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Lane bias maneuver for autonomous vehicles to negotiate a curved road

Abstract

A system for implementing a lane bias maneuver to negotiate a curved road comprises an autonomous vehicle and a control device. The control device determines that the autonomous vehicle is approaching a curved road. The control device determines a road radius of the curved road. The control device calculates a first lane bias adjustment amount associated with a road curvature of the curved road based on the road radius. The control device calculates a second lane bias adjustment amount associated with a trailer angle between a trailer and a semi-truck tractor unit of the autonomous vehicle. The control device calculates a total lane bias adjustment amount by combining the first and second lane bias adjustment amounts. The control device instructs the autonomous vehicle to perform a lane bias maneuver that comprises driving the autonomous vehicle off-center in a curved lane based on the total lane bias adjustment amount.

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Background/Summary

PRIORITY (1) The application claims priority to U.S. Provisional Application No. 63/263,289 filed Oct. 29, 2021, and titled “Lane Bias Maneuver for Autonomous Vehicles to Avoid an Intruding Vehicle,” and U.S. Provisional Application No. 63/263,303 filed Oct. 29, 2021, and titled “Lane Bias Maneuver for Autonomous Vehicles to Negotiate a Curved Road,” which are incorporated herein by reference.

TECHNICAL FIELD
(1) The present disclosure relates generally to autonomous vehicles. More particularly, the present disclosure is related to lane bias maneuver for autonomous vehicles to negotiate a curved road.
BACKGROUND
(2) One aim of autonomous vehicle technologies is to provide vehicles that can safely navigate towards a destination. It is inevitable that an autonomous vehicle encounters other vehicles while traveling on a road. An autonomous vehicle may sometimes drive on straight roads and sometimes on curved roads.
SUMMARY
(3) This disclosure recognizes various problems and previously unmet needs related to implementing safe navigation for autonomous vehicle in situations where the autonomous vehicle encounters an intruding, invading, or oversized vehicle or when the autonomous vehicle approaches a curved road. Certain embodiments of this disclosure provide unique technical solutions to technical problems of current autonomous vehicle technologies, including those problems described above to: 1) implement a lane bias maneuver to avoid intruding, invading, or oversized vehicles; and 2) implement a lane bias maneuver to negotiate a curved road.
(4) Implementing a Lane Bias Maneuver to Avoid a Vehicle
(5) This disclosure contemplates systems and methods for implementing a lane bias maneuver to avoid a vehicle. While traveling on a road, the autonomous vehicle may encounter an invading, intruding, or oversized vehicle in an adjacent lane. The lane bias maneuver may enable the autonomous vehicle to drive off-center in its current lane to avoid the encountered vehicle and to keep a safe distance (e.g., more than a predefined threshold distance) from the encountered vehicle. In other words, the lane bias maneuver may enable the autonomous vehicle to drive off-center in its current lane without changing to another lane.
(6) In some cases, changing to another lane may not be a safe maneuver because of traffic on the road. In other cases, the autonomous vehicle may need to stay on its current lane to perform the next navigation maneuver on its predefined routing plan, such as take a particular exit, take a particular turn, etc. In such cases, changing to another lane may not be a practical solution for

the autonomous vehicle.

(7) Thus, the disclosed system in this disclosure is integrated into a practical application of improving the navigation of the autonomous vehicles by implementing the lane bias maneuver in cases where the autonomous vehicle encounters an invading, intruding, or oversized vehicle in the adjacent lane.

(8) The invading vehicle in the adjacent lane may be classified as a vehicle that is constantly driving in close proximity from the autonomous vehicle, for example, closer than a threshold distance defined by a control device of the autonomous vehicle, such as six feet, seven feet, etc.

(9) The intruding vehicle in the adjacent lane may be classified as a vehicle that temporarily or suddenly drives too close to the autonomous vehicle, e.g., closer than the threshold distance from the autonomous vehicle. The oversized vehicle in the adjacent lane may be classified as a vehicle that is taking more space in the adjacent lane due to its size, and as a result, a distance between the oversized vehicle and the autonomous vehicle is less than the threshold distance. Each of the invading, intruding, and oversized vehicles may generally be referred to herein as a vehicle or encountered vehicle.

(10) In any case of encountering such vehicles in the adjacent lane from the autonomous vehicle, the control device of the autonomous vehicle may determine that a lateral distance between the autonomous vehicle and each vehicle is less than the threshold distance.

(11) In some cases, the control device of the autonomous vehicle may determine that the vehicle in the adjacent lane from the autonomous vehicle has crossed over a lane marker between the autonomous vehicle and the vehicle. In some cases, the control device of the autonomous vehicle may determine that the vehicle in the adjacent lane has not crossed over the lane marker, but is driving within the threshold distance from the autonomous vehicle. In other cases, the control device of the autonomous vehicle may determine that a vehicle has previously crossed over one or more lane markers on the road based on historical driving behaviors or patterns of the vehicle. In other cases, the control device of the autonomous vehicle may determine that the vehicle is in an emergency lane, either parked or in transit.

(12) The vehicle may be detected on either side of the autonomous vehicle, or on either side and in front of the autonomous vehicle. The vehicle may be in transit or stationary. For example, the control device of the autonomous vehicle may determine that the vehicle is driving on either side of the autonomous vehicle in the adjacent lane. In another example, the control device of the autonomous vehicle may determine that the vehicle is driving on either side of the autonomous vehicle in the adjacent lane and in front of the autonomous vehicle. In another example, the control device of the autonomous vehicle may determine that the vehicle is stopped (or stalled) on a side of the road in front of the autonomous vehicle, for example, in a case where the vehicle is stopped on a side of the road to change its tire.

(13) In any of these cases, the control device of the autonomous vehicle may determine whether to instruct the autonomous vehicle to perform the lane bias maneuver. The lane bias maneuver may enable the autonomous vehicle to drive off-center in its current lane toward the opposite direction with respect to the vehicle until the lateral distance between the vehicle and the autonomous vehicle is at least equal to the threshold distance. In other words, the autonomous vehicle biases toward the other side of the current lane. In some embodiments, the autonomous vehicle may perform the lane bias maneuver until the autonomous vehicle and the vehicle are no longer adjacent to each other, for example, until either the autonomous vehicle passes by the vehicle or the vehicle passes by the autonomous vehicle. In one example, the autonomous vehicle may perform the lane bias maneuver until it is determined that no portion of the autonomous vehicle overlaps with any portion of the vehicle that is traveling in an adjacent lane. In another example, the autonomous vehicle may perform the lane bias maneuver until it is determined that less than a threshold portion of the vehicle that is traveling in an adjacent lane overlaps with any portion of the autonomous vehicle. The threshold portion of the vehicle may be one-third, half, two-third, or any other suitable portion of a length of the vehicle.

(14) If the control device of the autonomous vehicle determines that the lateral distance between the autonomous vehicle and the vehicle is less than the threshold distance, the control device may determine whether performing the lane bias maneuver is executable and safe.

(15) In this process, the control device of the autonomous vehicle may determine that performing the lane bias maneuver is executable if it is determined that the lane bias maneuver can be performed within a threshold time period, e.g., two minutes, five minutes, or any other suitable time period, depending on the traffic on the road. For example, if there is congested traffic on the road, the control device may determine that the lane bias maneuver cannot be performed within the threshold time period.

(16) The control device may determine that the lane bias maneuver is executable if it is determined that there is enough room or distance on the other side of the autonomous vehicle on its current lane to perform the lane bias maneuver.

(17) In some embodiments, if the control device may determine that there is not enough distance on the other side of the autonomous vehicle to perform the lane bias maneuver, the control device may temporarily cross over into an adjacent lane on the other side of the autonomous vehicle (compared to where the vehicle is detected) and take as much space of the adjacent lane (if traffic in the adjacent lane allows) until the lateral distance between the autonomous vehicle and the encountered vehicle is equal to the threshold distance.

(18) The control device of the autonomous vehicle may determine that performing the lane bias maneuver is executable based on the road structure. For example, if the road has a high curvature (e.g., more than fifty degrees, sixty degrees, etc.), the control device may determine that performing the lane bias maneuver is not executable.

(19) The control device may determine that the lane bias maneuver is safe based on the historical driving behavior of the encountered vehicle. For example, if the historical driving behavior of the encountered vehicle indicates that the driving pattern of the vehicle is highly unpredictable (e.g., the driving pattern or trajectory prediction of the vehicle is less than a threshold percentage, such as 70%, 65%, etc.), the control device may determine that the lane bias maneuver is not safe.

(20) If the control device determines that the lane bias maneuver is not executable and/or safe, the control device may instruct the autonomous vehicle to perform a minimal risk maneuver. The minimal risk maneuver may include slowing down the autonomous vehicle or speeding up the autonomous vehicle until the autonomous vehicle and the vehicle are not adjacent to each other.

(21) In some embodiments, a system may comprise an autonomous vehicle and a control device. The autonomous vehicle is configured to travel along a road. The autonomous vehicle comprises at least one sensor configured to capture sensor data associated with one or more objects on the road. The control device is associated with the autonomous vehicle. The control device comprises a processor. The processor may detect a presence of a vehicle from the sensor data. The processor may determine a lateral distance between the autonomous vehicle and the vehicle. The processor may compare the lateral distance between the autonomous vehicle and the vehicle with a threshold distance from the autonomous vehicle. The processor may determine whether to instruct the autonomous vehicle to perform a lane bias maneuver based at least in part upon the comparison between the lateral distance and the threshold distance. The lane bias maneuver comprises driving the autonomous vehicle off-center in a current lane traveled by the autonomous vehicle toward an opposite direction with respect to the vehicle until the lateral distance between the autonomous vehicle and the vehicle is at least equal to the threshold distance.
(22) Accordingly, the disclosed systems provide several practical applications and technical advantages, which include: 1) technology that improves the navigation of the autonomous vehicle by enabling the autonomous vehicle to drive off-center on its current lane to avoid intruding, invading, or oversized vehicles in the adjacent lane; and 2) technology that determines a lane bias distance that the autonomous vehicle drives off-center in its current lane so that a distance between the autonomous vehicle and the encountered vehicle is equal to a predetermined threshold distance.
(23) Implementing a Lane Bias Maneuver Based on a Road Curvature and Trailer Angle
(24) This disclosure further contemplates systems and methods for implementing a lane bias maneuver for autonomous vehicles based on a road curvature and trailer angle. For example, the autonomous vehicle may be a semi-truck tractor unit attached with a trailer. While traveling on a curved road, a trailer of the autonomous vehicle may divert from the straight line due to a road curvature. In other words, the trailer of the autonomous vehicle may swing to left or right depending on the direction of the road curvature. Likewise, while traveling on a straight road, wind going across the autonomous vehicle may cause the trailer of the autonomous vehicle to swing or divert from the straight line. This may create a trailer angle between the trailer of the autonomous vehicle and a semi-truck tractor unit of the autonomous vehicle. In such cases, the disclosed system may instruct the autonomous vehicle to perform a lane bias maneuver to compensate for the diversion of the trailer of the autonomous vehicle from the straight line.
(25) The disclosed system calculates a first lane bias adjustment distance amount associated with the road curvature and a second lane bias adjustment distance amount associated with the trailer angle. The disclosed system calculates a total lane bias adjustment distance amount by combining the first and second lane bias adjustment distance amounts. The total lane bias adjustment distance amount is a distance that the autonomous vehicle drives off-center in the current lane to compensate for the diversion of the trailer of the autonomous vehicle from the straight line. The disclosed system may instruct the autonomous vehicle to bias toward the right or left direction (while in the current lane) based on the total lane bias adjustment distance amount.
(26) According to an embodiment, a system comprises an autonomous vehicle and a control device. The autonomous vehicle is configured to travel along a road. The autonomous vehicle is a semi-truck tractor unit attached with a trailer. The control device is associated with the autonomous vehicle. The control device comprises a memory and a processor. The memory is configured to store map data that comprises one or more roads ahead of the autonomous vehicle. The processor is operably coupled with the memory. The processor may determine that the autonomous vehicle is approaching a curved road based at least in part upon the map data. The processor may determine a road radius of the curved road from the map data. The processor may calculate a first lane bias adjustment amount associated with a road curvature of the curved road based at least in part upon the road radius. The processor may determine a trailer angle between the trailer and the semi-truck tractor unit. The processor may calculate a second lane bias adjustment amount associated with the trailer angle based at least in part upon the trailer angle. The processor may calculate a total lane bias adjustment amount by combining the first lane bias adjustment amount and the second lane bias adjustment amount. The processor may instruct the autonomous vehicle to perform a lane bias maneuver, wherein the lane bias maneuver comprises driving the autonomous vehicle off-center in a curved lane currently traveled by the autonomous vehicle based at least in part upon the total lane bias adjustment amount.
(27) Accordingly, the disclosed systems provide several practical applications and technical advantages, which include: 1) technology that improves operating an autonomous vehicle's safety, such as with respect to surrounding vehicles; 2) technology that improves the navigation of the autonomous vehicle in curved roads by enabling the autonomous vehicle to drive off-center in its current lane to compensate for the diversion of the trailer of the autonomous vehicle from the straight line; and 3) technology that determines the total lane bias adjustment distance that the autonomous vehicle drives off-center in its current lane so that neither the semi-truck tractor unit nor the trailer of the autonomous vehicle invades side lanes.
(28) As such, the systems described in this disclosure may be integrated into practical applications of determining a more efficient, safe, and reliable navigation solution for autonomous vehicles as well as other vehicles on the same road as the autonomous vehicle.
(29) Certain embodiments of this disclosure may include some, all, or none of these advantages. These advantages and other features will be more clearly understood from the following detailed description taken in conjunction with the accompanying drawings and claims.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
(1) For a more complete understanding of this disclosure, reference is now made to the following brief description, taken in connection with the accompanying drawings and detailed description, wherein like reference numerals represent like parts.
(2) FIG. **1** illustrates an embodiment of a system configured to implement a lane bias maneuver to avoid a vehicle;
(3) FIG. **2** illustrates an example flowchart of a method for implementing a lane bias maneuver to avoid a vehicle;
(4) FIG. **3** illustrates an embodiment of a system configured to implement a lane bias maneuver to negotiate a curved road;

(5) FIG. **4** illustrates an example flowchart of a method for implementing a lane bias maneuver to negotiate a curved road;
(6) FIG. **5** illustrates a block diagram of an example autonomous vehicle configured to implement autonomous driving operations;
(7) FIG. **6** illustrates an example system for providing autonomous driving operations used by the autonomous vehicle of FIG. **5**; and
(8) FIG. **7** illustrates a block diagram of an in-vehicle control computer included in the autonomous vehicle of FIG. **5**.

DETAILED DESCRIPTION

(9) In some cases, while an autonomous vehicle is traveling along a road, a vehicle may drive too close to the autonomous vehicle and invade a lane that the autonomous vehicle is in. In some cases, a trailer of the autonomous vehicle may swing to left or right depending on the direction of the road. Such cases may lead to unsafe driving conditions for the autonomous vehicle and other vehicles.

(10) As described above, previous technologies fail to provide efficient, reliable, and safe navigation solutions for an autonomous vehicle in situations where the autonomous vehicle encounters an intruding, invading, or oversized vehicle or when the autonomous vehicle approaches a curved road. This disclosure provides various systems, methods, and devices to: 1) implement a lane bias maneuver to avoid intruding, invading, or oversized vehicles; 2) implement a lane bias maneuver to negotiate a curved road; and 3) providing a safe driving experience for autonomous vehicles, other vehicles, and pedestrians. FIG. **1** illustrates an embodiment of a system **100** for implementing a lane bias maneuver to avoid a vehicle. FIG. **2** illustrates an embodiment of a method **200** for implementing a lane bias maneuver to avoid a vehicle. FIG. **3** illustrates an embodiment of a system **300** for implementing a lane bias maneuver to negotiate a curved road. FIG. **4** illustrates an embodiment of a method **400** for implementing a lane bias maneuver to negotiate a curved road. FIGS. **5-7** illustrate an example autonomous vehicle and its various systems and devices for implementing autonomous driving operations by the autonomous vehicle.

(11) Example System for Implementing a Lane Bias Maneuver for Autonomous Vehicles

(12) FIG. **1** illustrates an embodiment of a system **100** for implementing a lane bias maneuver **130** for an autonomous vehicle **502**. FIG. **1** further illustrates a simplified schematic diagram of a road **102** traveled by an autonomous vehicle **502**. In some embodiments, system **100** comprises an autonomous vehicle **502** and its components, including a control device **550** and sensors **546**.

(13) The control device **550** comprises a processor **122** in signal communication with a memory **126**. Memory **126** may store software instructions **128** that when executed by the processor **122** cause the control device **550** to perform one or more functions described herein. For example, when the software instructions **128** are executed, the processor **122** may instruct the autonomous vehicle **502** to implement a lane bias maneuver **130**, such that the autonomous vehicle **502** may drive off-center in its current lane to keep a safe distance from one or more surrounding vehicles **108**. The system **100** may be configured as shown or in any other suitable configuration.

(14) In general, system **100** may be configured to implement a lane bias maneuver **130** in response to detecting that: 1) a vehicle **108** is intruding the current lane **104***a* traveled by the autonomous vehicle **502**; 2) a distance between a vehicle **108** and a lane marker **106** between the autonomous vehicle **502** and the vehicle **108** is less than a threshold distance **132**; and/or 3) historical driving behavior **162** associated with a vehicle **108** indicates that the vehicle **108** has intruded or invaded one or more lanes **104** (in one or more instances).

(15) While driving along a road **102**, the autonomous vehicle **502** may face an intruding, invading, or oversized vehicle **108** on an adjacent lane **104**. There may be a situation where a distance between the autonomous vehicle **502** and such a vehicle **108** may become less than a threshold distance **132**. For example, an intruding or invading vehicle **108** may drive too close to the lane marker **106***a* between the autonomous vehicle **502** and the vehicle **108** (e.g., pass the threshold distance **132**) or even cross over the lane marker **106***a*. In another example, the distance between an oversized vehicle **108** and the autonomous vehicle **502** may become less than the threshold distance **132** due to the larger space that the oversized vehicle **108** occupies.

(16) In such cases, diverting to another lane **104** may not be safe or executable. For example, the autonomous vehicle **502** may be at a side lane **104***a* on the road **102**, and there may not be another lane **104** to divert to. In another example, there may be traffic in the adjacent lane **104**. In another example, the autonomous vehicle **502** may need to stay on the current lane **104***a* to follow its navigation or routing plan **116** to reach its destination.

(17) In such cases, a safer driving maneuver may be to perform the lane bias maneuver **130**. The lane bias maneuver **130** may enable the autonomous vehicle **502** to drive off-center in the current lane **104***a* traveled by the autonomous vehicle **502** toward the opposite direction with respect to the vehicle **108** until the lateral distance **138** between the vehicle **108** and the autonomous vehicle **502** is at least equal to the threshold distance **132**. In other words, the autonomous vehicle **502** biases toward the other side of the current lane **104***a* (away from the vehicle **108**) until the lateral distance **138** between the vehicle **108** and the autonomous vehicle **502** is at least equal to the threshold distance **132**. In some embodiments, the autonomous vehicle **502** may perform the lane bias maneuver **130** until the autonomous vehicle **502** and the vehicle **108** are no longer adjacent to each other, for example, until either the autonomous vehicle **502** passes by the vehicle **108** or the vehicle **108** passes by the autonomous vehicle **502**. In one example, the autonomous vehicle **502** may perform the lane bias maneuver **130** until it is determined that no portion of the autonomous vehicle **502** overlaps with any portion of the vehicle **108** that is traveling in an adjacent lane **104**. In another example, the autonomous vehicle **502** may perform the lane bias maneuver **130** until it is determined that less than a threshold portion of the vehicle **108** that is traveling in an adjacent lane **104** overlaps with any portion of the autonomous vehicle **502**. The threshold portion of the vehicle **108** may be one-third, half, two-third, or any other suitable portion of a length of the vehicle **108**.

(18) System **100** may be further configured to perform a minimal risk maneuver **140** if it is determined that the lane bias maneuver **130** is not executable or that it is not safe to perform the lane bias maneuver **130**. The minimal risk maneuver **140** may include slowing down the autonomous vehicle **502**, speeding up the autonomous vehicle **502**, among others until the autonomous vehicle **502** and the vehicle **108** are not adjacent to each other.

(19) Various use cases where the autonomous vehicle **502** encounters a situation that may lead to performing the lane bias maneuver **130** are described further below in conjunction with the operational flow of the system **100**. In the example use cases

described in FIG. **1**, the autonomous vehicle **502** encounters intruding, invading, and oversized vehicles **108**. However, the example use cases described in FIG. **1** are not meant to limit the scope of this disclosure. One of ordinary skill in the art would recognize other use cases and embodiments in light of the present disclosure. In some examples, the autonomous vehicle **502** may encounter an obstacle or object **142** obstructing at least a portion of the road **102** including, a construction zone, a pedestrian on a side of the road **102**, an emergency vehicle **108** parked or in transit on an emergency lane, and a person standing on a side of a lane **104** attending to their vehicle **108**. In any of these examples and the use cases of encountering intruding, invading, and oversized vehicles **108**, system **100** may treat each of these as a non-player character **144** that may lead to performing the lane bias maneuver **130** to avoid each of these non-player characters **144**. A non-player character **144** may be any object **142** that the autonomous vehicle **502** interacts with.

(20) System Components

(21) In some embodiments, the autonomous vehicle **502** may include a semi-truck tractor unit attached to a trailer to transport cargo or freight from one location to another location (see FIG. **5**). The autonomous vehicle **502** may be generally configured to travel along a road **102** in an autonomous mode. The autonomous vehicle **502** may be navigated using a plurality of components described in detail in FIGS. **5-7**. The operation of the autonomous vehicle **502** is described in greater detail in FIGS. **5-7**. The corresponding description below includes brief descriptions of certain components of the autonomous vehicle **502**.

(22) Control device **550** may be generally configured to control the operation of the autonomous vehicle **502** and its components, and facilitate autonomous driving of the autonomous vehicle **502**. The control device **550** may be further configured to determine a pathway in front of the autonomous vehicle **502** that is safe to travel and free of objects/obstacles, and navigate the autonomous vehicle **502** to travel in that pathway. This process is described in more detail in FIGS. **5-7**. The control device **550** may generally include one or more data processors in signal communication with subsystem components of the autonomous vehicle **502** (see FIG. **5**).

(23) The control device **550** may be configured to detect objects on and around road **102** by analyzing the sensor data **134** and/or map data **114**. For example, the control device **550** may detect objects on and around road **102** by implementing object detection machine learning modules **112**. The object detection machine learning module **112** may be implemented using neural networks and/or machine learning algorithms for detecting objects from images, videos, infrared images, point clouds, radar data, etc. The object detection machine learning module **112** is described in more detail further below. The control device **550** may receive sensor data **134** from the sensors **546** positioned on the autonomous vehicle **502** to determine a safe pathway to travel. The sensor data **134** may include data captured by the sensors **546**.

(24) Sensors **546** may be configured to capture any object within their detection zones or fields of view, such as landmarks, lane markers, lane boundaries, road boundaries, vehicles **108**, pedestrians, road/traffic signs, among others. The sensors **546** may include cameras, LiDAR sensors, motion sensors, infrared sensors, and the like. In some embodiments, the sensors **546** may be positioned around the autonomous vehicle **502** to capture the environment surrounding the autonomous vehicle **502**. See the corresponding description of FIG. **5** for further description of the sensors **546**.

(25) Control Device

(26) The control device **550** is described in detail in FIG. **5**. In brief, the control device **550** may include a processor **122** in signal communication with a memory **126** and a network interface **124**. The processor **122** may include one or more processing units that perform various functions as described herein. The memory **126** may store any data and/or instructions used by the processor **122** to perform its functions. For example, the memory **126** may store software instructions **128** that when executed by the processor **122** causes the control device **550** to perform one or more functions described herein.

(27) The processor **122** may be one of the data processor **570** described in FIG. **5**. The processor **122** comprises one or more processors operably coupled to the memory **126**. The processor **122** is any electronic circuitry, including, but not limited to, state machines, one or more central processing unit (CPU) chips, logic units, cores (e.g., a multi-core processor), field-programmable gate array (FPGAs), application-specific integrated circuits (ASICs), or digital signal processors (DSPs). The processor **122** may be a programmable logic device, a microcontroller, a microprocessor, or any suitable combination of the preceding. The processor **122** is communicatively coupled to and in signal communication with the network interface **124** and memory **126**. The one or more processors may be configured to process data and may be implemented in hardware or software. For example, the processor **122** may be 8-bit, 16-bit, 32-bit, 64-bit or of any other suitable architecture. The processor **122** may include an arithmetic logic unit (ALU) for performing arithmetic and logic operations, processor registers that supply operands to the ALU and store the results of ALU operations, and a control unit that fetches instructions from memory and executes them by directing the coordinated operations of the ALU, registers and other components. The one or more processors may be configured to implement various instructions. For example, the one or more processors may be configured to execute software instructions **128** to implement the functions disclosed herein, such as some or all of those described with respect to FIGS. **1-7**. In some embodiments, the function described herein is implemented using logic units, FPGAs, ASICs, DSPs, or any other suitable hardware or electronic circuitry.

(28) The network interface **124** may be a component of the network communication subsystem **592** described in FIG. **5**. The network interface **124** may be configured to enable wired and/or wireless communications. The network interface **124** may be configured to communicate data between the control device **550** and other network devices, systems, or domain(s). For example, the network interface **124** may comprise a WIFI interface, a local area network (LAN) interface, a wide area network (WAN) interface, a modem, a switch, or a router. The processor **122** may be configured to send and receive data using the network interface **124**. The network interface **124** may be configured to use any suitable type of communication protocol.

(29) The memory **126** may be one of the data storages **590** described in FIG. **5**. The memory **126** may store any of the information described in FIGS. **1-7** along with any other data, instructions, logic, rules, or code operable to implement the function(s) described herein when executed by processor **122**. For example, the memory **126** may store software instructions **128**, lane bias maneuver **130**, minimal risk maneuver **140**, location of lane markers **106**, threshold distance **132**, sensor data **134**, lateral distances **138***a-c*, distance **136**, intruded distance **146**, threshold time period **148**, trajectories **150**, **152**, **158**, and **168**, road

condition data **154**, longitudinal distances **156** and **166**, distance **160**, historical driving behaviors **162**, obstacle/object **142**, non-player character **144**, driving pattern predictions **164**, lane bias amount **110**, object detection machine learning modules **112**, map data **114**, routing plan **116**, driving instructions **118**, and/or any other data/instructions. The software instructions **128** include code that when executed by the processor **122** causes the control device **550** to perform the functions described herein, such as some or all of those described in FIGS. **1-7**. The memory **126** comprises one or more disks, tape drives, or solid-state drives, and may be used as an over-flow data storage device, to store programs when such programs are selected for execution, and to store instructions and data that are read during program execution. The memory **126** may be volatile or non-volatile and may comprise read-only memory (ROM), random-access memory (RAM), ternary content-addressable memory (TCAM), dynamic random-access memory (DRAM), and static random-access memory (SRAM). The memory **126** may include one or more of a local database, cloud database, network-attached storage (NAS), etc.

(30) Object detection machine learning modules **112** may be implemented by the processor **122** executing software instructions **128**, and may be generally configured to detect objects and obstacles **142** from the sensor data **134**. The object detection machine learning modules **112** may be implemented using neural networks and/or machine learning algorithms for detecting objects from any data type, such as images, videos, infrared images, point clouds, Radar data, etc.

(31) In some embodiments, the object detection machine learning modules **112** may be implemented using machine learning algorithms, such as Support Vector Machine (SVM), Naive Bayes, Logistic Regression, k-Nearest Neighbors, Decision Trees, or the like. In some embodiments, the object detection machine learning modules **112** may utilize a plurality of neural network layers, convolutional neural network layers, and/or the like, in which weights and biases of these layers are optimized in the training process of the object detection machine learning modules **112**. The object detection machine learning modules **112** may be trained by a training dataset that may include samples of data types labeled with one or more objects in each sample. For example, the training dataset may include sample images of objects (e.g., vehicles, lane markings, pedestrians, road signs, obstacles, etc.) labeled with object(s) in each sample image. Similarly, the training dataset may include samples of other data types, such as videos, infrared images, point clouds, Radar data, etc. labeled with object(s) in each sample data. The object detection machine learning modules **112** may be trained, tested, and refined by the training dataset and the sensor data **134**. The object detection machine learning modules **112** use the sensor data **134** (which are not labeled with objects) to increase their accuracy of predictions in detecting objects. For example, supervised and/or unsupervised machine learning algorithms may be used to validate the predictions of the object detection machine learning modules **112** in detecting objects in the sensor data **134**.

(32) Map data **114** may include a virtual map of a city or an area that includes the road **102**. In some examples, the map data **114** may include the map **658** and map database **636** (see FIG. **6** for descriptions of the map **658** and map database **636**). The map data **114** may include drivable areas, such as roads **102**, paths, highways, and undrivable areas, such as terrain (determined by the occupancy grid module **660**, see FIG. **6** for descriptions of the occupancy grid module **660**). The map data **114** may specify location coordinates of road signs, lanes, lane markings, lane boundaries, road boundaries, traffic lights, obstacles, etc.

(33) Routing plan **116** is a plan for traveling from a start location (e.g., a first autonomous vehicle launchpad/landing pad) to a destination (e.g., a second autonomous vehicle launchpad/landing pad). For example, the routing plan **116** may specify a combination of one or more streets, roads, and highways in a specific order from the start location to the destination. The routing plan **116** may specify stages, including the first stage (e.g., moving out from a start location/launch pad), a plurality of intermediate stages (e.g., traveling along particular lanes of one or more particular street/road/highway), and the last stage (e.g., entering the destination/landing pad). The routing plan **116** may include other information about the route from the start position to the destination, such as road/traffic signs in that routing plan **116**, etc.

(34) Driving instructions **118** may be implemented by the planning module **662** (See descriptions of the planning module **662** in FIG. **6**). The driving instructions **118** may include instructions and rules to adapt the autonomous driving of the autonomous vehicle **502** according to the driving rules of each stage of the routing plan **116**. For example, the driving instructions **118** may include instructions to stay within the speed range of a road **102** traveled by the autonomous vehicle **502**, adapt the speed of the autonomous vehicle **502** with respect to observed changes by the sensors **546**, such as speeds of surrounding vehicles, objects within the detection zones of the sensors **546**, etc.

(35) The control device **550** may receive the object detection machine learning modules **112**, map data **114**, routing plan **116**, driving instructions **118**, and/or any other data/instructions from an oversight server (not shown) that may be configured to oversee operations of the autonomous vehicle **502**, build the map data **114**, determine the routing plan **116**, and determine the driving instructions **118**, among other operations.

(36) Threshold distance **132** may generally represent a safe distance that the control device **550** keeps (or attempts to keep) between the autonomous vehicle **502** and its surrounding objects/obstacles **142**. In one example, the control device **550** may define the threshold distance **132** based on road conditions **154**, such as traffic and weather on the road **102** traveled by the autonomous vehicle **502**. For example, in congested traffic, the threshold distance **132** from the autonomous vehicle **502** may be larger (e.g., eight feet or any suitable distance) compared to a road without traffic. In another example, during severe weather conditions, the threshold distance **132** from the autonomous vehicle **502** may be larger (e.g., six feet, seven feet, or any suitable distance) compared to normal weather conditions. In another example, the control device **550** may define a different threshold distance **132** between the autonomous vehicle **502** and each object **142** based on one or more of the size of the object **142** and type of the object **142** (e.g., vehicle, pedestrian, road sign, etc.). For example, if a first object **142** is a small vehicle **108**, a first threshold distance **132** between the small vehicle **108** and the autonomous vehicle **502** may be determined to be smaller compared to a threshold distance **132** between the autonomous vehicle **502** and an oversized vehicle **108**. In another example, if a second object **142** is a pedestrian or a person on a side of a road, a second threshold distance **132** between the pedestrian and the autonomous vehicle **502** may be larger compared to a threshold distance **132** between the autonomous vehicle **502** and a road sign.

(37) In some embodiments, the control device **550** may define a safety boundary or bounding box around each object **142** on and around the road **102** based on the size and type of the object **142**, such as vehicle, pedestrian, road sign, etc. The bounding box

around each object **142** may represent a safe distance that the control device **550** keeps (or attempts to keep) between the autonomous vehicle **502** and each object **142**. The control device **550** may determine various threshold distances **132** between the autonomous vehicle **502** and each object **142** on and around the road **102** using the boundary boxes around each object **142**.
(38) Operational Flow for Implementing a Lane Bias Maneuver
(39) The operational flow of the system **100** begins when the control device **550** receives sensor data **134** from the sensors **546**.
(40) In an example operation, assume that the autonomous vehicle **502** is traveling along the road **102**. While traveling, the sensors **546** capture sensor data **134** that describe the environment around the autonomous vehicle **502**. The sensor data **134** is associated with one or more objects on the road **102**. From the sensor data **134**, the control device **550** may detect the position of the lane marker **106**, and the distances **136***a* and **136***b* between the autonomous vehicle **502** and the lane markers **106***a* and **106***b*, respectively, by implementing the object detection machine learning modules **112**.
(41) Assuming that a vehicle **108** is on the road **102**, the control device **550** may detect the presence of the vehicle **108** from the sensor data **134**. The control device **550** may determine a lateral distance **138** between the autonomous vehicle **502** and the vehicle **108**.
(42) The control device **550** may compare the lateral distance **138** with the threshold distance **132**. The control device **550** may determine whether to instruct the autonomous vehicle **502** to perform the lane bias maneuver **130** based on the comparison between the lateral distance **138** and the threshold distance **132**. If the control device **550** determines that performing the lane bias maneuver **130** is safe and executable, the control device **550** may instruct the autonomous vehicle **502** to perform the lane bias maneuver **130**. Otherwise, the control device **550** may instruct the autonomous vehicle **502** to perform a minimal risk maneuver **140**.
(43) In some example scenarios, the autonomous vehicle **502** may encounter a vehicle **108** 1) on either side adjacent to the autonomous vehicle **502**; 2) on either side and in front of the autonomous vehicle **502**; and 3) in front of the autonomous vehicle **502**, where the vehicle **108** is stopped on a side of a road **102**. The corresponding description below describes various exemplary use cases of encountering a vehicle **108** (or generally a non-player character **144**) that may lead to performing the lane bias maneuver **130**.
(44) Encountering a Vehicle Adjacent to the Autonomous Vehicle
(45) In an example use case, assume that the control device **550** detects the presence of a vehicle **108***a* from the sensor data **134** by implementing the object detection machine learning modules **112**, where the vehicle **108***a* is detected on either side of the autonomous vehicle **502**.
(46) The control device **550** may determine whether to instruct the autonomous vehicle **502** to perform the lane bias maneuver **130** to avoid the vehicle **108***a*, whether lane bias maneuver **130** is executable and safe, and instruct the autonomous vehicle **502** to perform the lane bias maneuver **130** if it is determined that the lane bias maneuver **130** is executable and safe, as described below.
(47) In this process, the control device **550** may determine the lateral distance **138***a* between the autonomous vehicle **502** and the vehicle **108***a* from the sensor data **134**. The control device **550** may compare the lateral distance **138***a* with the threshold distance **132**.
(48) In the example of FIG. **1**, the control device **550** may determine that the lateral distance **138***a* between the autonomous vehicle **502** and the vehicle **108***a* is less than the threshold distance **132**. In response, the control device **550** may determine whether to instruct the autonomous vehicle **502** to perform the lane bias maneuver **130**. If the control device **550** determines that performing the lane bias maneuver **130** is executable and safe, the control device **550** may instruct the autonomous vehicle **502** to perform the lane bias maneuver **130**. Otherwise, the control device **550** may instruct the autonomous vehicle **502** to perform a minimal risk maneuver **140**. The minimal risk maneuver **140** may include slowing down or speeding up the autonomous vehicle **502** until the autonomous vehicle **502** and the vehicle **108***a* are no longer adjacent to each other.
(49) In one example as illustrated in FIG. **1**, the vehicle **108***a* may have intruded (or crossed over) the lane marker **106***a*. To determine whether the vehicle **108***a* has crossed over the lane marker **106***a*, the control device **550** may perform one or more operations described below.
(50) The control device **550** may determine the distance **136***a* between the autonomous vehicle **502** and the lane marker **106***a*. The control device **550** may compare the distance **136***a* with the lateral distance **138***a* between the autonomous vehicle **502** and the vehicle **108***a*. If the control device **550** determines that the distance **136***a* is less that the lateral distance **138***a* between the autonomous vehicle **502** and the vehicle **108***a*, the control device **550** may determine that the vehicle **108***a* has intruded into the lane **104***a*. Otherwise, the control device **550** may determine that the vehicle **108***a* has not intruded into the lane **104***a*.
(51) In this example, the control device **550** may determine that the vehicle **108***a* is intruding into the current lane **104***a* traveled by the autonomous vehicle **502** in response to determining that the lateral distance **138***a* between the autonomous vehicle **502** and the vehicle **108***a* is less than the distance **136***a* between the autonomous vehicle **502** and the lane marker **106***a*. In response, the control device **550** may determine whether to instruct the autonomous vehicle **502** to perform the lane bias maneuver **130** and whether performing the lane bias maneuver is safe and executable.
(52) Determining Whether Performing the Lane Bias Maneuver is Executable
(53) To determine whether performing the lane bias maneuver **130** is executable, the control device **550** may perform one or more operations described below.
(54) In some embodiments, the control device **550** may determine whether performing the lane bias maneuver **130** is executable based on determining whether there is enough room or distance **136** available on the other side of the autonomous vehicle **502** to perform the lane bias maneuver **130**. To this end, the control device **550** may determine how much of the current lane **104***a* is intruded by the vehicle **108***a*. For example, the control device **550** may determine the amount of the intruded distance **146** into the lane **104***a* that is intruded by the vehicle **108***a*.
(55) The control device **550** may determine an available distance **136***b* (or available room **136***b*) on the other side of the autonomous vehicle **502** on the current lane **104***a*. The control device **550** may determine whether there is enough room **136***b* or available distance **136***b* on the other side of the autonomous vehicle **502** to perform the lane bias maneuver, i.e., drive off-center

and bias toward the lane marker **106***b*. To this end, the control device **550** may compare the intruded distance **146** with the available distance **136***b*.
(56) The control device **550** may determine whether the lane bias maneuver **130** can be performed based on the comparison between the intruded distance **146** and the available distance **136***b*. If the control device **550** determines that the available distance **136***b* is larger than the intruded distance **146** (and/or that there is enough available distance **136***b* to perform the lane bias maneuver **130**), the control device **550** may instruct the autonomous vehicle **502** to perform the lane bias maneuver **130**.
(57) The control device **550** may instruct the autonomous vehicle **502** to perform the lane bias maneuver **130** if the control device **550** determines that the lane bias maneuver **130** can be performed or is executable and safe. The process of determining whether performing the lane bias maneuver **130** is safe is described further below. In brief, the control device **550** may determine that performing the lane bias maneuver **130** is safe by determining whether there is traffic (e.g., another vehicle **108**) on the road **102**, i.e., whether the traffic allows the autonomous vehicle **502** to perform the lane bias maneuver **130**. If it is determined that there is no or minor traffic on the road **102**, the control device **550** may determine that performing the lane bias maneuver **130** is safe and instruct the autonomous vehicle **502** to perform the lane bias maneuver **130**.
(58) If the control device **550** determines that the available distance **136***b* is smaller than the intruded distance **146** (and/or that there is not enough available distance **136***b* to perform the lane bias maneuver **130**), the control device **550** may determine that the lane bias maneuver **130** cannot be performed or is not executable. In response, the control device **550** may instruct the autonomous vehicle **502** to perform a minimal risk maneuver **140**. In these operations, the control device **550** takes the size, width, and length of the autonomous vehicle **502** into account when determining whether there is enough available distance **136***b* to perform the lane bias maneuver **130**.
(59) In some embodiments, the control device **550** may determine whether performing the lane bias maneuver **130** is executable based on determining if the lane bias maneuver **130** is performed, the future lateral distance **138***a* between the autonomous vehicle **502** and the vehicle **108***a* will be at least equal to the threshold distance **132** within a threshold time period **148**.
(60) If the control device **550** determines that if the lane bias maneuver **130** is performed, the future lateral distance **138***a* between the autonomous vehicle **502** and the vehicle **108***a* will be at least equal to the threshold distance **132** within the threshold time period **148**, the control device **550** may determine that the lane bias maneuver **130** is executable. In response, the control device **550** may instruct the autonomous vehicle **502** to perform the lane bias maneuver **130**, if it is determined to be safe. Otherwise, the control device **550** may instruct the autonomous vehicle **502** to perform a minimal risk maneuver **140**.
(61) The threshold time period **148** may be two minutes, five minutes, or any other suitable time duration. The control device **550** may define the threshold time period **148** based on one or more of the road condition data **154** (such as traffic data and weather data associated with the road **102**), size of the autonomous vehicle **502**, speed of the autonomous vehicle **502**, trajectory **150** of the autonomous vehicle **502**, and size of the vehicle **108***a*, speed of the vehicle **108***a*, and trajectory **152** of the vehicle **108***a*.
(62) To determine whether the lane bias maneuver **130** can be performed within the threshold time period **148**, the control device **550** may perform one or more operations below.
(63) The control device **550** may determine a speed (or estimated speed) and position of the vehicle **108***a*, for example, from the sensor data **134**. Based on the speed and the position of the vehicle **108***a*, the control device **550** may determine the trajectory **152** of the vehicle **108***a*. Similarly, the control device **550** may determine the trajectory **150** of the autonomous vehicle **502** if the lane bias maneuver **130** is performed based on the speed and the position of the autonomous vehicle **502**.
(64) The control device **550** predicts the future lateral distance **138***a* between the autonomous vehicle **502** and the vehicle **108***a*, if the autonomous vehicle **502** followed the trajectory **150** and the vehicle **108***a* followed the trajectory **152**.
(65) The control device **550** may compare the future lateral distance **138***a* with the threshold distance **132**. The control device **550** may determine that the lane bias maneuver **130** can be performed within the threshold time period **148** if the future lateral distance **138***a* is at least equal to the threshold distance **132** within the threshold time period **148**. In response, the control device **550** may instruct the autonomous vehicle **502** to perform the lane bias maneuver **130** (if it is determined to be safe).
(66) In some embodiments, if the control device **550** determines that the predicated future lateral distance **138***a* will be less than the threshold distance **132** within the threshold time period **148**, the control device **550** may determine that the lane bias maneuver **130** cannot be performed and/or is not safe to be performed, e.g., due to traffic on the road **102**. In response, the control device **550** may instruct the autonomous vehicle **502** to perform a minimal risk maneuver **140**.
(67) In another embodiment, if the control device **550** determines that the predicated future lateral distance **138***a* will be less than the threshold distance **132** within the threshold time period **148**, the control device **550** may determine whether it is safe to cross over to the adjacent lane **104***c* based on traffic on the lane **104***c*. If the control device **550** determines that there is no or minor traffic (e.g., another vehicle **108**) in the adjacent lane **104***c*, the control device **550** may determine that it is safe to temporarily cross over to the lane **104***c*. In response, the control device **550** may instruct the autonomous vehicle **502** to perform the lane bias maneuver **130** and instruct the autonomous vehicle **502** to temporarily cross over to the lane **104***c* and take as much space from the lane **104***c* until the lateral distance **138***a* between the autonomous vehicle **502** and the vehicle **108***a* is equal to the threshold distance **132**. The control device **550** may instruct the autonomous vehicle **502** to drive back to its original lane **104***a* when it is determined that the autonomous vehicle **502** and the vehicle **108***a* are no longer adjacent to each other.
(68) In some embodiments, the control device **550** may determine whether performing the lane bias maneuver **130** is executable based on the road structure. For example, if the autonomous vehicle **502** is traveling on a curved road, a trailer attached to the semi-truck tractor unit of the autonomous vehicle **502** occupies more space in the lane. Thus, the control device **550** may take the road structure into account when determining whether performing the lane bias maneuver **130** is executable. This use case is described in detail in FIGS. **3** and **4**.
(69) Performing the Lane Bias Maneuver
(70) In some embodiments, in response to determining that performing the lane bias maneuver **130** is executable and safe, the control device **550** may instruct the autonomous vehicle **502** to perform the lane bias maneuver **130**.
(71) To this end, the control device **550** causes the autonomous vehicle **502** to drive off-center of the current lane **104***a* and bias

toward lane marker **106***b* (i.e., the other side of the lane **104***a* compared to where the vehicle **108***a* is detected).
(72) The control device **550** may determine the lane bias amount **110**. The lane bias amount **110** is a distance between the centerline of the current lane **104***a* and the trajectory line **150**. In other words, the lane bias amount **110** is a distance that the autonomous vehicle **502** diverts from the centerline of the lane **104***a* until the lateral distance **138***a* between the autonomous vehicle **502** and the vehicle **108***a* is at least equal to the threshold distance **132**. The autonomous vehicle **502** may perform the lane bias maneuver **130** until the lateral distance **138***a* between the autonomous vehicle **502** and the vehicle **108***a* is at least equal to the threshold distance **132**.
(73) The control device **550** may maintain a consistent lane bias amount **110** until the autonomous vehicle **502** is no longer adjacent to the vehicle **108**. In some embodiments, the control device **550** may maintain a consistent lane bias amount **110** even if the vehicle **108** swerves causing the lateral distance **138** to change. In some embodiments, the control device **550** may adjust the lane bias amount **110** to keep at least the threshold distance **132** with the vehicle **108**.
(74) Performing a Minimal Risk Maneuver
(75) In some embodiments, in response to determining that performing the lane bias maneuver **130** is not executable (and is not safe to be performed), the control device **550** may instruct the autonomous vehicle **502** to perform a minimal risk maneuver **140**. The minimal risk maneuver **140** may include slowing down the autonomous vehicle **502**, speeding up the autonomous vehicle **502**, among other maneuvers until the autonomous vehicle **502** and the vehicle **108***a* are not adjacent to each other.
(76) In the example of encountering the vehicle **108***a* that is on either side of the autonomous vehicle **502**, if the control device **550** determines that the speed of the vehicle **108***a* is more than the speed of the autonomous vehicle **502**, the minimal risk maneuver **140** may include slowing down the autonomous vehicle **502** and letting the vehicle **108***a* to pass by the autonomous vehicle **502**. In another example, if the control device **550** determines that the speed of the vehicle **108***a* is less than the speed of the autonomous vehicle **502**, the minimal risk maneuver **140** may include speeding up the autonomous vehicle **502**. In another example, if the vehicle **108***a* is behind the autonomous vehicle **502**, the minimal risk maneuver **140** may include speeding up the autonomous vehicle **502**. In another example, if the vehicle **108***a* is in front of the autonomous vehicle **502**, the minimal risk maneuver **140** may include slowing down the autonomous vehicle **502**.
(77) In some embodiments, the control device **550** may perform the minimal risk maneuver **140** in addition to the lane bias maneuver **130** if it is determined that the lane bias maneuver is executable and safe.
(78) Encountering a Vehicle in Front and on Either Side of the Autonomous Vehicle
(79) In another use case, assume that the control device **550** detects the presence of a vehicle **108***b* from the sensor data **134** by implementing the object detection machine learning modules **112**, where the vehicle **108***b* is detected in front of the autonomous vehicle **502** and on either side of the lane **104***a* traveled by the autonomous vehicle **502**.
(80) The control device **550** may determine whether to instruct the autonomous vehicle **502** to perform the lane bias maneuver **130** to avoid the vehicle **108***b*, whether lane bias maneuver **130** is executable and safe, and instruct the autonomous vehicle **502** to perform the lane bias maneuver **130** if it is determined that the lane bias maneuver **130** is executable and safe, as described below.
(81) In this process, the control device **550** may determine the lateral distance **138***b* between the autonomous vehicle **502** and the vehicle **108***b* by analyzing the sensor data **134**. The control device **550** may compare the lateral distance **138***b* with the threshold distance **132**.
(82) In the example of FIG. **1**, the control device **550** may determine that the lateral distance **138***b* between the autonomous vehicle **502** and the vehicle **108***b* is less than the threshold distance **132**. In the illustrated example, the control device **550** may determine that the vehicle **108***b* is driving too close to the lane marker **106***a* between the autonomous vehicle **502** and the vehicle **108***b*. For example, the control device **550** may determine that the distance **160** between the vehicle **108***b* and the lane marker **106***a* is less than a threshold, e.g., less than twenty inches, forty inches, or any other suitable distance.
(83) In response, the control device **550** may determine whether to instruct the autonomous vehicle **502** to perform the lane bias maneuver **130**. Similar to that described above with respect to the example of vehicle **108***a*, if the control device **550** determines that performing the lane bias maneuver **130** is executable and safe, the control device **550** may instruct the autonomous vehicle **502** to perform the lane bias maneuver **130**. Otherwise, the control device **550** may instruct the autonomous vehicle **502** to perform a minimal risk maneuver **140**. These operations are described below.
(84) Determining Whether Performing the Lane Bias Maneuver is Executable
(85) In some embodiments, the control device **550** may determine whether performing the lane bias maneuver **130** is executable within the threshold time period **148** based on the lateral distance **138***b*, longitudinal distance **156**, trajectory **150** of the autonomous vehicle **502** if the lane bias maneuver **130** is executed, and the trajectory **158** of the vehicle **108***b*, as described below.
(86) The control device **550** may determine the longitudinal distance **156** between the autonomous vehicle **502** and the vehicle **108***b* from the sensor data **134**.
(87) The control device **550** may determine the trajectory **150** of the autonomous vehicle **502** if the lane bias maneuver **130** is performed based on the speed and the position of the autonomous vehicle **502**, similar to that described above. Similarly, the control device **550** may determine the trajectory **158** of the vehicle **108***b* based on the position and speed (or estimated speed) of the vehicle **108***b*.
(88) The control device **550** predicts the future lateral distance **138***b* between the autonomous vehicle **502** and the vehicle **108***b* if the autonomous vehicle **502** followed the trajectory **150** and the vehicle **108***b* followed the trajectory **158**.
(89) The control device **550** may compare the predicted future lateral distance **138***b* with the threshold distance **132**. If the control device **550** determines that the predicated future lateral distance **138***b* will be more than or equal to the threshold distance **132** within the threshold time period **148**, the control device **550** may determine that the lane bias maneuver **130** can be performed. In response, the control device **550** may instruct the autonomous vehicle **502** to perform the lane bias maneuver **130** (if it is determined to be safe).
(90) In some embodiments, if the control device **550** determines that the predicated future lateral distance **138***b* will be less than the threshold distance **132** within the threshold time period **148**, the control device **550** may determine that the lane bias maneuver

130 cannot be performed within the threshold time period **148**. In response, the control device **550** may instruct the autonomous vehicle **502** to perform a minimal risk maneuver **140**.
(91) In another embodiment, if the control device **550** determines that the predicated future lateral distance **138***b* will be less than the threshold distance **132** within the threshold time period **148**, the control device **550** may determine whether it is safe to temporarily cross over to the adjacent lane **104***c*, similar to that described above with respect to the example use case of encountering the vehicle **108***a*. If it is determined that it is safe to temporarily cross over to the lane **104***c*, the control device **550** may drive the autonomous vehicle **502** over the lane marker **106***b* until the lateral distance **138***b* between the autonomous vehicle **502** and the vehicle **108***b* is at least equal to the threshold distance **132**. Once the autonomous vehicle **502** and the vehicle **108***b* are no longer adjacent to each other, the control device **550** may drive the autonomous vehicle **502** back to its original lane **104***a*.
(92) Determining Whether it is Safe to Perform the Lane Bias Maneuver
(93) In some embodiments, the control device **550** may determine whether it is safe to perform the lane bias maneuver **130** based on road condition data **154** (e.g., traffic data and weather data) and/or historical driving behaviors **162** associated with the surrounding vehicles **108**. To this end, while traveling along the road **102**, the control device **550** may record the driving behaviors **162** associated with the vehicles **108** on the road **102**.
(94) In one example, the control device **550** may determine that it is not safe to perform the lane bias maneuver **130** if it is determined that a driving pattern prediction **164** of a vehicle **108** is less than a threshold percentage, e.g., less than 70%, 60%, etc., i.e., the driving pattern of the vehicle **108** is highly unpredictable. The control device **550** may determine the driving pattern prediction **164** based on the historical driving behaviors **162**. In another example, the control device **550** may determine that it is not safe to perform the lane bias maneuver **130** if it is determined that the historical driving behavior **162** of a vehicle **108** indicates that the vehicle **108** has been intruding or invading one or more lanes **104**, or driving too close to lane markers **106** (e.g., driving with less than a threshold distance from the lane markers **106**).
(95) In one example with respect to the vehicle **108***b*, the control device **550** may determine that the historical driving behavior **162** of the vehicle **108***b* indicates that the vehicle **108***b* has been intruding or invading one or more lanes **104**. In another example with respect to the vehicle **108***b*, the control device **550** may determine that the historical driving behavior **162** of the vehicle **108***b* indicates that the vehicle **108***b* has been driving too close to lane markers **106** (e.g., with less than a threshold distance from the lane markers **106**).
(96) In such cases, the control device **550** may determine that it is not safe to perform the lane bias maneuver **130**.
(97) In some embodiments, the control device **550** may determine that it is not safe to perform the lane bias maneuver **130** if it is determined that the lane bias maneuver **130** cannot be performed within the threshold time period **148**, for example, due to road conditions **154**, such as congested traffic or undesirable weather conditions on the road **102**.
(98) Encountering a Stopped Vehicle in Front of the Autonomous Vehicle
(99) In another use case, assume that the control device **550** detects the presence of a vehicle **108***c* from the sensor data **134** by implementing the object detection machine learning modules **112**, where the vehicle **108***c* is stopped in front of the autonomous vehicle on a side of the road **102** traveled by the autonomous vehicle **502**. Similarly, the control device **550** may detect the presence of a person on a side of the road **102** from the sensor data **134**.
(100) In a similar use case, the sensors **546** may detect any stationary object **142** on a side of the road **102** that is: 1) occupying at least a portion of the road; 2) invading a lane **104** of the road **102**; 3) on an emergency lane; or 4) on the other side of the lane marker **106***b* but too close to the lane marker **106***b* (e.g., a distance between the object **142** and the lane marker **106***b* is less than a threshold, such as twenty inches, forty inches, etc.). The stationary object **142** may include construction cones, construction barriers, construction workers, construction equipment, pedestrians, vehicles, and/or any other object **142**.
(101) The control device **550** may determine whether to instruct the autonomous vehicle **502** to perform the lane bias maneuver **130** to avoid the vehicle **108***c*, whether the lane bias maneuver **130** is executable and safe, and instruct the autonomous vehicle **502** to perform the lane bias maneuver **130** if it is determined that the lane bias maneuver **130** is executable and safe, as described below.
(102) In this process, the control device **550** may determine the lateral distance **138***c* between the autonomous vehicle **502** and the vehicle **108***c* by analyzing the sensor data **134**. The control device **550** may compare the lateral distance **138***c* with the threshold distance **132**.
(103) In the example of FIG. **1**, the control device **550** may determine that the lateral distance **138***c* between the autonomous vehicle **502** and the vehicle **108***c* is less than the threshold distance **132**. In the illustrated example, the control device **550** determines that the vehicle **108***c* has crossed over the lane boundary **106***b* based on determining that the lateral distance **138***c* is less than the distance **136***b* between the autonomous vehicle **502** and the lane boundary **106***b*.
(104) In response, the control device **550** may determine whether to instruct the autonomous vehicle **502** to perform the lane bias maneuver **130**. Similar to that described above with respect to the example of vehicle **108***a*, if the control device **550** determines that performing the lane bias maneuver **130** is executable and safe, the control device **550** may instruct the autonomous vehicle **502** to perform the lane bias maneuver **130**. Otherwise, the control device **550** may instruct the autonomous vehicle **502** to perform a minimal risk maneuver **140**. These operations are described below.
(105) Determining Whether Performing the Lane Bias Maneuver is Executable
(106) In some embodiments, the control device **550** may determine whether performing the lane bias maneuver **130** is executable within the threshold time period **148** based on the lateral distance **138***c*, longitudinal distance **166**, trajectory **150** of the autonomous vehicle **502** if the lane bias maneuver **130** is executed, and determining whether there is enough room or distance **136***a* on the other side of the autonomous vehicle **502** to perform the lane bias maneuver **130**, as described below.
(107) The control device **550** may determine the trajectory **166** of the autonomous vehicle **502** based on the speed and position of the autonomous vehicle **502** if the lane bias maneuver **130** is performed, similar to that described above with respect to determining the trajectory **150**.
(108) The control device **550** predicts the future lateral distance **138***c* between the autonomous vehicle **502** and the vehicle **108***c* if

the autonomous vehicle **502** followed the trajectory **166**. The control device **550** may compare the predicted future lateral distance **138***c* with the threshold distance **132**.
(109) If the control device **550** determines that the predicted future lateral distance **138***c* will be more than or equal to the threshold distance **132** within the threshold time period **148**, the control device **550** may determine that the lane bias maneuver **130** can be performed. In response, the control device **550** may perform the lane bias maneuver **130** (if it is determined to be safe).
(110) In some embodiments, the control device **550** may determine a classification of vehicles **108** based on their size. For example, the control device **550** may classify oversized vehicles **108**, such as buses, into a first class, normal-sized vehicles **108**, such as family cars, into a second class, and so on. Thus, determining whether to perform the lane bias maneuver **130** may further be based on a particular class to which the encountered vehicle **108** belongs.
(111) In some embodiments, if the control device **550** determines that the predicted future lateral distance **138***c* will be less than the threshold distance **132** within the threshold time period **148**, the control device **550** may determine that the lane bias maneuver **130** cannot be performed within the threshold time period **148**. In response, the control device **550** may instruct the autonomous vehicle **502** to perform a minimal risk maneuver **140**. In another embodiment, if the control device **550** determines that the predicated future lateral distance **138***c* will be less than the threshold distance **132** within the threshold time period **148**, the control device **550** may determine whether it is safe to cross over to the adjacent lane **104***d*, similar to that described above with respect to the example use case of encountering the vehicle **108***a*.
(112) Example Method for Implementing a Lane Bias Maneuver
(113) FIG. **2** illustrates an example flowchart of a method **200** for implementing a lane bias maneuver **130** for autonomous vehicles **502**. Modifications, additions, or omissions may be made to method **200**. Method **200** may include more, fewer, or other operations. For example, operations may be performed in parallel or in any suitable order. While at times discussed as the autonomous vehicle **502**, control device **550**, or components of any of thereof performing operations, any suitable system or components of the system may perform one or more operations of the method **200**. For example, one or more operations of method **200** may be implemented, at least in part, in the form of software instructions **128** and processing instructions **580**, respectively, from FIGS. **1** and **5**, stored on non-transitory, tangible, machine-readable media (e.g., memory **126** and data storage **590**, respectively, from FIGS. **1** and **5**) that when run by one or more processors (e.g., processors **122** and **570**, respectively, from FIGS. **1** and **5**) may cause the one or more processors to perform operations **202-218**.
(114) Method **200** begins at operation **202** where the control device **550** receives sensor data **134** from sensors **546** associated with an autonomous vehicle **502**. The control device **550** may receive the sensor data **134** from the sensors **546** continuously, periodically (e.g., every second, every five seconds, or any suitable duration), and/or on-demand.
(115) At operation **204**, the control device **550** may detect the presence of a vehicle **108** from the sensor data **134**. For example, the control device **550** may implement the object detection machine learning modules **112** to detect the vehicle **108** from the sensor data **134**. The control device **550** may detect the presence of any of the vehicles **108***a*, **108***b*, or **108***c* described in FIG. **1**. Similarly, the control device **550** may detect the presence of any obstacle/object **142** and/or non-player character **144** from the sensor data **134**.
(116) At operation **206**, the control device **550** may determine a lateral distance **138** between the autonomous vehicle **502** and the vehicle **108**. For example, the control device **550** may determine the lateral distance **138***a*, **138***b*, or **138***c* between the autonomous vehicle **502** and each of the vehicles **108***a*, **108***b*, and **108***c*, respectively, similar to that described in FIG. **1**.
(117) At operation **208**, the control device **550** may compare the lateral distance **138** with the threshold distance **132** from the autonomous vehicle **502**. The control device **550** may define the threshold distance **132**, similar to that described in FIG. **1**.
(118) At operation **210**, the control device **550** may determine whether the lateral distance **138** between the autonomous vehicle **502** and the vehicle **108** is less than the threshold distance **132**. In this process, the control device **550** may determine whether to instruct the autonomous vehicle **502** to perform the lane bias maneuver **130**. If the control device **550** determines that the lateral distance **138** between the autonomous vehicle **502** and the vehicle **108** is less than the threshold distance **132**, method **200** may proceed to operation **212**. Otherwise, method **200** returns to operation **202**. In other words, if the control device **550** determines that the lateral distance **138** between the autonomous vehicle **502** and the vehicle **108** is equal to or more than the threshold distance **132**, the control device **550** may determine that the autonomous vehicle **502** is keeping a safe distance from the vehicle **108**. Thus, the control device **550** may continue to monitor and evaluate distances between the autonomous vehicle **502** and other vehicles **108** (or objects **142**).
(119) At operation **212**, the control device **550** may determine whether a lane bias maneuver **130** is executable.
(120) In some embodiments, the control device **550** may determine that the lane bias maneuver **130** is executable if it is determined that the lane bias maneuver **130** can be performed within a threshold time period **148**. In other words, the control device **550** may determine that the lane bias maneuver **130** is executable if by performing the lane bias maneuver **130**, the future lateral distance **138** between the autonomous vehicle **502** and the vehicle **108** will be at least equal to the threshold distance **132** within the threshold time period **148**, similar to that described in FIG. **1**.
(121) In some embodiments, the control device **550** may determine whether the lane bias maneuver **130** is executable based on the road structure. For example, if the road **102** has high curvature (e.g., more than sixty degrees, seventy degrees, etc.), the control device **550** may determine that the lane bias maneuver **130** is not executable. If the control device **550** determines that the lane bias maneuver **130** is executable, method **200** may proceed to operation **216**. Otherwise, method **200** may proceed to operation **214**.
(122) At operation **214**, the control device **550** may instruct the autonomous vehicle **502** to perform a minimal risk maneuver **140**. For example, the minimal risk maneuver **140** may include slowing down or speeding up the autonomous vehicle **502** until the autonomous vehicle **502** and the vehicle **108** are no longer adjacent to each other.
(123) At operation **216**, the control device **550** may determine whether performing the lane bias maneuver **130** is safe.
(124) In some embodiments, the control device **550** may determine whether performing the lane bias maneuver **130** is safe based on the historical driving behavior **162** associated with the vehicle **108**. For example, if the control device **550** determines that the

historical driving behavior **162** associated with the vehicle **108** indicates that the driving behavior of the vehicle **108** is highly unpredictable, e.g., the driving pattern prediction **164** of the vehicle **108** is less than a threshold percentage, such as 60%, 55%, etc., the control device **550** may determine that it is not safe to perform the lane bias maneuver **130**, similar to that described in FIG. **1**.

(125) In another example, the control device **550** may determine whether performing the lane bias maneuver **130** is safe based on road conditions **154**, such as traffic and weather on the road **102**. For example, if the control device **550** determines that there is congested traffic on the road **102** and/or there is a severe weather condition to the extent that a risk of collision with another vehicle **108** may become more than a threshold percentage (e.g., more than 10%, 15%, etc.) by performing the lane bias maneuver **130**, the control device **550** may determine that it is not safe to perform the lane bias maneuver **130**. If it is determined that it is not safe to perform the lane bias maneuver **130**, method **200** may proceed to operation **214**. Otherwise, method **200** may proceed to operation **218**.

(126) At operation **218**, the control device **550** may instruct the autonomous vehicle **502** to perform the lane bias maneuver **130**. In this process, the control device **550** drives the autonomous vehicle **502** off-center (with the distance of the lane bias amount **110**) in the current lane **104***a* toward the opposite direction with respect to the vehicle **108** until the lateral distance **138** between the vehicle **108** and the autonomous vehicle **502** is at least equal to the threshold distance **132**, similar to that described above in FIG. **1**.

(127) Example System for Implementing a Lane Bias Maneuver to Negotiate a Curved Road

(128) FIG. **3** illustrates an embodiment of a system **300** for implementing a lane bias maneuver **130** for autonomous vehicles **502** to negotiate a curved road **302**. FIG. **3** further illustrates a simplified diagram of a curved road **302** traveled by the autonomous vehicle **502**. In some embodiments, system **300** comprises an autonomous vehicle **502** and its components, including the control device **550** and sensors **546**.

(129) The control device **550** comprises the processor **122** in signal communication with the memory **126**. Memory **126** may store software instructions **312** that when executed by the processor **122** cause the control device **550** to perform one or more functions described herein. For example, when the software instructions **312** are executed, the processor **122** implements the lane bias maneuver **130** to negotiate a curved road **302**. The system **300** may be configured as shown or in any other configuration.

(130) In general, system **300** may be configured to implement the lane bias maneuver **130** in response to detecting that the autonomous vehicle **502** is approaching a curved road, such as the exemplary illustrated curved road **302** and/or when the trailer **318** of the autonomous vehicle **502** swings or diverts from the straight line and creates a trailer angle **342** between the semi-truck tractor unit **316** and the trailer **318** of the autonomous vehicle **502**, for example, due to the wind going across the autonomous vehicle **502** even on a straight road. The semi-truck tractor unit **316** is interchangeably referred to herein as a cab **316** of the autonomous vehicle **502**.

(131) As briefly described in FIG. **1**, in some cases, when the autonomous vehicle **502** is driving on a curved lane **304** on the curved road **302**, the trailer **318** of the autonomous vehicle **502** may inadvertently divert or swing from the centerline of the curved lane **304**.

(132) In some cases, a distance between the autonomous vehicle **502** and a vehicle on the curved road **302** may become less than a threshold distance **132** due to the trailer **318** of the autonomous vehicle **502** diverting from the centerline of the curved lane **304**. Likewise, when wind is going across the autonomous vehicle **502** (either when the autonomous vehicle **502** is on a curved or straight road), the wind might cause the trailer **318** of the autonomous vehicle **502** to divert or swing from the centerline of the current lane, and create a trailer angle **342** between the trailer **318** and the cab **316** of the autonomous vehicle **502**. For example, a distance between the autonomous vehicle **502** and a vehicle on the curved or a straight road may become less than a threshold distance **132** due to the trailer **318** of the autonomous vehicle **502** diverting from the centerline of the curved or the straight lane.

(133) These situations may lead to unsafe driving conditions for the autonomous vehicle **502** and the vehicle(s) on either side of the autonomous vehicle **502** on the curved or the straight road. In such cases, the control device **550** may implement the lane bias maneuver **130** to drive the autonomous vehicle **502** off-center in the curved lane **304** so that the autonomous vehicle **502** does not invade the side lanes. In other words, the control device **550** may implement the lane bias maneuver **130** so neither the cab **316** nor the trailer **318** divert into a side lane.

(134) To this end, the control device **550** calculates the total lane bias adjustment amount **320** that is the distance of driving the autonomous vehicle **502** off-center in the current lane to perform the lane bias maneuver **130**. The process of calculating the distance to drive the autonomous vehicle **502** off-center in the current lane **304** (i.e., total lane bias adjustment amount **320**) is described further below in conjunction with the operational flow of system **300**.

(135) In brief, to calculate the total lane bias adjustment amount **320**, the control device **550** calculates the first lane bias adjustment amount **330** that is associated with the road curvature **328**, calculates the second lane bias adjustment amount **340** that is associated with the trailer angle **342**, and combines them together. In calculating the first lane bias adjustment amount **330**, that the trailer angle **342** is represented (or assumed) to be zero, and the control device **550** calculates the first lane bias adjustment amount **330** in isolation. In calculating the second lane bias adjustment amount **340**, the road **302** is represented (or assumed) to be straight, and the control device **550** calculates the second lane bias adjustment amount **340** in isolation. In this disclosure, the first lane bias adjustment amount **330** may be interchangeably referred to herein as the first lane bias adjustment distance amount **330**, the second lane bias adjustment amount **340** may be interchangeably referred to herein as the second lane bias adjustment distance amount **340**, and the total lane bias adjustment amount **320** may be interchangeably referred to herein as the total lane bias adjustment distance amount **320**.

(136) In certain embodiments, the system **100** of FIG. **1** or the system **300** of FIG. **3** may perform one or more operations of the operational flow described in FIG. **1**, one or more operations of the method **200** described in FIG. **2**, one or more operations of the operational flow described in FIG. **3**, and one or more operations of the method **400** described in FIG. **4**.

(137) In certain embodiments, a system may include one or more components of the system **100** of FIG. **1** and the system **300** of FIG. **3**, and may be configured to perform one or more operations of the operational flow described in FIG. **1**, one or more

operations of the method **200** described in FIG. **2**, one or more operations of the operational flow **300** described in FIG. **3**, and one or more operations of the method **400** described in FIG. **4**.

(138) System Components

(139) Aspects of the control device **550** are described in FIGS. **1** and **2**, and additional aspects are described below. The memory **126** may be further configured to store software instructions **312**, road radius **322**, trailer angle **342**, trailer length **326**, lane bias maneuver **130**, map data **114**, sensor data **314**, first lane bias adjustment amount **330**, second lane bias adjustment amount **340**, total lane bias adjustment amount **320**, lane bias amount **110**, final lane bias amount **350**, trailer bias amount **352**, and threshold distance **132**.

(140) The corresponding description below describes the operational flow of the system **300** for implementing the lane bias maneuver **130** when the autonomous vehicle **502** is approaching a curved road **302**.

(141) Operational Flow for Implementing the Lane Bias Maneuver to Negotiate a Curved Road

(142) The operational flow of the system **300** begins when the control device **550** may determine that the autonomous vehicle **502** is approaching a curved road **302**.

(143) In some embodiments, the control device **550** may determine that the autonomous vehicle **502** is approaching a curved road **302** based on analyzing the map data **114**. The map data **114** is described in FIG. **1**. For example, the map data **114** may include a virtual map of a city in which the autonomous vehicle **502** is driving. The map data **114** may include one or more roads ahead of the autonomous vehicle **502**. The control device **550** may implement data processing algorithms, such as image processing algorithms to analyze the map data **114** to determine a shape of one or more roads ahead of the autonomous vehicle **502**.

(144) In some embodiments, the control device **550** may determine that the autonomous vehicle **502** is approaching the curved road **302** based on sensor data **314**. In this process, the control device **550** may receive sensor data **314** from the sensors **546** of the autonomous vehicle **502**, where the sensor data **314** describes the environment around the autonomous vehicle **502**. The sensor data **314** may include data that indicates a set of locations of lane markers **306** on the curved road **302**. The control device **550** may implement the object detection machine learning module **166** to process the sensor data **314** and determine the set of locations of the lane markers **306** from the sensor data **314**. The control device **550** may determine that the autonomous vehicle **502** is approaching the curved road **302** based on determining that the set of locations of the lane markers **306** follows a curved line.

(145) Now that the control device **550** has determined that the autonomous vehicle **502** is approaching the curved road **302**, the control device **550** may determine a distance to drive the autonomous vehicle **502** off-center from the centerline of the curved lane **304** to perform the lane bias maneuver **130**. To this end, the control device **550** may determine the total lane bias adjustment amount **320**.

(146) To determine the total lane bias adjustment amount **320**, the control device **550** combines the first lane bias adjustment amount **330** and the second lane bias adjustment amount **340**. The first lane bias adjustment amount **330** may be associated with the road curvature **328**. The second lane bias adjustment amount **340** may be associated with the trailer angle **342**. The control device **550** may instruct the autonomous vehicle **502** to perform the lane bias maneuver **130**, where the lane bias maneuver **130** comprises driving the autonomous vehicle **502** off-center in a curved lane currently traveled by the autonomous vehicle **502** based on the total lane bias adjustment amount **320**.

(147) The corresponding description below described calculating the first lane bias adjustment amount **330** and the second lane bias adjustment amount **340**.

(148) Calculating a First Lane Bias Adjustment Amount Associated with a Road Curvature

(149) In some embodiments, in calculating the first lane bias adjustment amount **330**, the trailer angle **342** is represented to be zero. As can be seen in FIG. **3**, in calculating the first lane bias adjustment amount **330**, the cab **316** and the trailer **318** of the autonomous vehicle **502** are substantially aligned with each other such that the trailer angle **342** between the cab **316** and the trailer **318** of the autonomous vehicle **502** is zero.

(150) To determine the first lane bias adjustment amount **330**, the control device **550** may determine a road radius **322** of the curved road **302**. In some embodiments, the control device **550** may determine the road radius **322** from the map data **114**. In this process, the control device **550** may determine a virtual circle **324** on the map data **114** such that the curved road **302** is a part of a circumference of the virtual circle **324**. In other words, the centerline of the road **302** may be a part of the circumference of the virtual circle **324**.

(151) The control device **550** may determine the road radius **322** of the curved road **302** by calculating a distance between the center of the virtual circle **324** and a point **332** where the cab **316** of the autonomous vehicle **502** meets the trailer **318** of the autonomous vehicle **502**. The control device **550** calculates the first lane bias adjustment amount **330** associated with the road curvature **328** using the road radius **322** and a trailer length **326** as described below. The trailer length **326** may be provided to the control device **550** in the software instructions **312**.

(152) In some embodiments, the control device **550** may calculate the first lane bias adjustment amount **330** according to an Equation (1).

(153) $$\text{Firstlanebiasadjustmentvalue} = (\text{roadradius}^2 - \text{trailerlength}^2)^{1/2} - \text{roadradius} \quad \text{Equation(1)}$$

(154) The trailer length in Equation (1) is the trailer length **326** which is the length of the trailer **318**.

(155) In some embodiments, the control device **550** may adjust a sign of the first lane bias adjustment amount **330** based on a direction of the road curvature **328** and/or a direction of the first lane bias adjustment amount **330**. As can be inferred from Equation (1), the calculated first lane bias adjustment amount **330** using the Equation (1) will always be positive. However, the sign of the first lane bias adjustment amount **330** may need to be adjusted based on the direction of the road curvature **328** and/or the direction of the first lane adjustment amount **330**.

(156) In the example situation illustrated in FIG. **3**, it is assumed that if the road curvature **328** is to the left direction, the sign associated with the road curvature **328** is positive; and if the road curvature **328** is to the right direction, the sign associated with the road curvature **328** is negative. Further, it is assumed that if the first lane bias adjustment amount **330** is to the left direction,

the sign of the first lane bias adjustment amount **330** is negative; and if the first lane bias adjustment amount **330** is to the right direction, the sign of the first lane bias adjustment amount **330** is positive.
(157) In this example, the first lane bias adjustment amount **330** is to the left direction because the middle-end point of the trailer **318** is on the right side of the centerline of the lane **304**. Thus, the sign of the first lane bias adjustment amount **330** is negative. Thus, in this example situation where the direction of the road curvature **328** is to the left and the direction of the first lane bias adjustment amount **330** is to the left, the first lane bias adjustment amount **330** with the adjusted sign may be calculated according to an Equation (2).
(158)

$$\text{Firstlanebiasadjustmentvaluewiththeadjustmentsign} = ((\text{roadraius}^2 - \text{trailerlength}^2)^{1/2} - \text{roadradius})) \times \text{sign}(-\text{roadcurvature}) \quad \text{Equation(2}$$

(159) The sign (road curvature) in Equation (2) indicates a sign associated with the road curvature **328**.
(160) Calculating the Second Lane Bias Adjustment Amount Associated with the Trailer Angle
(161) In some embodiments, in calculating the second lane bias adjustment amount **340**, the road **302** is represented to be straight. As can be seen in FIG. **3**, in calculating the second lane bias adjustment amount **340**, the autonomous vehicle **502** is assumed to be on a straight line **348**. The straight line **348** may be the centerline of a road that is assumed to be straight.
(162) To calculate the second lane bias adjustment amount **340**, the control device **550** may determine a trailer angle **342** between the trailer **318** and the cab **316**. The control device **550** may determine the trailer angle **342** from sensor data **314** received from a sensor **546** that may be configured to measure the trailer angle **342** between the trailer **318** and the cab **316** by measuring mechanical rotations and converting them into a scaled electrical signal. The control device **550** calculates the second lane bias adjustment amount **340** associated with the trailer angle **342** using the trailer angle **342** and the trailer length **326**, as described below.
(163) In some embodiments, the control device **550** may calculate the second lane bias adjustment amount **340** according to an Equation (3).
Second lane bias adjustment value=trailer length×sin(trailer angle)   Equation (3)
(164) In some embodiments, the control device **550** may adjust a sign of the second lane bias adjustment amount **340** based on a direction of the trailer angle **342** and/or a direction of the second lane bias adjustment amount **340**.
(165) The sign of the trailer angle **342** may depend on which direction the trailer **318** is diverting from the straight line **348**. For example, if the trailer **318** swings to the left direction, a sign associated with the trailer angle **342** is negative; and if the trailer **318** swings to the right direction, the sign associated with the trailer angle **342** is positive. Also, if the second lane bias adjustment amount **340** is to the left direction, the sign of the second lane bias adjustment amount **340** is negative; and if the second lane bias adjustment amount **340** is to the right direction, the sign of the second lane bias adjustment amount **340** is positive.
(166) In the example situation illustrated in FIG. **3**, the direction of the second lane bias adjustment amount **340** is to the right because the trailer **318** is diverted to the left direction. Thus, the right direction of the second lane bias adjustment amount **340** means that the sign of the second lane bias adjustment amount **340** is positive.
(167) Thus, in this example where the direction of the trailer angle **342** is to the left and the direction of the second lane bias adjustment amount **340** is to the right, the control device **550** may calculate the second lane bias adjustment amount **340** with the adjusted sign according to an Equation (4).
Second lane bias adjustment value with the assigned sign=−trailer length×sin(trailer angle)   Equation (4)
(168) As described above, each of the first lane bias adjustment amount **330** and the second lane bias adjustment amount **340** may be toward the left or right direction and is associated with a sign.
(169) If a lane bias direction is to the left, the sign for that lane bias adjustment amount is negative; and if a lane bias direction is to the right, the sign of that lane bias adjustment amount is positive. The direction and amount of the total lane bias adjustment amount **320** may depend on the sign and the amount of each of the first lane bias adjustment amount **330** and the second lane bias adjustment amount **340**.
(170) In other words, the direction and amount of the total lane bias adjustment amount **320** may depend on which of the first lane bias adjustment amount **330** or the second lane bias adjustment amount **340** has more effect on the autonomous vehicle **502**. For example, if the first lane bias adjustment amount **330** has a negative sign (i.e., toward the left direction), the second lane bias adjustment amount **340** has a positive sign (i.e., toward the right direction), and the first lane bias adjustment amount **330** is larger than the second lane bias adjustment amount **340**, the total lane bias adjustment amount **320** will be negative (i.e., toward the left direction).
(171) Performing the Lane Bias Maneuver
(172) The control device **550** calculates the total lane bias adjustment amount **320** by combining the first lane bias adjustment amount **330** and the second lane bias adjustment amount **340**.
(173) Once the total lane bias adjustment amount **320** is calculated, the control device **550** may instruct the autonomous vehicle **502** to perform the lane bias maneuver **130** using the total lane bias adjustment amount **320**. In this maneuver, the control device **550** drives the autonomous vehicle **502** off-center from the centerline of the curved lane **304** based on the calculated total lane bias adjustment amount **320** so that the autonomous vehicle **502** does not invade the side lanes.
(174) In cases where the autonomous vehicle **502** encounters a vehicle **310** along the curved road **302**, the control device **550** may account for the keeping a safe distance from the vehicle **310** in addition to accounting for the lane bias adjustment amounts **330** and/or **340** associated with the road curvature **328** and/or the trailer angle **342**.
(175) To this end, the control device **550** may determine the lane bias amount **110** to keep a safe distance from the vehicle **310**, i.e., until the distance between the autonomous vehicle **502** and the vehicle **310** is at least equal to the threshold distance **132**, similar to that described in FIGS. **1** and **2**. The control device **550** may also determine the total lane bias adjustment amount **320**, similar to that described above in FIG. **3**. The control device **550** may combine or add the total lane bias adjustment amount **320** with the lane bias amount **110** described in FIGS. **1** and **2** to determine the final lane bias amount **350** to drive the autonomous vehicle **502** off-center from a centerline of the lane **304**.

(176) If there are no vehicles **310** on the curved road **302**, the total lane bias adjustment amount **320** may be equal to the final lane bias amount **350**.
(177) An example scenario where the autonomous vehicle **502** encounters a vehicle **310** on a curved road **302** is described below.
(178) Encountering a Vehicle on a Curved Road
(179) In an example scenario, assume that the autonomous vehicle **502** encounters a vehicle **310** while traveling on a curved road **302**. In such cases, the control device **550** may calculate the lane bias amount **110** for keeping at least the threshold distance **132** from the vehicle **310**, similar to that described in FIGS. **1** and **2**.
(180) The control device **550** may also calculate the total lane bias adjustment amount **320** by calculating and combining the first lane bias adjustment amount **330** and the second lane bias adjustment amount **340**, similar to that described above. The control device **550** may determine the final lane bias amount **350** by combining the lane bias amount **110** and the total lane bias adjustment amount **320**.
(181) In the example of FIG. **3**, if the autonomous vehicle **502** encounters the vehicle **310***a* on the outer side of the curved road **302**, the control device **550** may combine the lane bias amount **110** to the total lane bias adjustment amount **320** to calculate the final lane bias amount **350**.
(182) If the autonomous vehicle **502** encounters the vehicle **310***b* on the inner side of the curved road **302**, the control device **550** may determine not to combine the lane bias amount **110** to the total lane bias adjustment amount **320** and only use the total lane bias adjustment amount **320** to drive the autonomous vehicle **502** off-center from the lane **304**. One reason for determining not to combine the lane bias amount **110** to the total lane bias adjustment amount **320** is to not reduce a distance between the autonomous vehicle **502** and the vehicle **310***b* and not to reduce the final lane bias amount **350**.
(183) Performing the Lane Bias Maneuver on a Straight Road
(184) In some embodiments, the control device **550** may determine whether to instruct the autonomous vehicle **502** to perform the lane bias maneuver **130** while traveling on a straight road. The control device **550** may determine that the autonomous vehicle **502** is traveling along a straight road by analyzing the map data **114** and/or sensor data **314**, similar to that described above with respect to determining that the autonomous vehicle **502** is approaching the curved road **302**. Thus, the control device **550** may determine that the first lane bias adjustment amount **330** is zero because the road radius **322** is substantially large, such as more than a threshold distance, e.g., 1000 meters.
(185) In some cases, the wind might push the trailer **318** of the autonomous vehicle **502** to divert from the centerline of a straight road. In such cases, the control device **550** may detect that wind is causing the trailer **318** of the autonomous vehicle **502** to divert from a straight line. The control device **550** may determine that wind is causing the trailer **318** of the autonomous vehicle **502** to divert from the straight line based on sensor data **314** received from the sensors **546** that indicates the trailer angle **342** is more than zero. In response, the control device **550** may determine the trailer angle **342** associated with the wind from sensor data **314** received from a sensor **546** that may be configured to measure the trailer angle **342**.
(186) The control device **550** calculates the second lane bias adjustment amount **340** caused by the wind, similar to that described above using the Equations (3) and (4). Since the first lane bias adjustment amount **330** is determined to be zero, the control device **550** may determine that the total lane bias adjustment amount **320** is equal to the second lane bias adjustment amount **340**.
(187) Calculating the Total Lane Bias Adjustment Amount Using a Trailer Bias
(188) In another embodiment, the control device **550** may calculate the final lane bias amount **350** as described below.
(189) In this embodiment, the control device **550** may calculate a trailer bias amount **352** according to an Equation (5):
(190)
$$\text{trailerbias} = (\text{roadradius}^2 + \text{trailerlength}^2 - 2\times\text{roadradius}\times\text{trailerlenght}\times\cos(\tfrac{\pi}{2} - \text{trailerangle})^{1/2} - \text{roadradius} \quad \text{Equation}(5)$$
(191) The calculated trailer bias amount **352** may be positive or negative. When the trailer bias amount **352** is positive, it means that the trailer **318** is biased or diverted toward the outer side of the curved road **302**. When the trailer bias amount **352** is negative, it means that the trailer **318** is biased or diverted toward the inner side of the curved road **302**. For each of the trailer angle **342**, the road curvature **328**, and the final lane bias amount **350**, the positive sign means the left direction, and the negative sign means the right direction.
(192) Thus, the direction or sign of the trailer bias amount **352** may need to be adjusted to align with the correct lane bias direction. Thus, the control device **550** may calculate the final lane bias amount **350** by combining the lane bias amount **110** with the trailer bias amount **352** with the adjusted sign.
(193) The process of adjusting the sign of the trailer bias amount **352** is described below. In some cases, the autonomous vehicle **502** may encounter a vehicle **310** on either side and on a curved road **302**, where the curvature of the curved road **302** may be toward left or right direction. For example, the autonomous vehicle **502** may encounter: 1) a road with a left curvature and the vehicle **310** may be on the right side of the autonomous vehicle **502**; 2) a road with a left curvature and the vehicle **310** may be on the left side of the autonomous vehicle **502**; 3) a road with a right curvature and the vehicle **310** may be on the left side of the autonomous vehicle **502**; and 4) a road with a right curvature and the vehicle **310** may be on the right side of the autonomous vehicle **502**.
(194) The control device **550** may determine the direction and sign of each of the trailer angle **342**, the curvature, the trailer bias amount **352**, and the final lane bias amount **350**, as illustrated in the Table 1 below.
(195) TABLE-US-00001 TABLE 1 Example scenarios where the autonomous vehicle 502 encounters a vehicle 310 on a curved road 302. Left curve, trailer Left curve, trailer Right curve, trailer Right curve, trailer 318 is biased to 318 is biased to 318 is biased to 318 is biased to outer side, vehicle inner side, vehicle outer side, vehicle inner side, vehicle 310 is on right, 310 is on left, 310 is on left, 310 is on right, thus, autonomous thus, autonomous thus, autonomous thus, autonomous vehicle 502 is lane vehicle 502 is lane vehicle 502 is lane vehicle 502 is lane biased to left biased to right biased to right biased to left Trailer − − + + angle 342 (trailer 318 swings (trailer 318 swings (trailer 318 swings (trailer 318 swings to left side) to left side) to right side) to right side) Road + + − − curvature (left curve) (left curve) (right curve) (right curve) 328 Direction + − + − of trailer (trailer 318 biased (trailer 318 biased (trailer 318 biased (trailer 318 biased bias to outer side) to inner side) to outer side) to inner side)

amount 352 Direction − + + − of final (autonomous (autonomous (autonomous (autonomous lane bias vehicle 502 is lane vehicle 502 is lane vehicle 502 is lane vehicle 502 is lane amount biased to the left) biased to the right) biased to the right) biased to the left) 350

(196) As can be seen from the Table 1, for left curves, the direction of the trailer bias amount **352** has the opposite sign compared to the direction of the lane bias amount **110**, while for the right curves, the direction of the trailer bias amount **352** has the same sign as the direction of the lane bias amount **110**. Thus, the control device **550** may reverse the sign of the trailer bias amount **352** if it is going through a left curve. This can be done by multiplying the sign of the trailer angle **342** with the trailer bias amount **352**.

(197) In some cases, the trailer angle **342** may be too small, for example, less than a threshold degree, e.g., less than five degrees, four degrees, etc. In such cases, the sign of the road curvature **328** (opposite to the trailer angle **342**) may be used to adjust the sign of the trailer bias amount **352**.

(198) In another use case, assume that the autonomous vehicle **502** is traveling along a straight road, and the trailer **318** is biased or diverted from the straight line due to road banks (roll angles) or wind. In such cases, since the road radius **322** is very large (e.g., more than a threshold amount), the trailer bias amount **352** will always be negative (inner side compared to the large circle associated with the large road radius **322**).

(199) In such cases, the control device **550** may determine the direction and sign of each of the trailer angle **342**, the curvature, the trailer bias amount **352**, and the final lane bias amount **350**, as illustrated in the Table 2 below.

(200) TABLE-US-00002 TABLE 2 Example scenarios where the autonomous vehicle 502 encounters a vehicle 310 on a straight road. Straight road, trailer Straight road, trailer 318 biased to left 318 biased to side, vehicle 310 right side, vehicle on left, thus the 310 on right, thus autonomous vehicle autonomous vehicle 502 is lane biased 502 is lane to right biased to left Trailer angle − + 342 (trailer 318 swings (trailer 318 swings to left side) to right side) Road N/A N/A curvature 328 Direction of − − trailer bias (trailer 318 biased (trailer 318 biased amount 352 to inner side) to inner side) Direction of + − final lane bias (autonomous (autonomous amount 350 vehicle 502 lane vehicle 502 lane bias to the right) bias to the left)

(201) As can be seen from the Table 2, the road curvature **328** is not usable because the road is straight. As further can be seen from the Table 2, the trailer bias amount **352** has the opposite sign compared to the final lane bias amount **350** if the trailer **318** swings to the left side, while the trailer bias amount **352** has the same sign as the final lane bias amount **350** if the trailer **318** swings to the right direction. In this case, the control device **550** may multiply the sign of the trailer angle **342** with the trailer bias amount **352** to adjust the sign of the trailer bias amount **352**.

(202) In an example scenario, assume that the road radius **322** (or the turning radius) is 620 meters (m), and the average of the trailer angle **342** is 0.01 radian (rad) with an average deviation or spike up to 0.02 rad. In this example, the average of the trailer bias amount **352** may be 0.0 m with an average deviation or spike up to −0.14 m. In this example, the negative value means the inner side. Thus, the trailer bias amount **352** is on the middle of the lane with some oscillations or deviations to the inner side.

(203) In another example scenario, assume that the road radius **322** (or the turning radius) is 502 m, and the average of the trailer angle **342** is 0.018 rad with an average deviation or spike up to −0.3 rad. The deviations or spikes could be caused by the wind, control adjustments to the autonomous vehicle **502**, and/or road bumps, but the trailer bias amount **352** is toward the inner side.

(204) The difference between biasing toward the inner and outer sides of the curved road **302** may be explained by the different roll angles. The inner side of the road has a large roll angle which may lead the trailer **318** to bias toward the inner side.

(205) In some cases, the trailer angle **342** may be too small to be measured due to a shape of the road curvature **328**, such as in sharp curves. In such cases, the road radius **322** may be at least 1000 m. Thus, the trailer bias amount **352** may be smaller than 0.15 m. Here, the trailer bias amount **352** is to the outer side (upon ignoring the very small trailer angle **342**). One possible reason is that such a curved road may be flat and the roll angle is much smaller than the curved angle.

(206) In some embodiments, the trailer bias amount **352** may be affected by the speed of the autonomous vehicle **502**, the road curvature **328** (or the turning radius), roll angle, and/or wind that is going across the autonomous vehicle **502**. To reduce the complexity of calculating the trailer bias amount **352**, the trailer angle **342** may be used. If the turning radius is larger than 1000 m, the trailer bias amount **352** may be calculated to be less than 0.15 m. This amount of bias is smaller than the lateral error range than is preconfigured in the control device **550**. Thus, it may not be noticeable by the control device **550**.

(207) In some embodiments, the control device **550** may be configured to reduce signal noise and self-existing control adjustments and driving behaviors in calculating the total lane bias adjustment amount **320** and/or the final lane bias amount **350**. In this operation, the control device **550** may implement smoothing filters to smooth the instruction signal that indicates to perform the lane bias maneuver **130**, thereby reducing the signal noise and self-existing control adjustments and driving behaviors. In some embodiments, the control device **550** may use a digital filter, such as a moving average filter, a finite impulse response filter, an infinite impulse response filter, and/or the like to reduce the noise or deviations in calculating the trailer angle **342**.

(208) In certain embodiments, the control device **550** may perform a similar operation with respect to determining a lateral distance (**138***a*-*c* in FIG. **1**) between the autonomous vehicle **502** and a vehicle **310***a* and/or vehicle **310***b*, compare the lateral distance with a threshold distance (**132** in FIG. **1**) to determine whether or not the lateral distance is less than the threshold distance. If it is determined that the lateral distance is less than the threshold distance, the control device **550** may instruct the autonomous vehicle to perform the lane bias maneuver **130**.

(209) In certain embodiments, the control device **550** may perform similar operations when encountering a curved road **302**, similar to that described in FIGS. **1** and **2** when encountering a straight road **102**, and vice versa. For example, the control device **550** may adjust one or more operations for navigating the autonomous vehicle **502** described herein according to the shape of the road to achieve a more optimal and safe navigation path for the autonomous vehicle **502**, surrounding vehicles, and pedestrians.

(210) In certain embodiments, the control device **550** may perform a similar operation with respect to determining a lateral distance (**138***a*-*c* in FIG. **1**) between the autonomous vehicle **502** and a vehicle **310***a* and/or vehicle **310***b*, compare the lateral distance with a threshold distance (**132** in FIG. **1**) to determine whether or not the lateral distance is less than the threshold

distance. If it is determined that the lateral distance is less than the threshold distance, the control device **550** may instruct the autonomous vehicle to perform the lane bias maneuver **130**.
(211) In certain embodiments, the control device **550** may perform similar operations when encountering a curved road **302**, similar to that described in FIGS. **1** and **2** when encountering a straight road **102**, and vice versa. For example, the control device **550** may adjust one or more operations for navigating the autonomous vehicle **502** described herein according to the shape of the road to achieve a more optimal and safe navigation path for the autonomous vehicle **502**, surrounding vehicles, and pedestrians.
(212) The embodiments, examples, and operations described in the present disclosure are not exclusive from one another. In certain embodiments, any and any combination of embodiments, examples, and operations may be implemented in conjunction to one another as a situation encountered by an autonomous vehicle **502** requires.
(213) Example Method for Implementing a Lane Bias Maneuver to Negotiate a Curved Road
(214) FIG. **4** illustrates an example flowchart of a method **400** for implementing a lane bias maneuver **130** to negotiate a curved road. Modifications, additions, or omissions may be made to method **400**. Method **400** may include more, fewer, or other operations. For example, operations may be performed in parallel or in any suitable order. While at times discussed as the autonomous vehicle **502**, control device **550**, or components of any of thereof performing operations, any suitable system or components of the system may perform one or more operations of the method **400**. For example, one or more operations of method **400** may be implemented, at least in part, in the form of software instructions **312** and processing instructions **580**, respectively, from FIGS. **3** and **5**, stored on non-transitory, tangible, machine-readable media (e.g., memory **126** and data storage **590**, respectively, from FIGS. **3** and **5**) that when run by one or more processors (e.g., processors **122** and **570**, respectively, from FIGS. **3** and **5**) may cause the one or more processors to perform operations **402-418**.
(215) Method **400** begins at operation **402** where the control device **550** may determine whether the autonomous vehicle **502** is approaching a curved road **302**. In this process, the control device **550** may determine whether the autonomous vehicle **502** is approaching a curved road **302** based on analyzing the map data **114** and/or sensor data **314**, similar to that described in FIG. **3**. If the control device **550** determines that the autonomous vehicle **502** is approaching a curved road **302**, method **400** may proceed to operation **404**. Otherwise, method **400** may proceed to operation **416**.
(216) At operation **404**, the control device **550** may determine a road radius **322** of the curved road **302**, similar to that described in FIG. **3**.
(217) At operation **406**, the control device **550** may calculate a first lane bias adjustment amount **330** associated with a road curvature **328** of the curved road **302** based on the road radius **322**. In this process, the control device **550** may calculate the first lane bias adjustment amount **330** according to Equations (1) and (2) described in FIG. **3**.
(218) At operation **408**, the control device **550** may determine a trailer angle **342** between the trailer **318** and the cab **316** of the autonomous vehicle **502**, similar to that described in FIG. **3**.
(219) At operation **410**, the control device **550** may calculate a second lane bias adjustment amount **340** associated with the trailer angle **342** based on the trailer angle **342**. In this process, the control device **550** may calculate the second lane bias adjustment amount **340** according to Equations (3) and (4), similar to that described in FIG. **3**.
(220) At operation **412**, the control device **550** may calculate a total lane bias adjustment amount **320** by combining the first and second lane bias adjustment amounts **330** and **340**.
(221) At operation **414**, the control device **550** may combine the total lane bias adjustment value **320** with an original lane bias amount **110**. The control device **550** may instruct the autonomous vehicle **502** to perform a lane bias maneuver **130** based on the total lane bias adjustment amount **320** and the original lane bias amount **110**. The lane bias maneuver **130** comprises driving the autonomous vehicle **502** off-center in a curved lane **304** currently traveled by the autonomous vehicle **502** based on the total lane bias adjustment amount **320** and the original lane bias amount **110**.
(222) In cases where the autonomous vehicle **502** is on a straight road, the control device **550** may perform the operations **416-420** described below.
(223) At operation **416**, the control device **550** may determine whether the trailer angle **342** between the cab **316** and the trailer **318** of the autonomous vehicle **502** is more than zero. For example, the control device **550** may determine whether the trailer angle **342** is more than zero if sensor data **314** comprises data that indicates the trailer angle **342** is more than zero. In this process, the control device **550** may determine whether wind going across the autonomous vehicle **502** pushing the trailer **318** of the autonomous vehicle to left or right and causing the trailer angle **342** between the cab **316** and the trailer **318** of the autonomous vehicle **502** to become more than zero, similar to that described in FIG. **3**. If the control device **550** determines that the trailer angle **342** is more than zero, method **400** may proceed to operation **418**. Otherwise, method **400** may proceed to operation **420**.
(224) At operation **418**, the control device **550** may determine that the first lane bias adjustment value **330** is zero. In response, method **200** may proceed to **414**.
(225) At operation **420**, the control device **550** may determine that the total lane bias adjustment value **320** is zero. In one embodiment, the control device **750** may determine not to instruct the autonomous vehicle **502** to perform the lane bias maneuver **130** if the lane bias amount **110** and the total lane bias adjustment value **320** are zero.
(226) Example Autonomous Vehicle and its Operation
(227) FIG. **5** shows a block diagram of an example system **500** in which autonomous driving operations can be performed. As shown in FIG. **5**, the autonomous vehicle **502** may be a semi-trailer truck. The system **500** may include several subsystems and components that can generate and/or deliver one or more sources of information/data and related services to the in-vehicle control computer **550** that may be located in an autonomous vehicle **502**. The in-vehicle control computer **550** can be in data communication with a plurality of vehicle subsystems **540**, all of which can be resident in the autonomous vehicle **502**. A vehicle subsystem interface **560** may be provided to facilitate data communication between the in-vehicle control computer **550** and the plurality of vehicle subsystems **540**. In some embodiments, the vehicle subsystem interface **560** can include a controller area network (CAN) controller to communicate with devices in the vehicle subsystems **540**.
(228) The autonomous vehicle **502** may include various vehicle subsystems that support the operation of autonomous vehicle **502**.

The vehicle subsystems **540** may include a vehicle drive subsystem **542**, a vehicle sensor subsystem **544**, a vehicle control subsystem **548**, and/or network communication subsystem **592**. The components or devices of the vehicle drive subsystem **542**, the vehicle sensor subsystem **544**, and the vehicle control subsystem **548** shown in FIG. **5** are examples. The autonomous vehicle **502** may be configured as shown or any other configurations.
(229) The vehicle drive subsystem **542** may include components operable to provide powered motion for the autonomous vehicle **502**. In an example embodiment, the vehicle drive subsystem **542** may include an engine/motor **542***a*, wheels/tires **542***b*, a transmission **542***c*, an electrical subsystem **542***d*, and a power source **542***e*.
(230) The vehicle sensor subsystem **544** may include a number of sensors **546** configured to sense information about an environment or condition of the autonomous vehicle **502**. The vehicle sensor subsystem **544** may include one or more cameras **546***a* or image capture devices, a radar unit **546***b*, one or more temperature sensors **546***c*, a wireless communication unit **546***d* (e.g., a cellular communication transceiver), an inertial measurement unit (IMU) **546***e*, a laser range finder/LiDAR unit **546***f*, a Global Positioning System (GPS) transceiver **546***g*, and/or a wiper control system **546***h*. The vehicle sensor subsystem **544** may also include sensors configured to monitor internal systems of the autonomous vehicle **502** (e.g., an O.sub.2 monitor, a fuel gauge, an engine oil temperature, etc.).
(231) The IMU **546***e* may include any combination of sensors (e.g., accelerometers and gyroscopes) configured to sense position and orientation changes of the autonomous vehicle **502** based on inertial acceleration. The GPS transceiver **546***g* may be any sensor configured to estimate a geographic location of the autonomous vehicle **502**. For this purpose, the GPS transceiver **546***g* may include a receiver/transmitter operable to provide information regarding the position of the autonomous vehicle **502** with respect to the Earth. The radar unit **546***b* may represent a system that utilizes radio signals to sense objects within the local environment of the autonomous vehicle **502**. In some embodiments, in addition to sensing the objects, the radar unit **546***b* may additionally be configured to sense the speed and the heading of the objects proximate to the autonomous vehicle **502**. The laser range finder or LiDAR unit **546***f* may be any sensor configured to use lasers to sense objects in the environment in which the autonomous vehicle **502** is located. The cameras **546***a* may include one or more devices configured to capture a plurality of images of the environment of the autonomous vehicle **502**. The cameras **546***a* may be still image cameras or motion video cameras.
(232) The vehicle control subsystem **548** may be configured to control the operation of the autonomous vehicle **502** and its components. Accordingly, the vehicle control subsystem **548** may include various elements such as a throttle and gear selector **548***a*, a brake unit **548***b*, a navigation unit **548***c*, a steering system **548***d*, and/or an autonomous control unit **548***e*. The throttle and gear selector **548***a* may be configured to control, for instance, the operating speed of the engine and, in turn, control the speed of the autonomous vehicle **502**. The throttle and gear selector **548***a* may be configured to control the gear selection of the transmission. The brake unit **548***b* can include any combination of mechanisms configured to decelerate the autonomous vehicle **502**. The brake unit **548***b* can slow the autonomous vehicle **502** in a standard manner, including by using friction to slow the wheels or engine braking. The brake unit **548***b* may include an anti-lock brake system (ABS) that can prevent the brakes from locking up when the brakes are applied. The navigation unit **548***c* may be any system configured to determine a driving path or route for the autonomous vehicle **502**. The navigation unit **548***c* may additionally be configured to update the driving path dynamically while the autonomous vehicle **502** is in operation. In some embodiments, the navigation unit **548***c* may be configured to incorporate data from the GPS transceiver **546***g* and one or more predetermined maps so as to determine the driving path for the autonomous vehicle **502**. The steering system **548***d* may represent any combination of mechanisms that may be operable to adjust the heading of autonomous vehicle **502** in an autonomous mode or in a driver-controlled mode.
(233) The autonomous control unit **548***e* may represent a control system configured to identify, evaluate, and avoid or otherwise negotiate potential obstacles or obstructions in the environment of the autonomous vehicle **502**. In general, the autonomous control unit **548***e* may be configured to control the autonomous vehicle **502** for operation without a driver or to provide driver assistance in controlling the autonomous vehicle **502**. In some embodiments, the autonomous control unit **548***e* may be configured to incorporate data from the GPS transceiver **546***g*, the radar unit **546***b*, the LiDAR unit **546***f*, the cameras **546***a*, and/or other vehicle subsystems to determine the driving path or trajectory for the autonomous vehicle **502**.
(234) The network communication subsystem **592** may comprise network interfaces, such as routers, switches, modems, and/or the like. The network communication subsystem **592** may be configured to establish communication between the autonomous vehicle **502** and other systems including an oversight server that may be configured to oversee operations of the autonomous vehicles **502**. The network communication subsystem **592** may be further configured to send and receive data from and to other systems.
(235) Many or all of the functions of the autonomous vehicle **502** can be controlled by the in-vehicle control computer **550**. The in-vehicle control computer **550** may include at least one data processor **570** (which can include at least one microprocessor) that executes processing instructions **580** stored in a non-transitory computer-readable medium, such as the data storage device **590** or memory. The in-vehicle control computer **550** may also represent a plurality of computing devices that may serve to control individual components or subsystems of the autonomous vehicle **502** in a distributed fashion. In some embodiments, the data storage device **590** may contain processing instructions **580** (e.g., program logic) executable by the data processor **570** to perform various methods and/or functions of the autonomous vehicle **502**, including those described with respect to FIGS. **1-7**.
(236) The data storage device **590** may contain additional instructions as well, including instructions to transmit data to, receive data from, interact with, or control one or more of the vehicle drive subsystem **542**, the vehicle sensor subsystem **544**, and the vehicle control subsystem **548**. The in-vehicle control computer **550** can be configured to include a data processor **570** and a data storage device **590**. The in-vehicle control computer **550** may control the function of the autonomous vehicle **502** based on inputs received from various vehicle subsystems (e.g., the vehicle drive subsystem **542**, the vehicle sensor subsystem **544**, and the vehicle control subsystem **548**).
(237) FIG. **6** shows a system **600** for providing precise autonomous driving operations. The system **600** may include several modules that can operate in the in-vehicle control computer **550**, as described in FIG. **5**. The in-vehicle control computer **550** may

include a sensor fusion module **602** shown in the top left corner of FIG. **6**, where the sensor fusion module **602** may perform at least four image or signal processing operations. The sensor fusion module **602** can obtain images from cameras located on an autonomous vehicle to perform image segmentation **604** to detect the presence of moving objects (e.g., other vehicles, pedestrians, etc.) and/or static obstacles (e.g., stop sign, speed bump, terrain, etc.) located around the autonomous vehicle. The sensor fusion module **602** can obtain LiDAR point cloud data item from LiDAR sensors located on the autonomous vehicle to perform LiDAR segmentation **606** to detect the presence of objects and/or obstacles located around the autonomous vehicle.
(238) The sensor fusion module **602** can perform instance segmentation **608** on image and/or point cloud data items to identify an outline (e.g., boxes) around the objects and/or obstacles located around the autonomous vehicle. The sensor fusion module **602** can perform temporal fusion **610** where objects and/or obstacles from one image and/or one frame of point cloud data item are correlated with or associated with objects and/or obstacles from one or more images or frames subsequently received in time.
(239) The sensor fusion module **602** can fuse the objects and/or obstacles from the images obtained from the camera and/or point cloud data item obtained from the LiDAR sensors. For example, the sensor fusion module **602** may determine based on a location of two cameras that an image from one of the cameras comprising one half of a vehicle located in front of the autonomous vehicle is the same as the vehicle captured by another camera. The sensor fusion module **602** may send the fused object information to the interference module **646** and the fused obstacle information to the occupancy grid module **660**. The in-vehicle control computer may include the occupancy grid module **660** which can retrieve landmarks from a map database **658** stored in the in-vehicle control computer. The occupancy grid module **660** can determine drivable areas and/or obstacles from the fused obstacles obtained from the sensor fusion module **602** and the landmarks stored in the map database **658**. For example, the occupancy grid module **660** can determine that a drivable area may include a speed bump obstacle.
(240) Below the sensor fusion module **602**, the in-vehicle control computer **550** may include a LiDAR-based object detection module **612** that can perform object detection **616** based on point cloud data item obtained from the LiDAR sensors **614** located on the autonomous vehicle. The object detection **616** technique can provide a location (e.g., in **3**D world coordinates) of objects from the point cloud data item. Below the LiDAR-based object detection module **612**, the in-vehicle control computer may include an image-based object detection module **618** that can perform object detection **624** based on images obtained from cameras **620** located on the autonomous vehicle. The object detection **618** technique can employ a deep machine learning technique **624** to provide a location (e.g., in **3**D world coordinates) of objects from the image provided by the camera **620**.
(241) The radar **656** on the autonomous vehicle can scan an area in front of the autonomous vehicle or an area towards which the autonomous vehicle is driven. The radar data is sent to the sensor fusion module **602** that can use the radar data to correlate the objects and/or obstacles detected by the radar **656** with the objects and/or obstacles detected from both the LiDAR point cloud data item and the camera image. The radar data also may be sent to the interference module **646** that can perform data processing on the radar data to track objects by object tracking module **648** as further described below.
(242) The in-vehicle control computer may include an interference module **646** that receives the locations of the objects from the point cloud and the objects from the image, and the fused objects from the sensor fusion module **602**. The interference module **646** also receives the radar data with which the interference module **646** can track objects by object tracking module **648** from one point cloud data item and one image obtained at one time instance to another (or the next) point cloud data item and another image obtained at another subsequent time instance.
(243) The interference module **646** may perform object attribute estimation **650** to estimate one or more attributes of an object detected in an image or point cloud data item. The one or more attributes of the object may include a type of object (e.g., pedestrian, car, or truck, etc.). The interference module **646** may perform behavior prediction **652** to estimate or predict motion pattern of an object detected in an image and/or a point cloud. The behavior prediction **652** can be performed to detect a location of an object in a set of images received at different points in time (e.g., sequential images) or in a set of point cloud data item received at different points in time (e.g., sequential point cloud data items). In some embodiments, the behavior prediction **652** can be performed for each image received from a camera and/or each point cloud data item received from the LiDAR sensor. In some embodiments, the interference module **646** can be performed (e.g., run or executed) to reduce computational load by performing behavior prediction **652** on every other or after every pre-determined number of images received from a camera or point cloud data item received from the LiDAR sensor (e.g., after every two images or after every three point cloud data items).
(244) The behavior prediction **652** feature may determine the speed and direction of the objects that surround the autonomous vehicle from the radar data, where the speed and direction information can be used to predict or determine motion patterns of objects. A motion pattern may comprise a predicted trajectory information of an object over a pre-determined length of time in the future after an image is received from a camera. Based on the motion pattern predicted, the interference module **646** may assign motion pattern situational tags to the objects (e.g., "located at coordinates (x,y)," "stopped," "driving at 50 mph," "speeding up" or "slowing down"). The situation tags can describe the motion pattern of the object. The interference module **646** may send the one or more object attributes (e.g., types of the objects) and motion pattern situational tags to the planning module **662**. The interference module **646** may perform an environment analysis **654** using any information acquired by system **600** and any number and combination of its components.
(245) The in-vehicle control computer may include the planning module **662** that receives the object attributes and motion pattern situational tags from the interference module **646**, the drivable area and/or obstacles, and the vehicle location and pose information from the fused localization module **626** (further described below).
(246) The planning module **662** can perform navigation planning **664** to determine a set of trajectories on which the autonomous vehicle can be driven. The set of trajectories can be determined based on the drivable area information, the one or more object attributes of objects, the motion pattern situational tags of the objects, location of the obstacles, and the drivable area information. In some embodiments, the navigation planning **664** may include determining an area next to the road where the autonomous vehicle can be safely parked in case of emergencies. The planning module **662** may include behavioral decision making **666** to determine driving actions (e.g., steering, braking, throttle) in response to determining changing conditions on the road (e.g., traffic light turned yellow, or the autonomous vehicle is in an unsafe driving condition because another vehicle drove in front of the

autonomous vehicle and in a region within a pre-determined safe distance of the location of the autonomous vehicle). The planning module **662** may perform trajectory generation **668** and select a trajectory from the set of trajectories determined by the navigation planning operation **664**. The selected trajectory information may be sent by the planning module **662** to the control module **670**.
(247) The in-vehicle control computer may include a control module **670** that receives the proposed trajectory from the planning module **662** and the autonomous vehicle location and pose from the fused localization module **626**. The control module **670** may include a system identifier **672**. The control module **670** can perform a model-based trajectory refinement **674** to refine the proposed trajectory. For example, the control module **670** can apply filtering (e.g., Kalman filter) to make the proposed trajectory data smooth and/or to minimize noise. The control module **670** may perform the robust control **676** by determining, based on the refined proposed trajectory information and current location and/or pose of the autonomous vehicle, an amount of brake pressure to apply, a steering angle, a throttle amount to control the speed of the vehicle, and/or a transmission gear. The control module **670** can send the determined brake pressure, steering angle, throttle amount, and/or transmission gear to one or more devices in the autonomous vehicle to control and facilitate precise driving operations of the autonomous vehicle.
(248) The deep image-based object detection **624** performed by the image-based object detection module **618** can also be used detect landmarks (e.g., stop signs, speed bumps, etc.) on the road. The in-vehicle control computer may include a fused localization module **626** that obtains landmarks detected from images, the landmarks obtained from a map database **636** stored on the in-vehicle control computer, the landmarks detected from the point cloud data item by the LiDAR-based object detection module **612**, the speed and displacement from the odometer sensor **644** and the estimated location of the autonomous vehicle from the GPS/IMU sensor **638** (i.e., GPS sensor **640** and IMU sensor **642**) located on or in the autonomous vehicle. Based on this information, the fused localization module **626** can perform a localization operation **628** to determine a location of the autonomous vehicle, which can be sent to the planning module **662** and the control module **670**.
(249) The fused localization module **626** can estimate pose **630** of the autonomous vehicle based on the GPS and/or IMU sensors **638**. The pose of the autonomous vehicle can be sent to the planning module **662** and the control module **670**. The fused localization module **626** can also estimate status (e.g., location, possible angle of movement) of the trailer unit based on (e.g., trailer status estimation **634**), for example, the information provided by the IMU sensor **642** (e.g., angular rate and/or linear velocity). The fused localization module **626** may also check the map content **632**.
(250) FIG. **7** shows an exemplary block diagram of an in-vehicle control computer **550** included in an autonomous vehicle **502**. The in-vehicle control computer **550** may include at least one processor **704** and a memory **702** having instructions stored thereupon (e.g., software instructions **128**, **312**, and processing instructions **580** in FIGS. **1**, **3**, and **5**, respectively). The instructions, upon execution by the processor **704**, configure the in-vehicle control computer **550** and/or the various modules of the in-vehicle control computer **550** to perform the operations described in FIGS. **1-7**. The transmitter **706** may transmit or send information or data to one or more devices in the autonomous vehicle. For example, the transmitter **706** can send an instruction to one or more motors of the steering wheel to steer the autonomous vehicle. The receiver **708** may receive information or data transmitted or sent by one or more devices. For example, the receiver **708** may receive a status of the current speed from the odometer sensor or the current transmission gear from the transmission. The transmitter **706** and receiver **708** also may be configured to communicate with the plurality of vehicle subsystems **540** and the in-vehicle control computer **550** described above in FIGS. **5** and **6**.
(251) While several embodiments have been provided in this disclosure, it should be understood that the disclosed systems and methods might be embodied in many other specific forms without departing from the spirit or scope of this disclosure. The present examples are to be considered as illustrative and not restrictive, and the intention is not to be limited to the details given herein. For example, the various elements or components may be combined or integrated into another system or certain features may be omitted, or not implemented.
(252) In addition, techniques, systems, subsystems, and methods described and illustrated in the various embodiments as discrete or separate may be combined or integrated with other systems, modules, techniques, or methods without departing from the scope of this disclosure. Other items shown or discussed as coupled or directly coupled or communicating with each other may be indirectly coupled or communicating through some interface, device, or intermediate component whether electrically, mechanically, or otherwise. Other examples of changes, substitutions, and alterations are ascertainable by one skilled in the art and could be made without departing from the spirit and scope disclosed herein.
(253) To aid the Patent Office, and any readers of any patent issued on this application in interpreting the claims appended hereto, applicants note that they do not intend any of the appended claims to invoke 35 U.S.C. § 112(f) as it exists on the date of filing hereof unless the words "means for" or "step for" are explicitly used in the particular claim.
(254) Implementations of the disclosure can be described in view of the following clauses, the features of which can be combined in any reasonable manner.
(255) Clause 1. A system comprising: a control device associated with an autonomous vehicle and comprising: a memory configured to store sensor data associated with one or more objects on a road, wherein the sensor data is captured by at least one sensor associated with the autonomous vehicle; and at least one processor operably coupled to the memory, and configured to at least: detect a presence of a vehicle from the sensor data; determine a lateral distance between the autonomous vehicle and the vehicle; compare the lateral distance between the autonomous vehicle and the vehicle with a threshold distance from the autonomous vehicle; and determine, based at least in part upon the comparison between the lateral distance and the threshold distance, whether to instruct the autonomous vehicle to perform a lane bias maneuver, wherein the lane bias maneuver comprises driving the autonomous vehicle off center in a current lane traveled by the autonomous vehicle toward an opposite direction with respect to the vehicle until the lateral distance between the autonomous vehicle and the vehicle is at least equal to the threshold distance.
(256) Clause 2. The system of Clause 1, wherein the at least one processor is further configured to at least determine a lane bias amount, wherein the lane bias amount is a distance that the autonomous vehicle moves off center in the current lane until the

lateral distance between the autonomous vehicle and the vehicle is at least equal to the threshold distance.
(257) Clause 3. The system of Clause 1, wherein the at least one processor is further configured to at least: determine a location of a lane marker between the autonomous vehicle and the vehicle; determine that the vehicle is intruding into the current lane in response to determining that the lateral distance between the autonomous vehicle and the vehicle is less than a distance between the autonomous vehicle and the lane marker; determine how much of the current lane is intruded by the vehicle; determine an available distance in the current lane on the other side of the autonomous vehicle compared to where the vehicle is detected; compare the intruded distance in the current lane by the vehicle with the available distance in the current lane on the other side of the autonomous vehicle; determine whether there is enough available distance in the current lane on the other side of the autonomous vehicle to perform the lane bias maneuver based at least in part the comparison between the intruded distance of the current lane by the vehicle with the available distance on the other side of the autonomous vehicle; in response to determining that there is enough available distance in the current lane on the other side of the autonomous vehicle to perform the lane bias maneuver, instruct the autonomous vehicle to perform the lane bias maneuver; and in response to determining that there is not enough available distance in the current lane on the other side of the autonomous vehicle to perform the lane bias maneuver, instruct the autonomous vehicle to perform a minimal risk maneuver.
(258) Clause 4. The system of Clause 3, wherein the minimal risk maneuver comprises: slowing down the autonomous vehicle so that the autonomous vehicle does not drive adjacent to the vehicle; or speeding up the autonomous vehicle so that the autonomous vehicle does not drive adjacent to the vehicle.
(259) Clause 5. The system of Clause 3, wherein the at least one processor is further configured to at least determine that there is enough available distance on the current lane on the other side of the autonomous vehicle to perform the lane bias maneuver if the available distance on the current lane on the other side of the autonomous vehicle is more than or equal to the intruded distance on the current lane by the vehicle.
(260) Clause 6. The system of Clause 3, wherein the at least one processor is further configured to at least determine that there is not enough available distance in the current lane on the other side of the autonomous vehicle to perform the lane bias maneuver if the available distance on the current lane on the other side of the autonomous vehicle is less than the intruded distance on the current lane by the vehicle.
(261) Clause 7. The system of Clause 1, wherein the at least one processor is further configured to at least: determine that the lateral distance between the autonomous vehicle and the vehicle is less than the threshold distance; determine that there is not enough available distance in the current lane on the other side of the autonomous vehicle to perform the lane bias maneuver; in response to determining that there is not enough available distance in the current lane on the other side of the autonomous vehicle to perform the lane bias maneuver: determine whether there is another vehicle on an adjacent lane of the autonomous vehicle; in response to determining that there is no other vehicle in the adjacent lane: instruct the autonomous vehicle to perform the lane bias maneuver; instruct the autonomous vehicle to temporarily drive into the adjacent lane until a distance between the autonomous vehicle and the vehicle is equal to the threshold distance; and instruct the autonomous vehicle to drive back to the current lane when the autonomous vehicle is no longer adjacent to the vehicle.
(262) Clause 8. A method comprising: detecting a presence of a vehicle from sensor data captured by at least one sensor associated with an autonomous vehicle; determining a lateral distance between the autonomous vehicle and the vehicle; comparing the lateral distance between the autonomous vehicle and the vehicle with a threshold distance from the autonomous vehicle, wherein the autonomous vehicle is configured to travel along a road; and determining, based at least in part upon the comparison between the lateral distance and the threshold distance, whether to instruct the autonomous vehicle to perform a lane bias maneuver, wherein the lane bias maneuver comprises driving the autonomous vehicle off center in a current lane traveled by the autonomous vehicle toward an opposite direction with respect to the vehicle until the lateral distance between the autonomous vehicle and the vehicle is at least equal to the threshold distance.
(263) Clause 9. The method of Clause 8, further comprising instructing the autonomous vehicle to perform the lane bias maneuver in response to determining that the lateral distance between the autonomous vehicle and the vehicle is less than the threshold distance, wherein the vehicle is detected on an adjacent lane on either side of the autonomous vehicle.
(264) Clause 10. The method of Clause 8, further comprising: determining whether the lane bias maneuver can be performed within a threshold time period; and in response to determining that the lane bias maneuver can be performed within the threshold time period, instructing the autonomous vehicle to perform the lane bias maneuver, wherein the vehicle is detected in front and on an adjacent lane on either side of the autonomous vehicle.
(265) Clause 11. The method of Clause 10, wherein determining whether the lane bias maneuver can be performed within the threshold time period comprises: determining a longitudinal distance between the autonomous vehicle and the vehicle; determining a first speed and a first position of the vehicle; determining a first trajectory of the vehicle based at least in part upon the first speed and the first position of the vehicle; determining a second speed and a second position of the autonomous vehicle; determining a second trajectory of the autonomous vehicle based at least in part upon the second speed and the second position of the autonomous vehicle if the lane bias maneuver is performed; predicting a future lateral distance between the autonomous vehicle and the vehicle based at least in part upon the first trajectory of the vehicle, the second trajectory of the vehicle, and the longitudinal distance between the autonomous vehicle and the vehicle; comparing the predicted lateral distance between the autonomous vehicle and the vehicle with the threshold distance; and performing the lane bias maneuver in response to determining that the predicted lateral distance between the autonomous vehicle and the vehicle will be at least equal to the threshold distance within the threshold time period, wherein the threshold time period is subject to at least one of traffic on the road, a speed of the autonomous vehicle, and a size of the vehicle.
(266) Clause 12. The method of Clause 10, further comprising instructing the autonomous vehicle to perform a minimal risk maneuver in response to determining that the lane bias maneuver cannot be performed within the threshold time period, wherein the minimal risk maneuver comprises: slowing down the autonomous vehicle so that the autonomous vehicle does not drive adjacent to the vehicle; or speeding up the autonomous vehicle so that the autonomous vehicle does not drive adjacent to the

vehicle.
(267) Clause 13. The method of Clause 8, further comprising: determining a longitudinal distance between the autonomous vehicle and the vehicle, wherein the vehicle is stopped on a side of the road ahead of the autonomous vehicle; determining how much of the current lane is intruded by the vehicle; determining an available distance on the current lane on the other side of the autonomous vehicle compared to where the vehicle is detected; determining that there is enough available distance on the current lane on the other side of the current lane to perform the lane bias maneuver; and instructing the autonomous vehicle to perform the lane bias maneuver.
(268) Clause 14. The method of Clause 8, further comprising determining not to instruct the autonomous vehicle to perform the lane bias maneuver in response to determining that a driving pattern of the vehicle indicates that a driving pattern prediction of the vehicle is less than a threshold percentage and that the driving pattern of the vehicle is highly unpredictable.
(269) Clause 15. The method of Clause 14, wherein: the driving pattern of the vehicle is determined based at least in part upon a historical driving behavior associated with the vehicle; and the historical driving behavior indicates that the vehicle has been intruding into other lanes.
(270) Clause 16. A non-transitory computer-readable medium storing instructions that when executed by one or more processors cause the one or more processors to: detect a presence of a vehicle from sensor data captured by at least one sensor associated with an autonomous vehicle; determine a lateral distance between the autonomous vehicle and the vehicle, wherein the autonomous vehicle is configured to travel along a road; compare the lateral distance between the autonomous vehicle and the vehicle with a threshold distance from the autonomous vehicle; and determine, based at least in part upon the comparison between the lateral distance and the threshold distance, whether to instruct the autonomous vehicle to perform a lane bias maneuver, wherein the lane bias maneuver comprises driving the autonomous vehicle off center in a current lane traveled by the autonomous vehicle toward an opposite direction with respect to the vehicle until the lateral distance between the autonomous vehicle and the vehicle is at least equal to the threshold distance.
(271) Clause 17. The non-transitory computer-readable medium of Clause 16, wherein the instructions when executed by the one or more processors, further cause the one or more processors to maintain a consistent lane bias until the autonomous vehicle is no longer adjacent to the vehicle in response to performing the lane bias maneuver.
(272) Clause 18. The non-transitory computer-readable medium of Clause 16, wherein: the autonomous vehicle comprises a semi-truck tractor unit attached to a trailer; the road is a curved road; and the instructions when executed by the one or more processors, further cause the one or more processors to: determine a road curvature associated with the road; determine a trailer angle between the semi-truck tractor unit and the trailer when the autonomous vehicle would reach the road curvature; calculate a total lane bias adjustment amount based at least in part upon the road curvature and the trailer angle; and instruct the autonomous vehicle to perform the lane bias maneuver based at least in part upon the total lane bias adjustment amount.
(273) Clause 19. The non-transitory computer-readable medium of Clause 16, wherein the instructions when executed by the one or more processors, further cause the one or more processors to determine a classification of vehicles based at least in part upon a size of each vehicle, wherein determining whether to perform the lane bias maneuver is further based at least in part upon a particular class to which the vehicle belongs.
(274) Clause 20. The non-transitory computer-readable medium of Clause 16, wherein the threshold distance is subject to at least one of traffic on the road, a speed of the autonomous vehicle, and a size of the vehicle.
(275) Clause 21. A system comprising: a control device associated with an autonomous vehicle and comprising: a memory configured to store map data that comprises one or more roads ahead of the autonomous vehicle, wherein the autonomous vehicle comprises a semi-truck tractor unit attached to a trailer; and at least one processor, operably coupled with the memory, and configured to at least: determine that the autonomous vehicle is approaching a curved road based at least in part upon the map data; determine, based at least in part upon the map data, a road radius of the curved road; calculate, based at least in part upon the road radius, a first lane bias adjustment amount associated with a road curvature of the curved road; determine a trailer angle between the trailer and the semi-truck tractor unit; calculate, based at least in part upon the trailer angle, a second lane bias adjustment amount associated with the trailer angle; calculate a total lane bias adjustment amount by combining the first lane bias adjustment amount and the second lane bias adjustment amount; and instruct the autonomous vehicle to perform a lane bias maneuver, wherein the lane bias maneuver comprises driving the autonomous vehicle off center in a curved lane currently traveled by the autonomous vehicle based at least in part upon the total lane bias adjustment amount.
(276) Clause 22. The system of Clause 21, wherein the autonomous vehicle comprises at least one sensor configured to capture sensor data that describes an environment around the autonomous vehicle; and wherein the at least one processor is further configured to at least: receive the sensor data from the at least one sensor; and determine a set of locations of lane markers on a road travelled by the autonomous vehicle from the sensor data, wherein to determine that the autonomous vehicle is approaching the curved road, the at least one processor is further configured to at least determine that the set of locations of lane markers follows a curved line.
(277) Clause 23. The system of Clause 21, wherein to determine the road radius of the curved road, the at least one processor is further configured to at least: determine a virtual circle on the map data such that the curved road is a part of a circumference of the virtual circle; and calculate a distance between the center of the virtual circle and a point where the semi-truck tractor unit meets the trailer.
(278) Clause 24. The system of Clause 21, wherein the first lane bias adjustment amount caused by the road curvature is calculated according to a first equation:
(279) $\mathrm{Firstlanebiasadjustmentamount} = (\mathrm{roadradius}^2 - \mathrm{trailerlength}^2)^{1/2} - \mathrm{roadradius}$ wherein the trailer length is a length of the trailer.
(280) Clause 25. The system of Clause 24, wherein the at least one processor is further configured to at least adjust a sign of the first lane bias adjustment amount based at least in part upon a direction of the road curvature and a direction of the first lane bias adjustment amount such that if the direction of the road curvature is to the left and the direction of the first lane bias adjustment

amount is to the left, the first lane bias adjustment amount with the adjusted sign is calculated according to a second equation:
(281) $\text{Firstlanebiasadjustmentamountwiththeadjustedsign} = ((\text{roadradius}^2 - \text{trailerlength}^2)^{\frac{1}{2}} - \text{roadradius})) \times \text{sign}(-\text{roadcurvature})$ wherein: if the direction of the road curvature is to the left, a sign associated with the road curvature is a positive sign; if the direction of the first lane bias adjustment amount is to the left, a sign associated with the first lane bias adjustment amount is a negative sign; and the sign (road curvature) indicates a sign associated with the direction of the road curvature.
(282) Clause 26. The system of Clause 21, wherein the trailer angle is determined from sensor data received from a sensor associated with the autonomous vehicle.
(283) Clause 27. The system of Clause 21, wherein in calculating the first lane bias adjustment amount, the trailer angle is represented to be zero.
(284) Clause 28. A method comprising: determining that an autonomous vehicle is approaching a curved road based at least in part upon map data that comprises one or more roads ahead of the autonomous vehicle, wherein the autonomous vehicle comprises a semi-truck tractor unit attached to a trailer; determining, based at least in part upon the map data, a road radius of the curved road; calculating, based at least in part upon the road radius, a first lane bias adjustment amount associated with a road curvature of the curved road; determining a trailer angle between the trailer and the semi-truck tractor unit; calculating, based at least in part upon the trailer angle, a second lane bias adjustment amount associated with the trailer angle; calculating a total lane bias adjustment amount by combining the first lane bias adjustment amount and the second lane bias adjustment amount; and instructing the autonomous vehicle to perform a lane bias maneuver, wherein the lane bias maneuver comprises driving the autonomous vehicle off center in a curved lane currently traveled by the autonomous vehicle based at least in part upon the total lane bias adjustment amount.
(285) Clause 29. The method of Clause 28, further comprising: receiving sensor data from at least one sensor associated with the autonomous vehicle; detecting a presence of a vehicle on a road from the sensor data; determining a lateral distance between the autonomous vehicle and the vehicle; comparing the lateral distance between the autonomous vehicle and the vehicle with a threshold distance; determining that the lateral distance is less than the threshold distance; and instructing the autonomous vehicle to perform the lane bias maneuver in response to determining that the lateral distance is less than the threshold distance, wherein the lane bias maneuver comprises driving the autonomous vehicle off center in a current lane traveled by the autonomous vehicle toward the opposite direction with respect to the vehicle until the lateral distance between the autonomous vehicle and the vehicle is at least equal to the threshold distance.
(286) Clause 30. The method of Clause 29, further comprising: determining a lane bias amount, wherein the lane bias amount is a distance that the autonomous vehicle moves off center until the lateral distance between the autonomous vehicle and the vehicle is at least equal to the threshold distance; and combining the total lane bias adjustment amount to the lane bias amount.
(287) Clause 31. The method of Clause 30, wherein the lane bias amount is determined based at least in part upon how much of the current lane is intruded by the vehicle and an available distance on the current lane on the other side of the autonomous vehicle compared to where the vehicle is detected.
(288) Clause 32. The method of Clause 30, wherein when the vehicle is on a right side of the autonomous vehicle and the road curvature is to a left direction, the total lane bias adjustment amount is combined to the lane bias amount.
(289) Clause 33. The method of Clause 30, wherein when the vehicle is on a left side of the autonomous vehicle and the road curvature is to a left direction, the total lane bias adjustment amount is not combined with the lane bias amount.
(290) Clause 34. The method of Clause 28, wherein in calculating the second lane bias adjustment amount, a road travelled by the autonomous vehicle is represented to be a straight line.
(291) Clause 35. The method of Clause 29, wherein the at least one sensor comprises at least one of a camera, a light detection and ranging (LiDAR) sensor, and an infrared sensor.
(292) Clause 36. A non-transitory computer-readable medium storing instructions that when executed by one or more processors cause the one or more processors to: determine that an autonomous vehicle is approaching a curved road based at least in part upon map data that comprises one or more roads ahead of the autonomous vehicle, wherein the autonomous vehicle comprises a semi-truck tractor unit attached to a trailer; determine, based at least in part upon the map data, a road radius of the curved road; calculate, based at least in part upon the road radius, a first lane bias adjustment amount associated with a road curvature of the curved road; determine a trailer angle between the trailer and the semi-truck tractor unit; calculate, based at least in part upon the trailer angle, a second lane bias adjustment amount associated with the trailer angle; calculate a total lane bias adjustment amount by combining the first lane bias adjustment amount and the second lane bias adjustment amount; and instruct the autonomous vehicle to perform a lane bias maneuver, wherein the lane bias maneuver comprises driving the autonomous vehicle off center in a curved lane currently traveled by the autonomous vehicle based at least in part upon the total lane bias adjustment amount.
(293) Clause 37. The non-transitory computer-readable medium of Clause 36, wherein the second lane bias adjustment amount caused by the trailer angle is calculated according to a third equation:
Second lane bias adjustment amount=trailer length×sin(trailer angle) wherein the trailer length is a length of the trailer.
(294) Clause 38. The non-transitory computer-readable medium of Clause 36, wherein the instructions, when executed by the one or more processors, further cause the one or more processors to adjust a sign of the second lane bias adjustment amount based at least in part upon a direction of the trailer angle and a direction of the second lane bias adjustment amount such that if the direction of the trailer angle is to the left and the direction of the second lane bias adjustment amount is to the right, the second lane bias adjustment amount with the adjusted sign is calculated according to a fourth equation:
Second lane bias adjustment amount with the adjusted sign=−trailer length×sin(trailer angle) wherein the trailer length is a length of the trailer.
(295) Clause 39. The non-transitory computer-readable medium of Clause 36, wherein the instructions when executed by the one or more processors, further cause the one or more processors to: determine that the autonomous vehicle is traveling along a straight road based at least in part upon the map data; determine that the first lane bias adjustment amount is zero since the road radius is substantially large; detect that wind is causing the trailer of the autonomous vehicle to divert from a straight line;

determine the trailer angle caused by the wind; calculate the second lane bias adjustment amount caused by the trailer angle; and determine that the total lane bias adjustment amount is equal to the second lane bias adjustment amount.
(296) Clause 40. The non-transitory computer-readable medium of Clause 36, wherein: when the trailer swings in a left direction, a sign associated with the trailer angle is negative; and when the trailer swings in a right direction, the sign associated with the trailer angle is positive.
(297) Clause 41. The system of any of Clauses 1-7, wherein the at least one processor is further configured to perform one or more operations of a method according to any of Clauses 8-15.
(298) Clause 42. The system of any of Clauses 1-7, wherein the processor is further configured to perform one or more operations according to any of Clauses 16-20.
(299) Clause 43. An apparatus comprising means for performing a method according to any of Clauses 8-15.
(300) Clause 44. An apparatus comprising means for performing one or more instructions according to any of Clauses 16-20.
(301) Clause 45. The non-transitory computer-readable medium of any of Clauses 16-20 storing instructions that when executed by the one or more processors further cause the one or more processors to perform one or more operations of a method according to any of Clauses 8-15 when run on a system.
(302) Clause 46. The system of any of Clauses 21-27, wherein the at least one processor is further configured to perform one or more operations of a method according to any of Clauses 28-35.
(303) Clause 47. The system of any of Clauses 21-27, wherein the processor is further configured to perform one or more operations according to any of Clauses 36-40.
(304) Clause 48. An apparatus comprising means for performing a method according to any of Clauses 28-25.
(305) Clause 49. An apparatus comprising means for performing one or more instructions according to any of Clauses 36-40.
(306) Clause 50. The non-transitory computer-readable medium of any of Clauses 36-40 storing instructions that when executed by the one or more processors further cause the one or more processors to perform one or more operations of a method according to any of Clauses 28-35 when run on a system.
(307) Clause 51. A system according to any of Clauses 1-7 and/or 21-27.
(308) Clause 52. A method comprising operations according to any of Clauses 8-15 and/or 28-35.
(309) Clause 53. An apparatus comprising means for performing a method according to any of Clauses 8-15 and/or 28-35.
(310) Clause 54. An apparatus comprising means for performing one or more instructions according to any of Clauses 16-20 and/or 36-40.
(311) Clause 55. The non-transitory computer-readable medium of any of Clauses 16-20 and/or 36-40 storing instructions that when executed by one or more processors further cause the one or more processors to perform one or more operations of a method according to any of Clauses 8-15 and/or 28-35 when run on a system.

Claims

1. A system comprising: a control device associated with an autonomous vehicle and comprising: a memory configured to store map data that comprises one or more roads ahead of the autonomous vehicle, wherein the autonomous vehicle comprises a semi-truck tractor unit attached to a trailer; and at least one processor, operably coupled with the memory, and configured to at least: determine that the autonomous vehicle is approaching a curved road based at least in part upon the map data; determine, based at least in part upon the map data, a road radius of the curved road; calculate, based at least in part upon the road radius, a first lane bias adjustment amount associated with a road curvature of the curved road; determine a trailer angle between the trailer and the semi-truck tractor unit; calculate, based at least in part upon the trailer angle, a second lane bias adjustment amount associated with the trailer angle; calculate a total lane bias adjustment amount by combining the first lane bias adjustment amount and the second lane bias adjustment amount; and instruct the autonomous vehicle to perform a lane bias maneuver, wherein the lane bias maneuver comprises driving the autonomous vehicle off center in a curved lane currently traveled by the autonomous vehicle based at least in part upon the total lane bias adjustment amount; wherein the at least one processor is further configured to: receive sensor data from at least one sensor associated with the autonomous vehicle; detect a presence of a vehicle on a road from the sensor data; determine a lateral distance between the autonomous vehicle and the vehicle; compare the lateral distance between the autonomous vehicle and the vehicle with a threshold distance; determine that the lateral distance is less than the threshold distance; and instruct the autonomous vehicle to perform the lane bias maneuver in response to determining that the lateral distance is less than the threshold distance, wherein the lane bias maneuver comprises driving the autonomous vehicle off center in a current lane traveled by the autonomous vehicle toward an opposite direction with respect to the vehicle until the lateral distance between the autonomous vehicle and the vehicle is at least equal to the threshold distance.
2. The system of claim 1, wherein the autonomous vehicle comprises at least one sensor configured to capture sensor data that describes an environment around the autonomous vehicle; and wherein the at least one processor is further configured to at least: receive the sensor data from the at least one sensor; and determine a set of locations of lane markers on a road travelled by the autonomous vehicle from the sensor data, wherein to determine that the autonomous vehicle is approaching the curved road, the at least one processor is further configured to at least determine that the set of locations of lane markers follows a curved line.
3. The system of claim 1, wherein to determine the road radius of the curved road, the at least one processor is further configured to at least: determine a virtual circle on the map data such that the curved road is a part of a circumference of the virtual circle; and calculate a distance between the center of the virtual circle and a point where the semi-truck tractor unit meets the trailer.
4. The system of claim 1, wherein the first lane bias adjustment amount caused by the road curvature is calculated according to a first equation:
First lane bias adjustment amount=(road radius.sup.2−trailer length.sup.2).sup.1/2−road radius wherein the trailer length is a length of the trailer.
5. The system of claim 4, wherein the at least one processor is further configured to at least adjust a sign of the first lane bias

adjustment amount based at least in part upon a direction of the road curvature and a direction of the first lane bias adjustment amount such that if the direction of the road curvature is to a left and the direction of the first lane bias adjustment amount is to the left, the first lane bias adjustment amount with the adjusted sign is calculated according to a second equation:

$$\text{Firstlanebiasadjustmentamountwiththeadjustedsign} = ((\text{roadradius}^2 - \text{trailerlength}^2)^{\frac{1}{2}} - \text{roadradius})) \times \text{sign}(-\text{roadcurvature})$$

wherein: if the direction of the road curvature is to the left, a sign associated with the road curvature is a positive sign; if the direction of the first lane bias adjustment amount is to the left, a sign associated with the first lane bias adjustment amount is a negative sign; and the sign (road curvature) indicates a sign associated with the direction of the road curvature.

6. The system of claim 1, wherein the trailer angle is determined from sensor data received from a sensor associated with the autonomous vehicle.

7. The system of claim 1, wherein in calculating the first lane bias adjustment amount, the trailer angle is represented to be zero.

8. A method comprising: determining that an autonomous vehicle is approaching a curved road based at least in part upon map data that comprises one or more roads ahead of the autonomous vehicle, wherein the autonomous vehicle comprises a semi-truck tractor unit attached to a trailer; determining, based at least in part upon the map data, a road radius of the curved road; calculating, based at least in part upon the road radius, a first lane bias adjustment amount associated with a road curvature of the curved road; determining a trailer angle between the trailer and the semi-truck tractor unit; calculating, based at least in part upon the trailer angle, a second lane bias adjustment amount associated with the trailer angle; calculating a total lane bias adjustment amount by combining the first lane bias adjustment amount and the second lane bias adjustment amount; and instructing the autonomous vehicle to perform a lane bias maneuver, wherein the lane bias maneuver comprises driving the autonomous vehicle off center in a curved lane currently traveled by the autonomous vehicle based at least in part upon the total lane bias adjustment amount; wherein the method further comprises: receiving sensor data from at least one sensor associated with the autonomous vehicle; detecting a presence of a vehicle on a road from the sensor data; determining a lateral distance between the autonomous vehicle and the vehicle; comparing the lateral distance between the autonomous vehicle and the vehicle with a threshold distance; determining that the lateral distance is less than the threshold distance; and instructing the autonomous vehicle to perform the lane bias maneuver in response to determining that the lateral distance is less than the threshold distance, wherein the lane bias maneuver comprises driving the autonomous vehicle off center in a current lane traveled by the autonomous vehicle toward an opposite direction with respect to the vehicle until the lateral distance between the autonomous vehicle and the vehicle is at least equal to the threshold distance.

9. The method of claim 8, further comprising: determining a lane bias amount, wherein the lane bias amount is a distance that the autonomous vehicle moves off center until the lateral distance between the autonomous vehicle and the vehicle is at least equal to the threshold distance; and combining the total lane bias adjustment amount to the lane bias amount.

10. The method of claim 9, wherein the lane bias amount is determined based at least in part upon how much of the current lane is intruded by the vehicle and an available distance on the current lane on other side of the autonomous vehicle compared to where the vehicle is detected.

11. The method of claim 9, wherein when the vehicle is on a right side of the autonomous vehicle and the road curvature is to a left direction, the total lane bias adjustment amount is combined to the lane bias amount.

12. The method of claim 9, wherein when the vehicle is on a left side of the autonomous vehicle and the road curvature is to a left direction, the total lane bias adjustment amount is not combined with the lane bias amount.

13. The method of claim 8, wherein in calculating the second lane bias adjustment amount, a road travelled by the autonomous vehicle is represented to be a straight line.

14. The method of claim 8, wherein the at least one sensor comprises at least one of a camera, a light detection and ranging (LiDAR) sensor, and an infrared sensor.

15. A non-transitory computer-readable medium storing instructions that when executed by one or more processors cause the one or more processors to: determine that an autonomous vehicle is approaching a curved road based at least in part upon map data that comprises one or more roads ahead of the autonomous vehicle, wherein the autonomous vehicle comprises a semi-truck tractor unit attached to a trailer; determine, based at least in part upon the map data, a road radius of the curved road; calculate, based at least in part upon the road radius, a first lane bias adjustment amount associated with a road curvature of the curved road; determine a trailer angle between the trailer and the semi-truck tractor unit; calculate, based at least in part upon the trailer angle, a second lane bias adjustment amount associated with the trailer angle; calculate a total lane bias adjustment amount by combining the first lane bias adjustment amount and the second lane bias adjustment amount; and instruct the autonomous vehicle to perform a lane bias maneuver, wherein the lane bias maneuver comprises driving the autonomous vehicle off center in a curved lane currently traveled by the autonomous vehicle based at least in part upon the total lane bias adjustment amount; wherein the instructions, when executed by the one or more processors, further cause the one or more processors to: receive sensor data from at least one sensor associated with the autonomous vehicle; detect a presence of a vehicle on a road from the sensor data; determine a lateral distance between the autonomous vehicle and the vehicle; compare the lateral distance between the autonomous vehicle and the vehicle with a threshold distance; determine that the lateral distance is less than the threshold distance; and instruct the autonomous vehicle to perform the lane bias maneuver in response to determining that the lateral distance is less than the threshold distance, wherein the lane bias maneuver comprises driving the autonomous vehicle off center in a current lane traveled by the autonomous vehicle toward an opposite direction with respect to the vehicle until the lateral distance between the autonomous vehicle and the vehicle is at least equal to the threshold distance.

16. The non-transitory computer-readable medium of claim 15, wherein the second lane bias adjustment amount caused by the trailer angle is calculated according to a third equation:

Second lane bias adjustment amount=trailer length×sin(trailer angle) wherein the trailer length is a length of the trailer.

17. The non-transitory computer-readable medium of claim 15, wherein the instructions, when executed by the one or more processors, further cause the one or more processors to adjust a sign of the second lane bias adjustment amount based at least in part upon a direction of the trailer angle and a direction of the second lane bias adjustment amount such that if the direction of the

trailer angle is to left and the direction of the second lane bias adjustment amount is to right, the second lane bias adjustment amount with the adjusted sign is calculated according to a fourth equation:
Second lane bias adjustment amount with the adjusted sign=−trailer length×sin(trailer angle) wherein the trailer length is a length of the trailer.
18. The non-transitory computer-readable medium of claim 15, wherein the instructions when executed by the one or more processors, further cause the one or more processors to: determine that the autonomous vehicle is traveling along a straight road based at least in part upon the map data; determine that the first lane bias adjustment amount is zero since the road radius is substantially large; detect that wind is causing the trailer of the autonomous vehicle to divert from a straight line; determine the trailer angle caused by the wind; calculate the second lane bias adjustment amount caused by the trailer angle; and determine that the total lane bias adjustment amount is equal to the second lane bias adjustment amount.
19. The non-transitory computer-readable medium of claim 15, wherein: when the trailer swings in a left direction, a sign associated with the trailer angle is negative; and when the trailer swings in a right direction, the sign associated with the trailer angle is positive.