, the AEB actives the emergency braking when faults present or triggered by external system, such as the AV stack 1304 of FIG. 13.

[0118] In embodiments, the arbiter 1402 receives inputs including deceleration requests 1404, safe stop requests 1406, and safe stop activations 1408. The arbiter determines a most conservative braking response in view of the inputs. In examples, the deceleration requests 1404 include a deceleration command from the AV stack, a deceleration command from the AEB system, a deceleration command from a driver via brake pedal application, or any combinations thereof. The arbiter arbitrates between the received and calculated deceleration values. In examples, the arbiter 1402 take as input a first safe handling deceleration request (DecelRequestSH1) that is a BSM stop deceleration, and a second safe handling deceleration request (DecelRequestSH2) that is a DOG stop deceleration. The arbiter 1402 also receives safe stop requests 1406 and safe stop activations 1408 as input. Safe stop requests are requests from the BSM system or DOG system that request a safe stop of the vehicle. Safe stop activations refer to a level of deceleration commanded by the AEB based on the brake control system of the vehicle. For ease of description, the examples describe herein refer to three levels. However, any number of levels can be used.

[0119] At the arbiter 1402, a decision 1420 determines if a safe stop request has been received. Safe stop requests include deceleration commands based on BSM or DOG inputs. In examples, a BSM safe stop request is indicated by a Boolean flag (AEB_DecelSH1_SafeStopActivated), and a DOG safe stop request is indicated by a Boolean flag (AEB_DecelSH2_SafeStopActivated). In response to a safe stop request from the BSM or DOG, a safety high deceleration is set equal to the respective BSM or DOG deceleration command value at block 1422. Simultaneously, safe stop activations generated by the AEB system are used to compare deceleration values at various stages of a safe stop.

[0120] In an embodiment, the AEB includes three stages or levels. For example, the first stage is prefill (AEB_SSA1_Rq (Bool, SSA1 request)), the second stage is partial-braking

(AEB_SSA2_Rq (Bool, SSA2 request)), and the third level is full braking (AEB_SSA3_Rq (Bool, SSA3 request)). Each of the stages are indicated through the use of a Boolean flag and correspond to a predetermined range of deceleration values. Once an object is observed, prefill occurs first. In an embodiment, brake prefill enables a fast brake actuator response of the automatic emergency braking.

[0121] In the example of FIG. 14, at a first safe stop activation decision 1424 prefilling occurs. In embodiments, prefill is associated with a predetermined level of deceleration (K_AEB_Comfort_decel_Mps2). AV stack data is used to generate deceleration commands during prefill. In embodiments, prefilling fills the brakes at a low pressure prior to actively operating the brake pedal. In embodiments, prefilling overcomes a clearance gap within the braking system prior to a braking action so that the brake pad is already resting on the brake disk. For example, resting the brake pad on the brake disk prior to the operation of the brake pedal results in less loss of time without braking due to the stroke of the brake and thus for the development of an effective braking force during the braking action. Once prefill is complete and the drive by wire system will no longer listen to the AV stack commands. Instead, the drive by wire system will send a first stage prefill signal to the brake system to prepare for braking. The drive-by-wire system will then move the next stage, which is referred to a partial braking.

[0122] At a second safe stop activation decision 1426, partial braking occurs. In examples, partial braking refers to a deceleration command of decelerations between 0 and -6m/s2. The partial braking levels are associated with a predetermined level of deceleration (K_AEB_Comfort_decel_Mps2). In embodiments, during partial braking the drive by wire system will switch to the command from the AEB for partial braking and send this command as a final deceleration output 1436. In embodiments, the deceleration command adjusts a position of the brake pedals accordingly to achieve the predetermined level of deceleration. At a third safe stop activation decision 1428, the AEB sends a deceleration command to enter a third stage: full braking. In embodiments, full braking is associated with a deceleration command of -6m/s2 to -10m/s2. The full braking levels are associated with a predetermined level of deceleration (K_AEB_Comfort_decel_Mps2).

[0123] Additionally, in embodiments, the arbiter 1402 obtains AEB longitudinal control values. The AEB longitudinal control values are captured by AEB sensors, and are used to generate acceleration/deceleration commands 1432 (e.g., AEB_VehAccelRq_Mps2) that are

arbitrated at block 1434. At block 1434, the received deceleration commands are compared, and the highest deceleration command is output as the final deceleration output 1436. During brake arbitration, the most aggressive braking value is selected. For example, a braking value of -10 m/s2 causes a greater rate of deceleration when compared to a braking value of -6 m/s2.

[0124] In the example of FIG. 14, the safety high deceleration set at block 1422, the deceleration commands associated with each safe stop activation decision 1424, 1426, and 1428, and the AEB system deceleration commands 1432 are continuously compared at the arbiter 1402, and the highest deceleration command is output as a final deceleration output 1436 (AEB_finalAccelRq_Mps2). The deceleration commands available for arbitration are based on an operational mode of the AV. In examples, the operational mode is managed by a mode manager. The operational mode can be provided to the arbiter 1502 as a flag input (e.g., MODMGR_SuperMode). In embodiments, the operational modes include manual mode, automated mode (safety driver in the driver seat but only monitoring), and driverless mode.

[0125] In examples, during automated mode, the deceleration values calculated from the trajectory output by the AV stack 1304 (Fig. 13) are compared with the deceleration value output by the AEB system 1306, which include any number of predetermined stages or levels. For example, the first prefill level charges the brake but does not initiate deceleration. The second partial level decelerates at -6m/s2, and the third full braking level. Arbitration compares deceleration values and chooses the most intense deceleration value and commands the actuator of the vehicle in accordance with that value. In embodiments, acceleration/deceleration calculations are performed using the following equations:

[0126] For a safety high deceleration determination:

Safety High1 decel = DecelRequestSH1 when AEB_DecelSH1_SafeStopActivated is true

Safety High2 decel = DecelRequestSH2 when AEB_DecelSH2_SafeStopActivated is true

[0127] To determine a final deceleration output 1536:

Generate AEB_VehAccelRq_Mps2

AEB_SSA1 = K_AEB_Comfort_decel_Mps2 when AEB_SSA1_Rq is true

AEB_SSA2 = K_AEB_Comfort_decel_Mps2 when AEB_SSA2_Rq is true

AEB_SSA3 = K_AEB_Max_decel_Mps2 when AEB_SSA3_Rq is true

[0128] The final output is the maximum of Safety High1 decel, Safety High2 decel, AEB_VehAccelRq_Mps2, AEB_SSA1, AEB_SSA2 and AEB_SSA3.

[0129] The block diagram of FIG. 14 is not intended to indicate that the arbitration 1400 is to include all of the components shown in FIG. 14. Rather, the system can include fewer or additional components not illustrated in FIG. 14 (e.g., additional deceleration inputs, levels, hardware, software, etc.). The arbitration 1400 may include any number of additional components not shown, depending on the details of the specific implementation. Furthermore, any of the arbiter 1402 and other described functionalities may be partially, or entirely, implemented in hardware and/or in a processor. For example, the functionality may be implemented with an application specific integrated circuit, in logic implemented in a processor, in logic implemented in a specialized graphics processing unit, or in any other device.

AEB Calibration

[0130] In embodiments, the AEB arbiter is calibrated. The AEB arbiter includes calibration of both BSM and DOG inputs. In some examples, the arbiter is calibrated in response to diagnostics output by the AV when a driver is present. In an embodiment, the AEB arbiter has a mechanism that enables calibrate of the deceleration values when triggered by diagnostics output.

Safe Stop Activation and Safe Handling Deceleration

[0131] In an embodiments, the safe stop activation levels can vary. For example, a first safe stop activation output shall set deceleration to -3m/s/s to arbitrate. In an embodiment, a second safe stop activation output shall set deceleration to -3m/s/s to arbitrate. In an embodiment, a second safe stop activation output shall set deceleration to -6m/s/s to arbitrate. In an embodiment, a third safe stop activation shall set deceleration to -10m/s/s to arbitrate. In an embodiment, safe handling output shall set deceleration to -10m/s/s to arbitrate.

Brake Arbitration

[0132] Figure 15 is a process flow diagram of a process 1500 that enables brake arbitration. The process 1500 can execute using the AV of FIG. 1, computer system of FIG. 3, or the braking subsystem of FIG. 13.

[0133] At block 1502, safe stop requests are obtained. A safe stop request is associated with a deceleration value of a vehicle in motion. At block 1504, safe stop activations associated with the safe stop request are determined. The safe stop activations are associated with predetermined deceleration values.

[0134] At block 1504, an automated emergency (AEB) system deceleration command is calculated. The AEB deceleration command includes a deceleration value calculated from data captured by the AEB system. At block 1506, arbitration is performed between the deceleration values associated with the safe stop request, predetermined deceleration values associated with the safe stop activations, and the deceleration value calculated from data captured by the AEB system to determine a final deceleration output. The final deceleration output is provided to actuators that cause deceleration of a vehicle in motion.

[0135] In the foregoing description, embodiments of the invention have been described with reference to numerous specific details that may vary from implementation to implementation. The description and drawings are, accordingly, to be regarded in an illustrative rather than a restrictive sense. The sole and exclusive indicator of the scope of the invention, and what is intended by the applicants to be the scope of the invention, is the literal and equivalent scope of the set of claims that issue from this application, in the specific form in which such claims issue, including any subsequent correction. Any definitions expressly set forth herein for terms contained in such claims shall govern the meaning of such terms as used in the claims. In addition, when we use the term "further comprising," in the foregoing description or following claims, what follows this phrase can be an additional step or entity, or a sub-step/sub-entity of a previously-recited step or entity.

WHAT IS CLAIMED IS:

1. A method comprising;

obtaining, using at least one processor, safe stop requests, wherein a safe stop request is associated with a deceleration value of a vehicle in motion;

determining, using the at least one processor, safe stop activations associated with the safe stop request, wherein the safe stop activations are associated with predetermined deceleration values;

calculating, using the at least one processor, an automated emergency (AEB) system deceleration command, wherein the AEB deceleration command comprises a deceleration value calculated from data captured by the AEB system; and

arbitrating, using the at least one processor, between the deceleration values associated with the safe stop request, predetermined deceleration values associated with the safe stop activations, and the deceleration value calculated from data captured by the AEB system to determine a final deceleration output.

2. The method of claim 1, wherein the safe stop request is output by a brake monitoring system.

3. The method of claim 1, wherein the safe stop request is output by a DOG system.

4. The method of any of claims 1-3, wherein the safe stop activations correspond to varying levels of deceleration and a status of the brake control system.

5. The method of any of claims 1-4, wherein the status of the brake control system is prefill, partial braking, or full braking.

6. The method of any of claims 1-5, wherein the AEB system is isolated from an autonomous vehicle stack of the vehicle.

7. The method of any of claims 1-6, wherein the final deceleration value causes deceleration of the vehicle in motion.

8. A non-transitory computer-readable storage medium comprising at least one program for execution by at least one processor of a first device, the at least one program including instructions which, when executed by the at least one processor, carry out a method comprising:

obtaining safe stop requests, wherein a safe stop request is associated with a deceleration value of a vehicle in motion;

determining safe stop activations associated with the safe stop request, wherein the safe stop activations are associated with predetermined deceleration values;

calculating an automated emergency (AEB) system deceleration command, wherein the AEB deceleration command comprises a deceleration value calculated from data captured by the AEB system; and

arbitrating between the deceleration values associated with the safe stop request, predetermined deceleration values associated with the safe stop activations, and the deceleration value calculated from data captured by the AEB system to determine a final deceleration output.

9. The non-transitory computer-readable storage medium of claim 8, wherein the safe stop request is output by a brake monitoring system.

10. The non-transitory computer-readable storage medium of claim 8, wherein the safe stop request is output by a DOG system.

11. The non-transitory computer-readable storage medium of any of claims 8-10, wherein the safe stop activations correspond to varying levels of deceleration and a status of the brake control system.

12. The non-transitory computer-readable storage medium of any of claims 8-11, wherein the status of the brake control system is prefill, partial braking, or full braking.

13. The non-transitory computer-readable storage medium of any of claims 8-12, wherein the AEB system is isolated from an autonomous vehicle stack of the vehicle.

14. The non-transitory computer-readable storage medium of any of claims 8-13, wherein the final deceleration value causes deceleration of the vehicle in motion.

15. A vehicle, comprising:

at least one computer-readable medium storing computer-executable instructions;

at least one processor communicatively coupled to the at least one sensor and configured to execute the computer executable instructions, the execution carrying out operations including:

obtaining safe stop requests, wherein a safe stop request is associated with a deceleration value of a vehicle in motion;

determining safe stop activations associated with the safe stop request, wherein the safe stop activations are associated with predetermined deceleration values;

calculating an automated emergency (AEB) system deceleration command, wherein the AEB deceleration command comprises a deceleration value calculated from data captured by the AEB system; and

arbitrating between the deceleration values associated with the safe stop request, predetermined deceleration values associated with the safe stop activations, and the deceleration value calculated from data captured by the AEB system to determine a final deceleration output.

16. The system of claim 15, wherein the safe stop request is output by a brake monitoring system.

17. The system of claim 15, wherein the safe stop request is output by a DOG system.

18. The system of any of claims 15-17, wherein the safe stop activations correspond to varying levels of deceleration and a status of the brake control system.

19. The system of any of claims 15-18, wherein the status of the brake control system is prefill, partial braking, or full braking.

20. The system of any of claims 15-19, wherein the AEB system is isolated from an autonomous vehicle stack of the vehicle.

21. The system of any of claims 15-20, wherein the final deceleration value causes deceleration of the vehicle in motion.

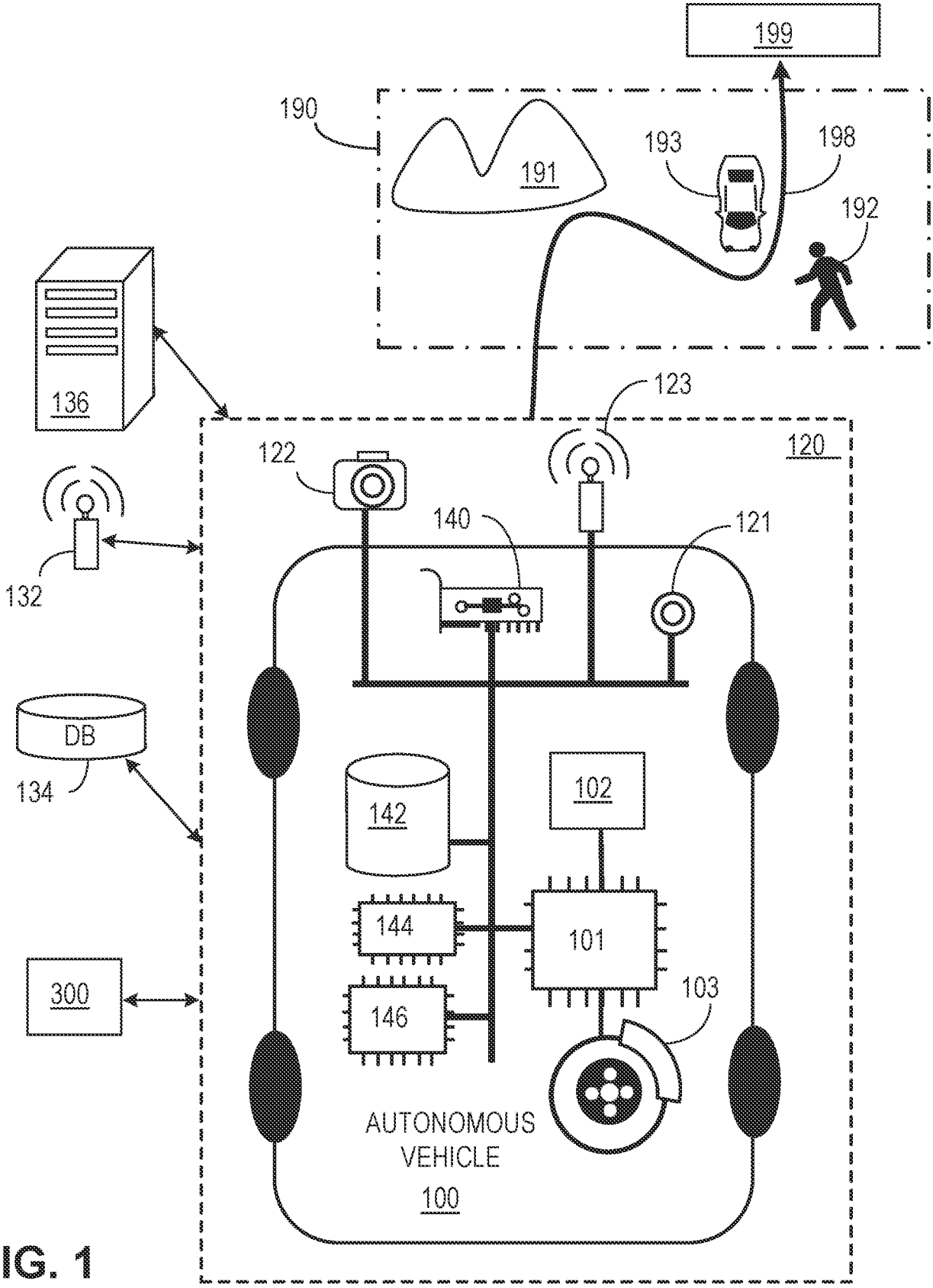

199
190
191
193
198
192
136
123
120
122
140
121
132
DB
134
142
102
144
101
103
146
300
AUTONOMOUS
VEHICLE
100

FIG. 1

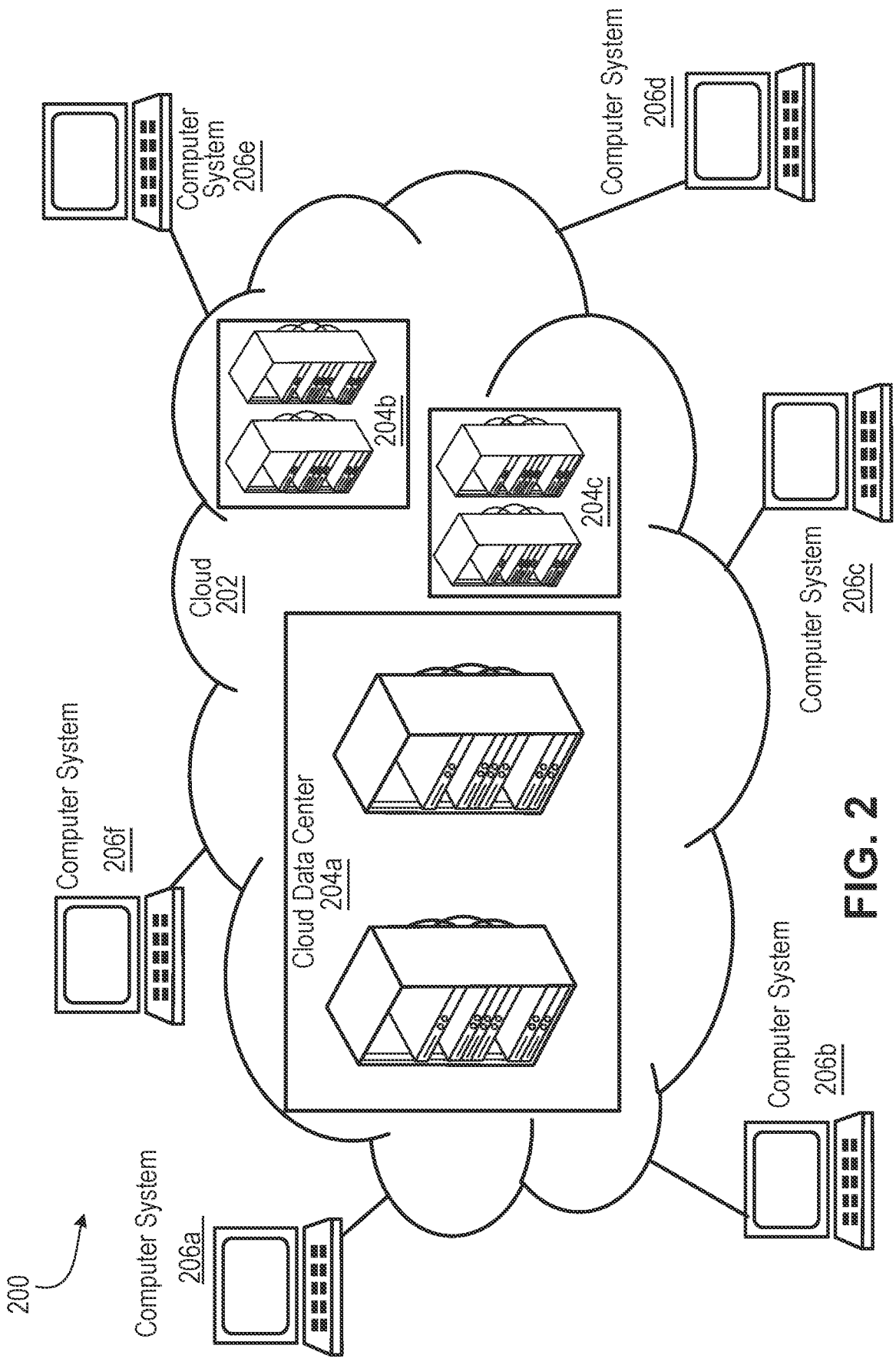

200
Computer System 206a
Computer System 206b
Computer System 206c
Computer System 206d
Computer System 206e
Computer System 206f
Cloud 202
Cloud Data Center 204a
204b
204c

FIG. 2

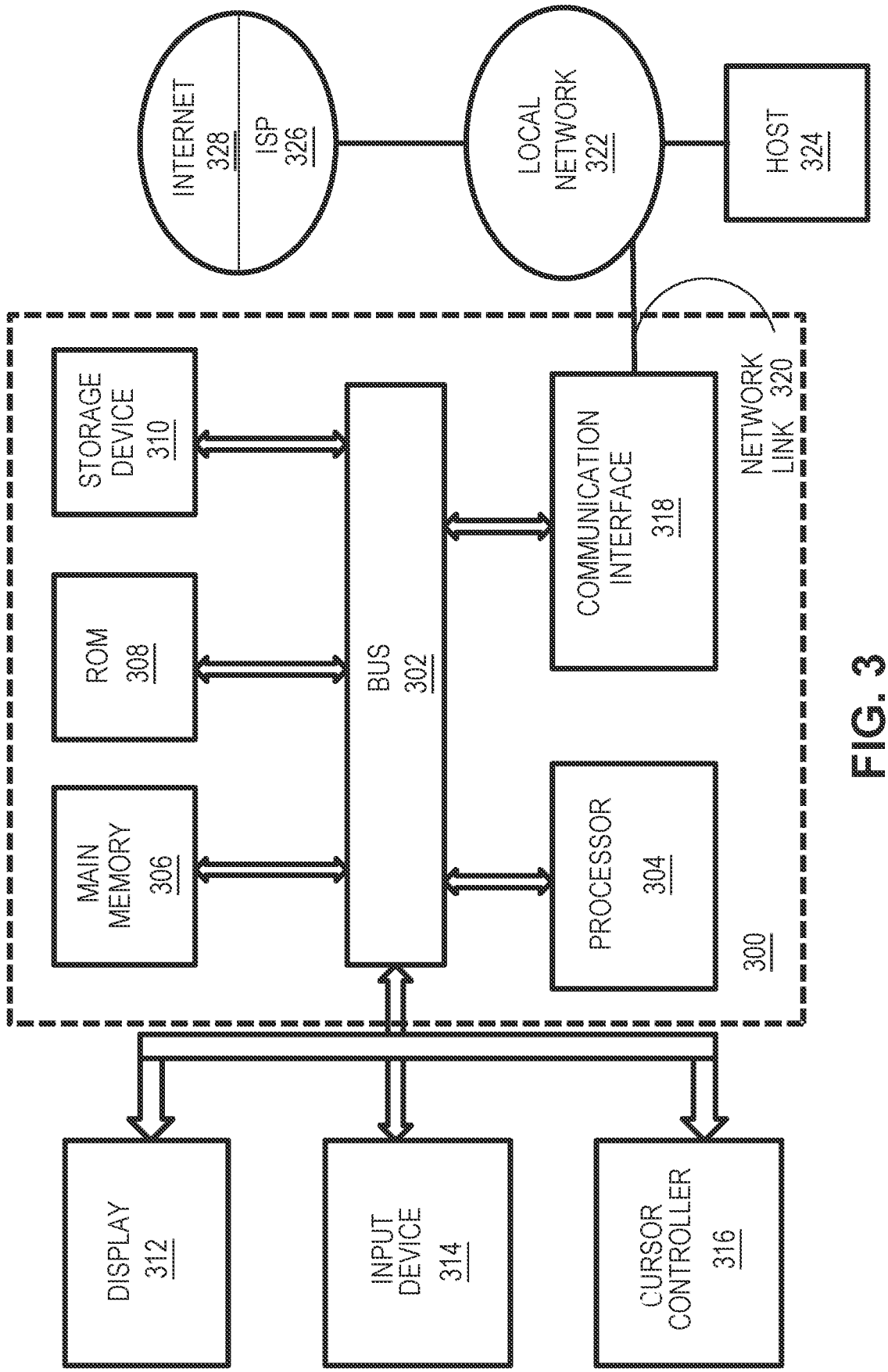

INTERNET
328
ISP
326
LOCAL
NETWORK
322
HOST
324
NETWORK
LINK 320
STORAGE
DEVICE
310
ROM
308
MAIN
MEMORY
306
BUS
302
COMMUNICATION
INTERFACE
318
PROCESSOR
304
300
DISPLAY
312
INPUT
DEVICE
314
CURSOR
CONTROLLER
316

FIG. 3

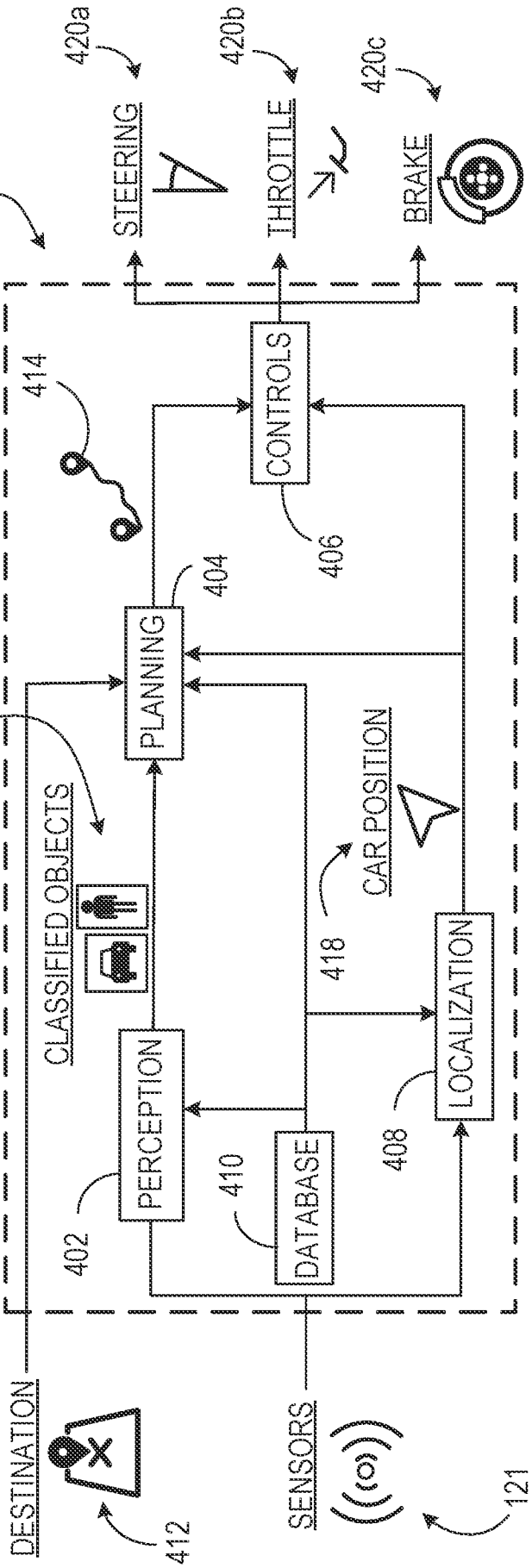

400
420a
STEERING
420b
THROTTLE
420c
BRAKE
CONTROLS
414
406
404
PLANNING
416
CLASSIFIED OBJECTS
CAR POSITION
418
PERCEPTION
LOCALIZATION
402
410
DATABASE
408
DESTINATION
SENSORS
412
121

FIG. 4

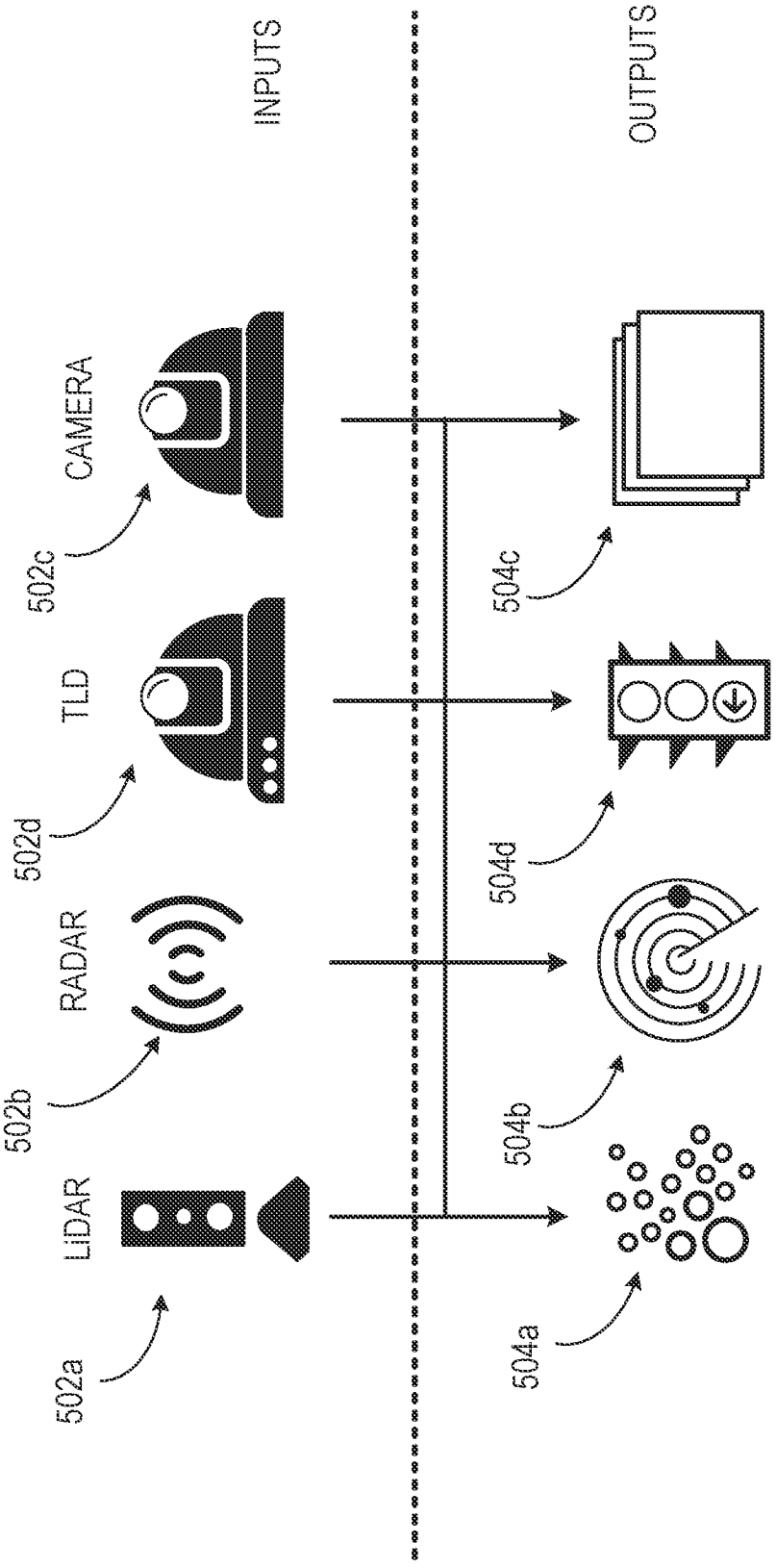

INPUTS
OUTPUTS
CAMERA
502c
TLD
502d
RADAR
502b
LiDAR
502a
504c
504d
504b
504a

FIG. 5

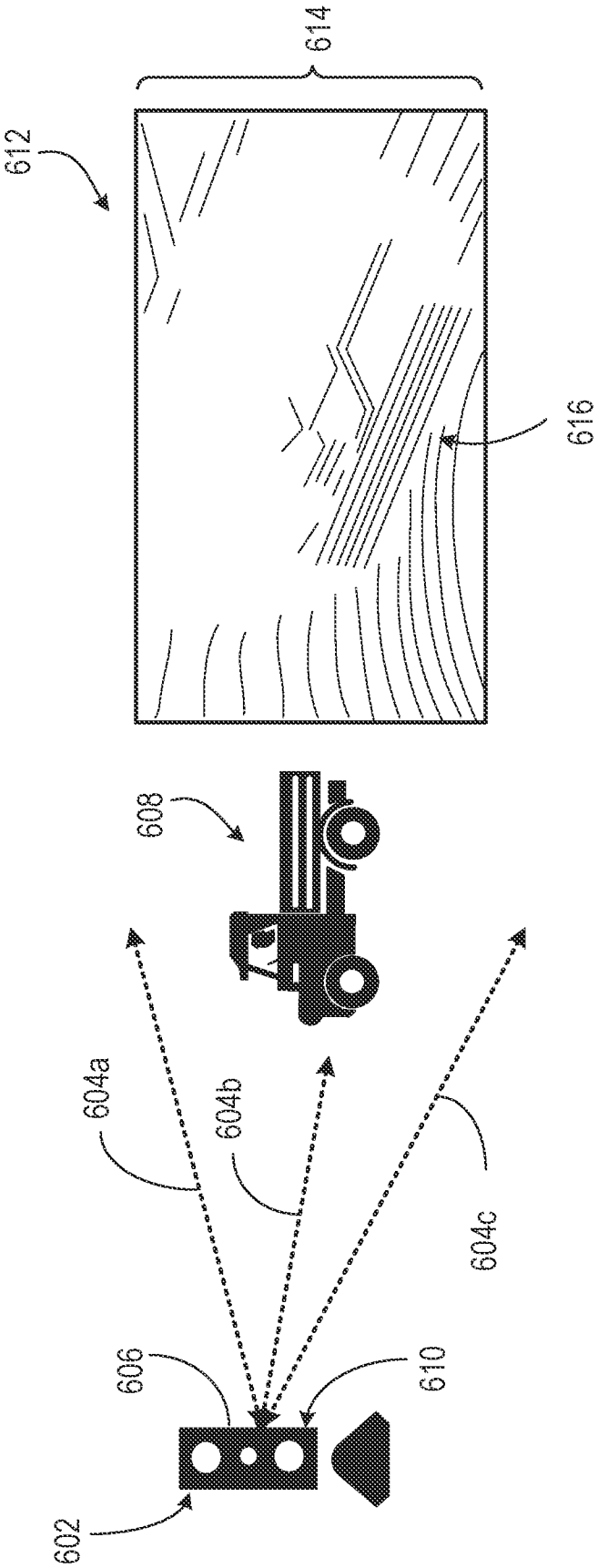


FIG. 6

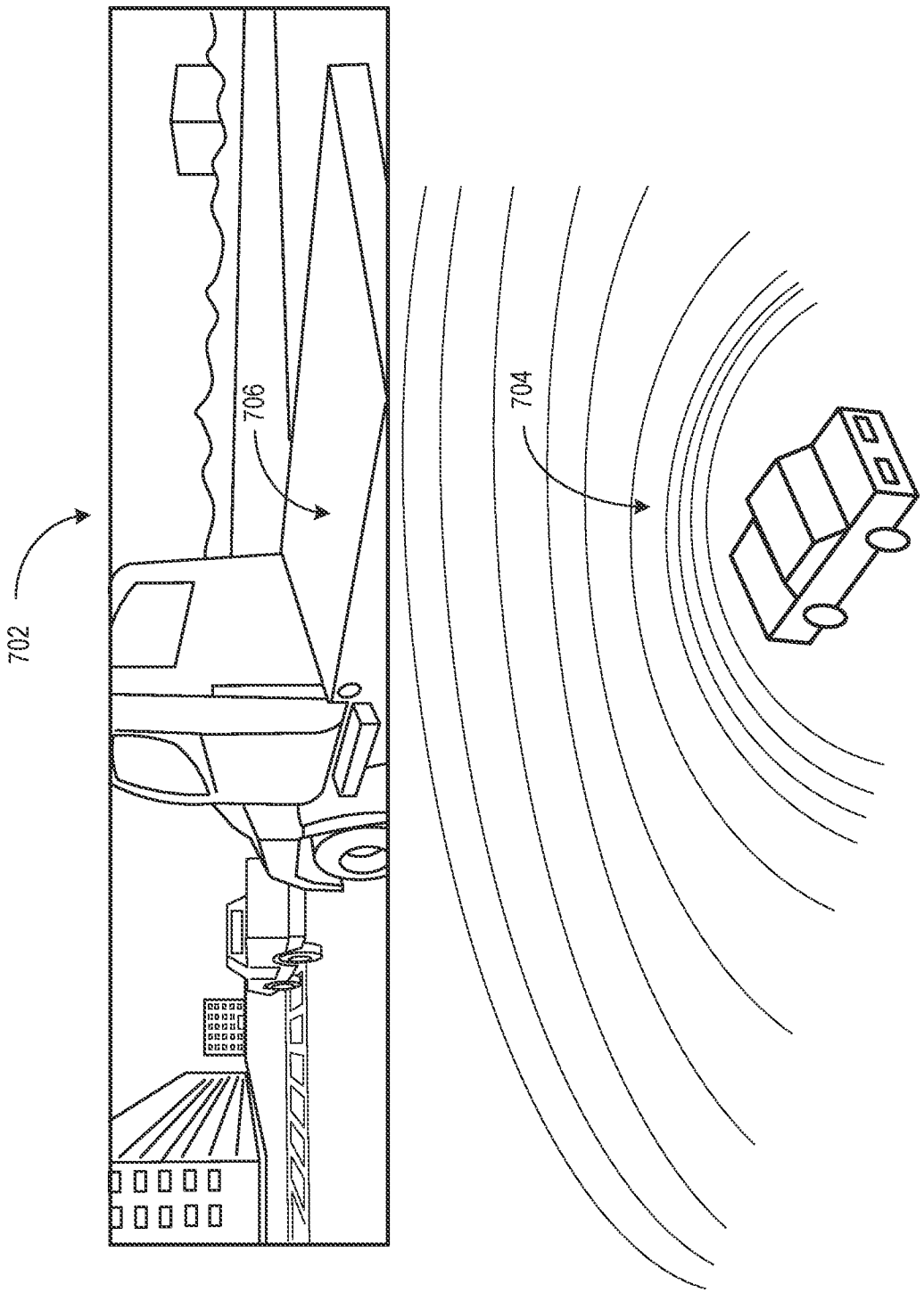


FIG. 7

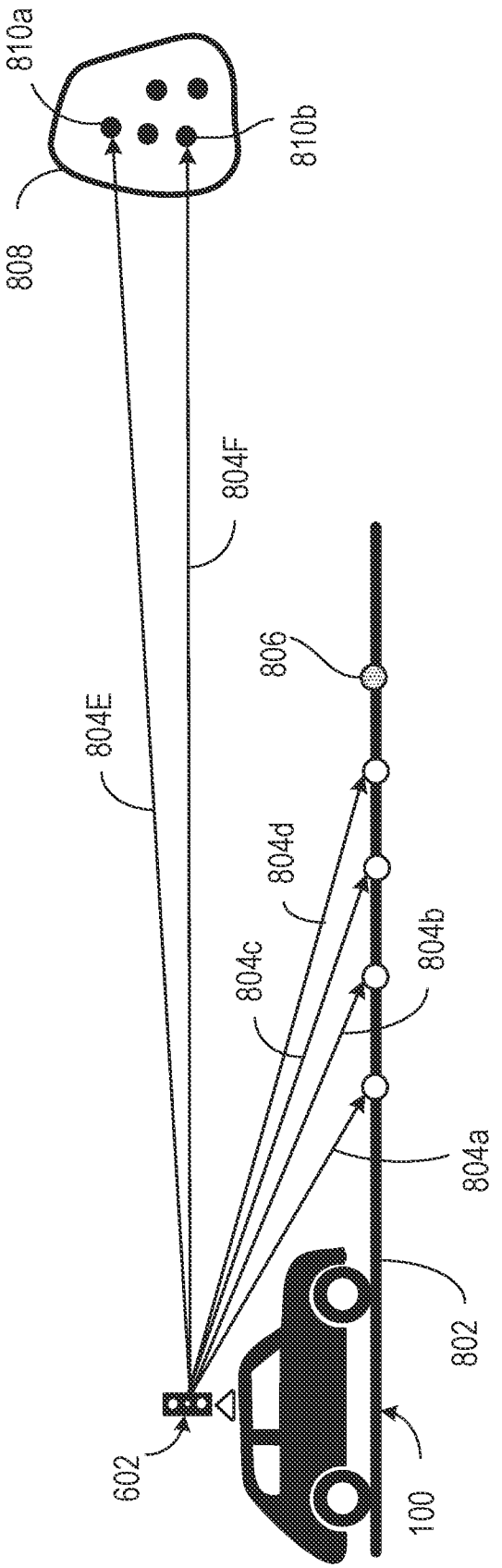


FIG. 8

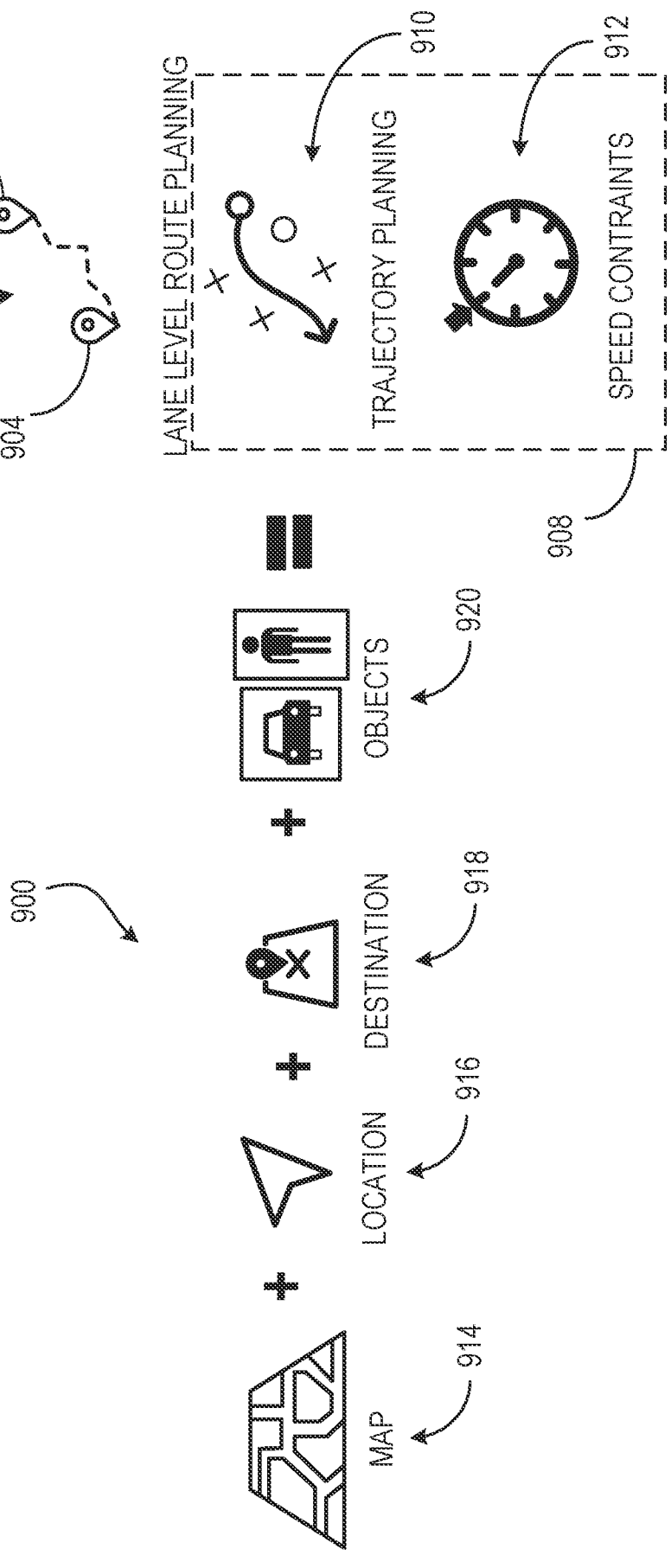

900
MAP
914
+
LOCATION
916
+
DESTINATION
918
+
OBJECTS
920
=
LANE LEVEL ROUTE PLANNING
908
TRAJECTORY PLANNING
910
SPEED CONTRAINTS
912
902
904
906

FIG. 9

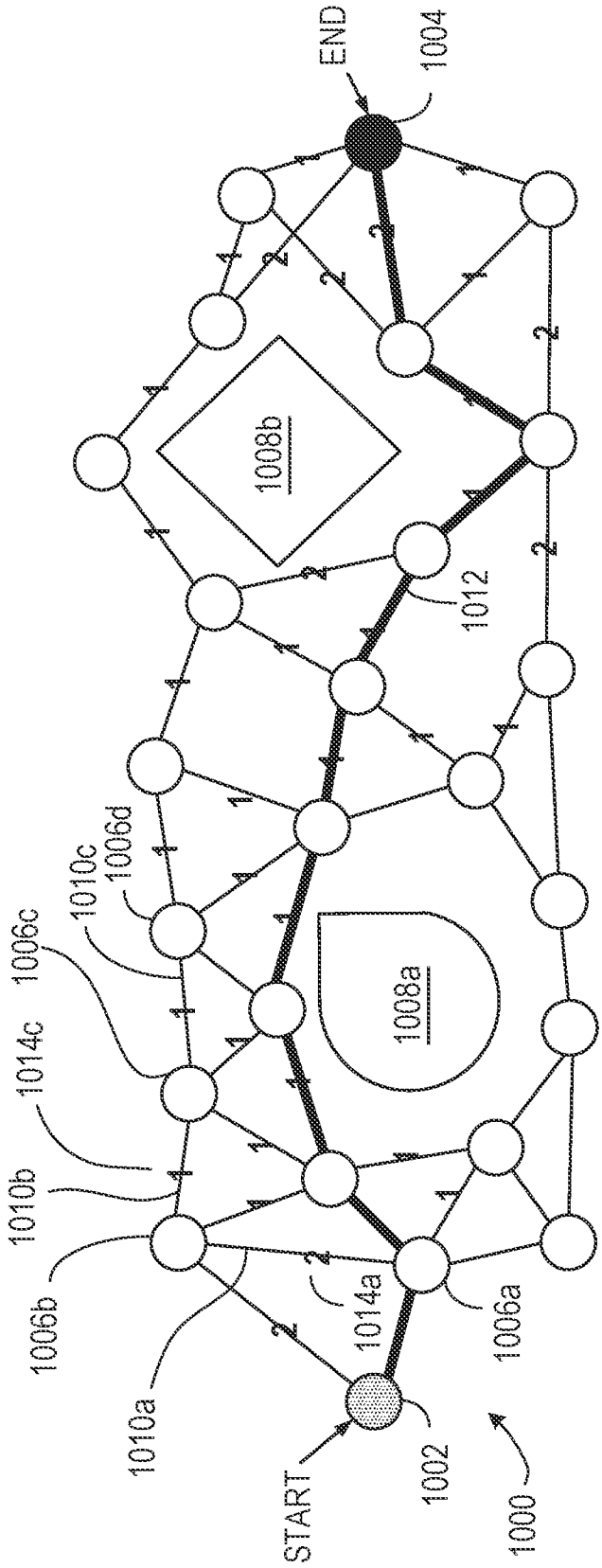

END
1004
1008b
1012
1006d
1010c
1006c
1014c
1010b
1006b
1010a
1008a
1014a
1006a
START
1002
1000

FIG. 10

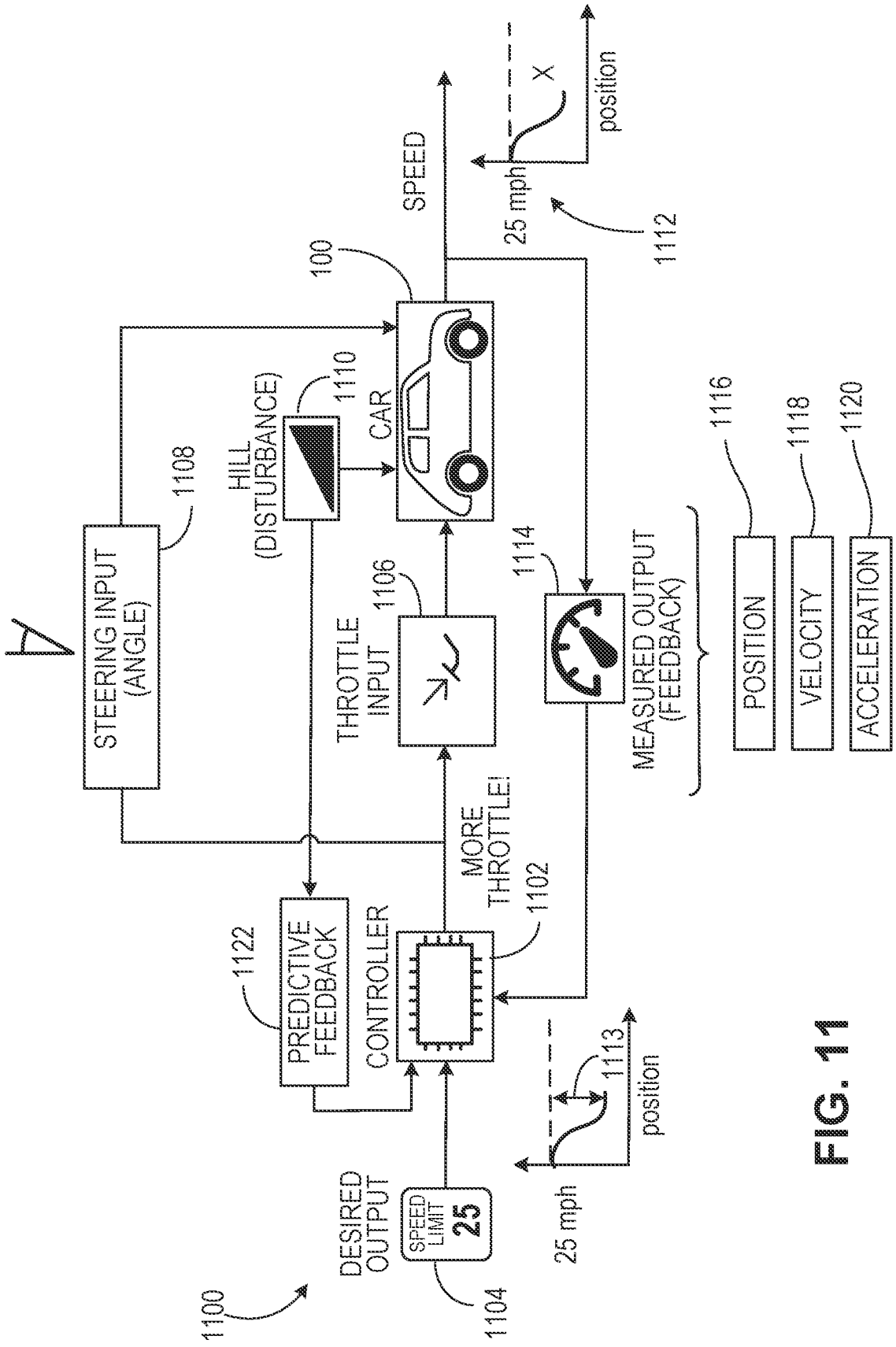

1100
DESIRED OUTPUT
SPEED LIMIT 25
1104
25 mph
1113
position
PREDICTIVE FEEDBACK
1122
CONTROLLER
MORE THROTTLE!
1102
THROTTLE INPUT
1106
STEERING INPUT (ANGLE)
1108
HILL (DISTURBANCE)
1110
CAR
100
SPEED
25 mph
X
position
1112
1114
MEASURED OUTPUT (FEEDBACK)
POSITION
1116
VELOCITY
1118
ACCELERATION
1120

FIG. 11

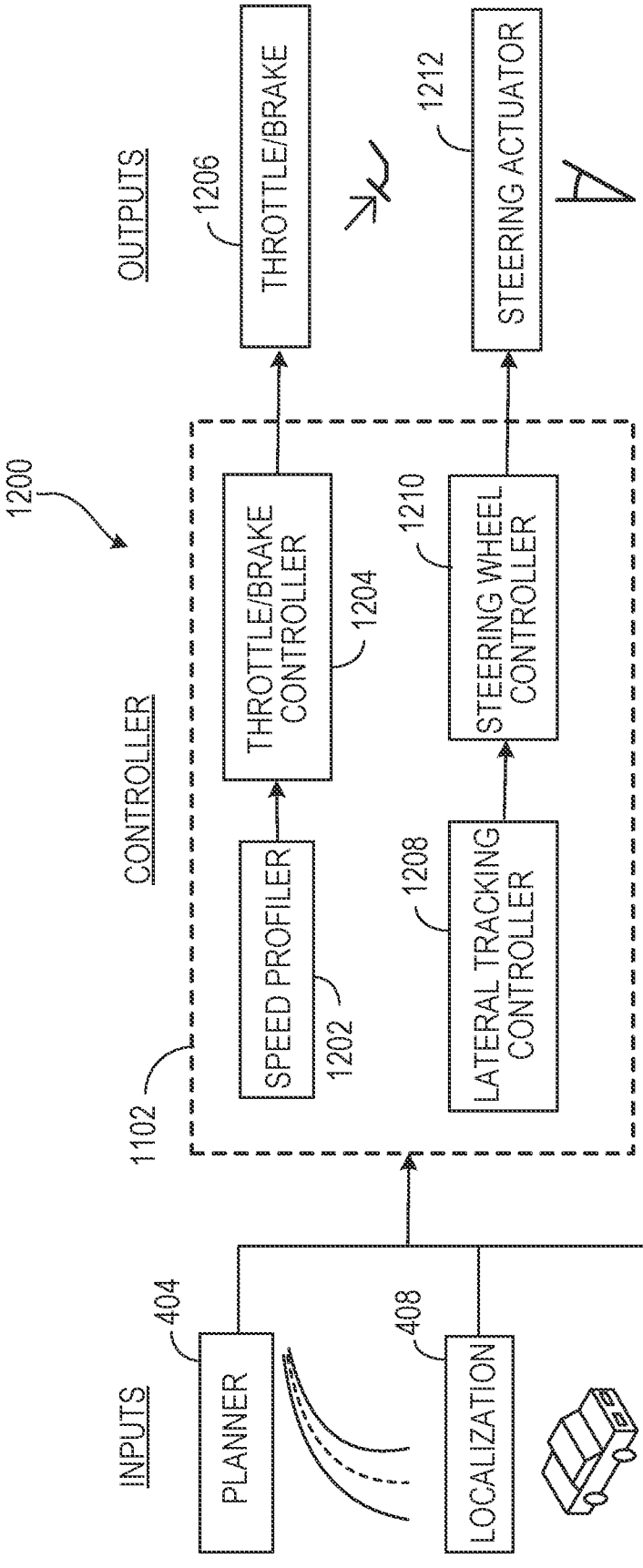

INPUTS
PLANNER
404
LOCALIZATION
408
OTHER INPUTS
1214
1200
CONTROLLER
1102
SPEED PROFILER
1202
THROTTLE/BRAKE CONTROLLER
1204
LATERAL TRACKING CONTROLLER
1208
STEERING WHEEL CONTROLLER
1210
OUTPUTS
THROTTLE/BRAKE
1206
STEERING ACTUATOR
1212

FIG. 12

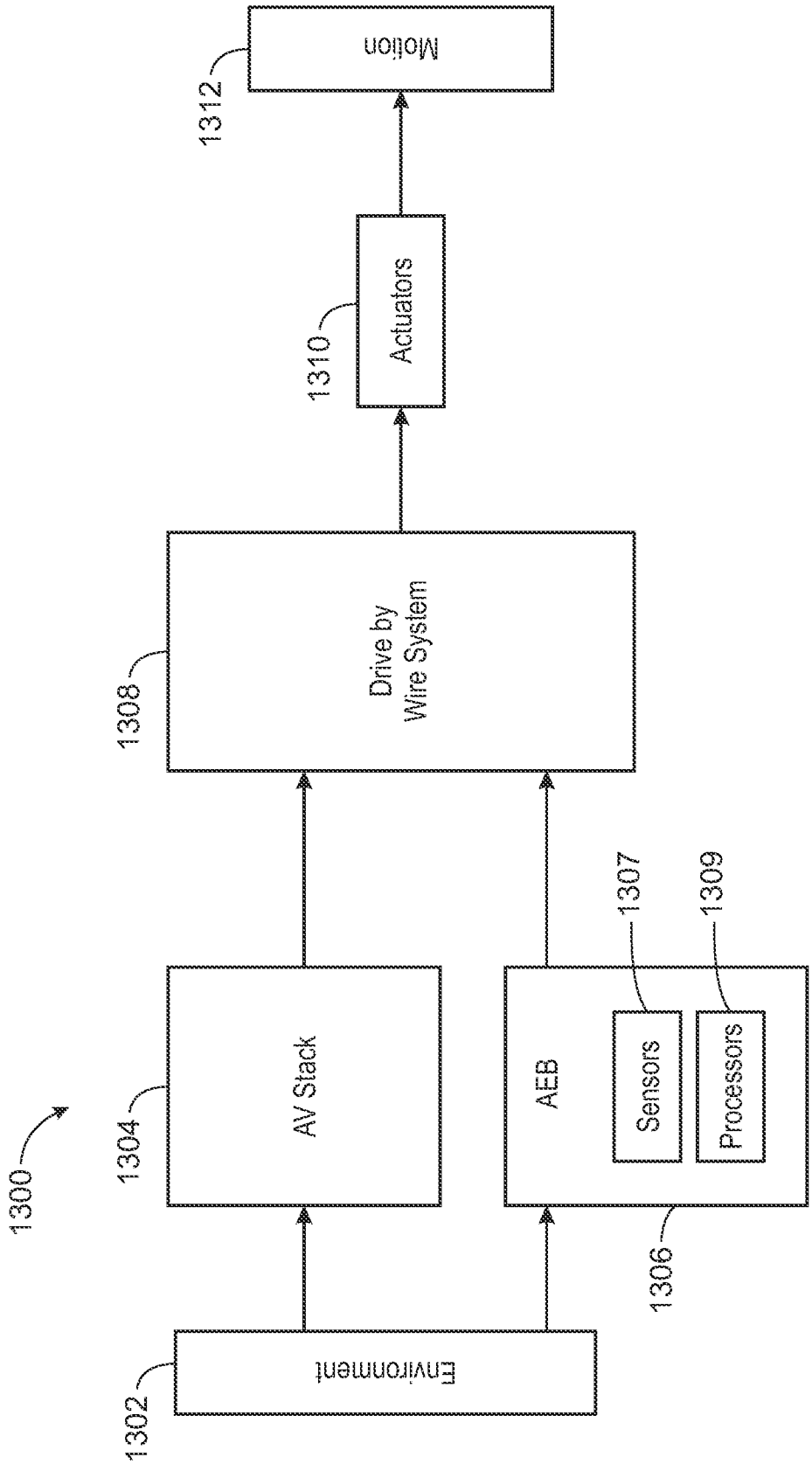

1300
1302
Environment
1304
AV Stack
1306
AEB
1307
Sensors
1309
Processors
1308
Drive by Wire System
1310
Actuators
1312
Motion

FIG. 13

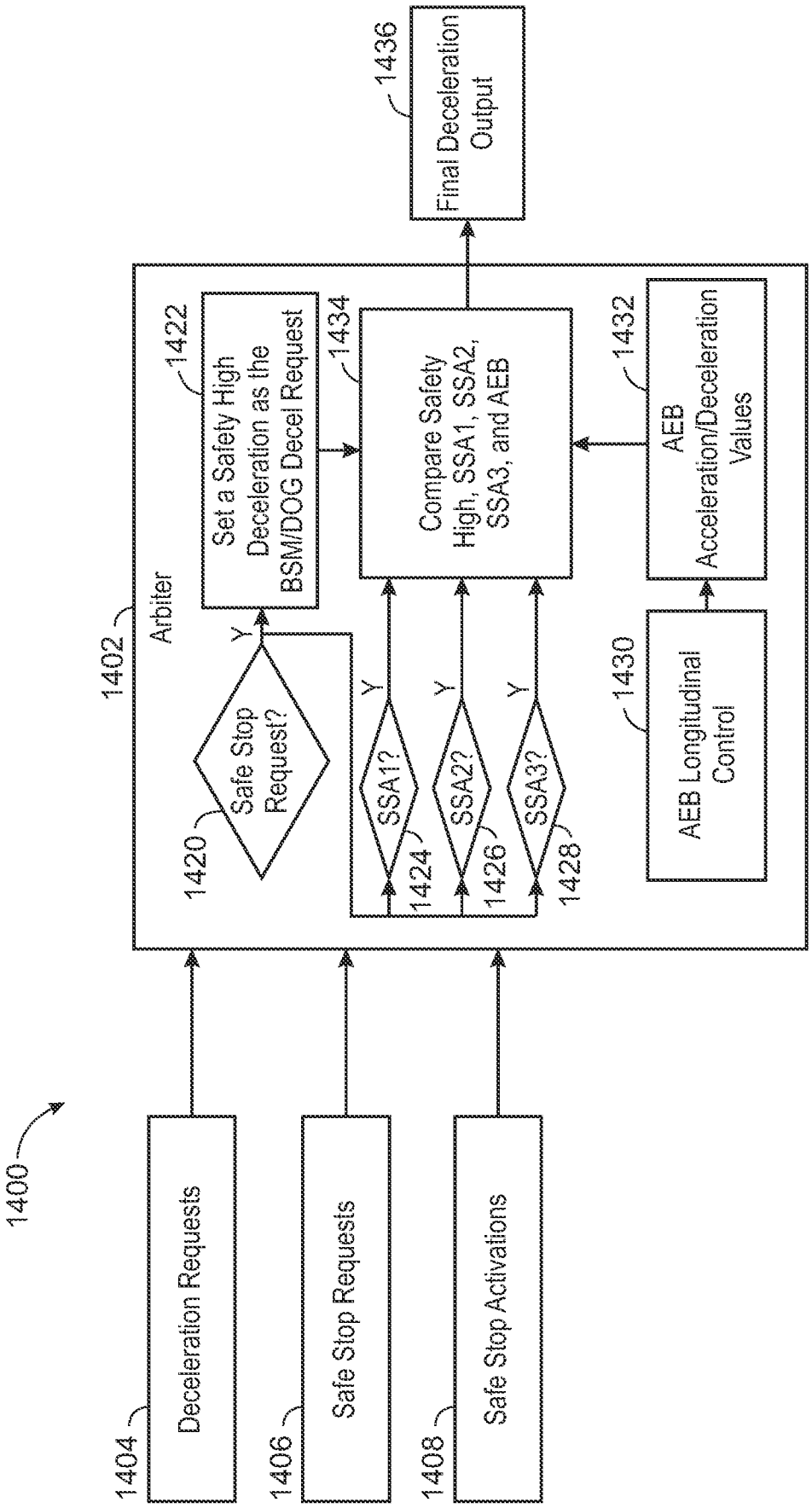

1400
1404
Deceleration Requests
1406
Safe Stop Requests
1408
Safe Stop Activations
1402
Arbiter
1420
Safe Stop Request?
Y
1422
Set a Safety High Deceleration as the BSM/DOG Decel Request
1424
SSA1?
Y
1426
SSA2?
Y
1428
SSA3?
Y
1430
AEB Longitudinal Control
1432
AEB Acceleration/Deceleration Values
1434
Compare Safety High, SSA1, SSA2, SSA3, and AEB
1436
Final Deceleration Output

FIG. 14

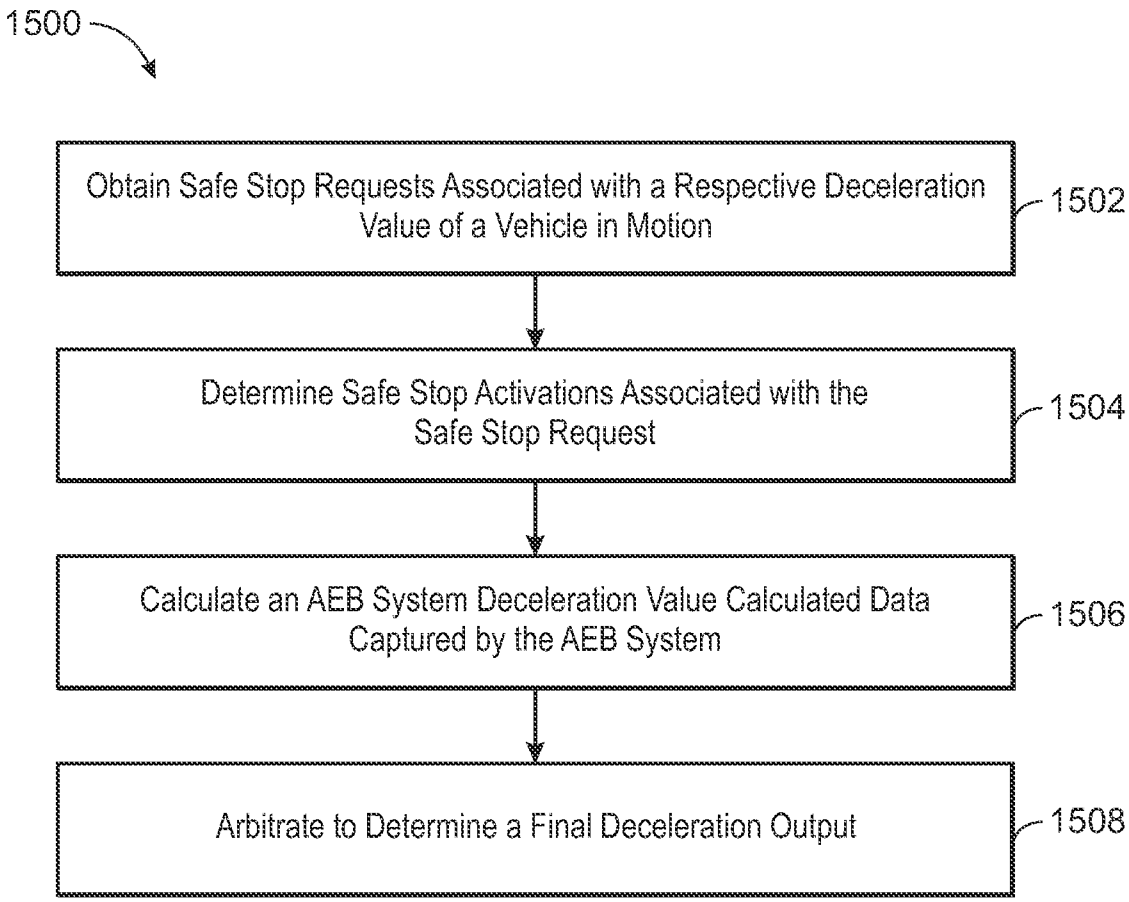

1500
Obtain Safe Stop Requests Associated with a Respective Deceleration Value of a Vehicle in Motion
1502
Determine Safe Stop Activations Associated with the Safe Stop Request
1504
Calculate an AEB System Deceleration Value Calculated Data Captured by the AEB System
1506
Arbitrate to Determine a Final Deceleration Output
1508

FIG. 15

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US22/20400

A. CLASSIFICATION OF SUBJECT MATTER

IPC - B60T 7/12; B60W 30/09; B60T 7/22; B60W 30/08; G08G 1/16 (2022.01)

CPC - B60T 7/12; B60W 30/09; B60T 7/22; B60W 30/08; G08G 1/16

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
See Search History document

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
See Search History document

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
See Search History document

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X --- Y	US 2013/0110370 A1 (TOYOTA JIDOSHA KABUSHIKI KAISHA) 02 May 2013; Figures: 1, 3 and paragraphs [0004], [0009]-[0014], [0031]-[0040], [0067], [0070], [0089]-[0091]	1-2, 4, 8-9, 11, 15-16 and 18 --- 3, 10 and 17
Y	US 2014/0358388 A1 (FCA US LLC) 04 December 2014; Paragraphs [0016], [0021]-[0022]	3, 10 and 17
A	US 2015/0012204 A1 (ZF CV) 08 January 2015; entire document	1-4, 8-11, 15-18
A	WO 2017/076436 A1 (VOLVO TRUCK CORP) 11 May 2017; entire document	1-4, 8-11, 15-18
A	US 2017/0113667 A1 (HYUNDAI MOTOR CO) 27 April 2017; entire document	1-4, 8-11, 15-18

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"D" document cited by the applicant in the international application
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
23 May 2022 (23.05.2022)	JUN 14 2022
Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-8300	Authorized officer Shane Thomas Telephone No. PCT Helpdesk: 571-272-4300

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US22/20400

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☒ Claims Nos.: 5-7, 12-14, 19-21
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.