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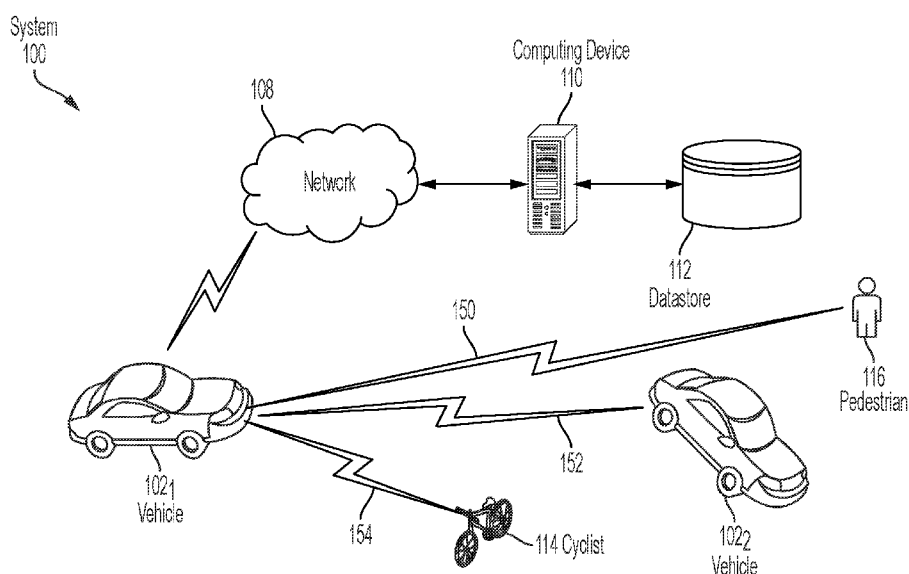


FIG. 1

(57) Abstract: Systems and methods for operating an autonomous vehicle. The methods comprising: obtaining one or more candidate vehicle trajectories for the autonomous vehicle and context information defining a state of an environment surrounding the autonomous vehicle; assigning class(es) to a scenario specified by the context information and a first candidate vehicle trajectory; generating a first quality score for the first candidate vehicle trajectory using scoring function(s) selected based on the assigned class(es); select a candidate vehicle trajectory based on the first quality score associated with the first candidate vehicle trajectory and second quality score(s) associated with at least one second candidate vehicle trajectory; and causing the autonomous vehicle to perform autonomous driving operations using the selected candidate vehicle trajectory.



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SYSTEMS AND METHODS FOR SCENARIO DEPENDENT TRAJECTORY SCORING

BACKGROUND

Cross-Reference and Claim of Priority

[0001] This patent application claims priority to U.S. Patent Application No. 17/152,894 filed January 20, 2021, which is incorporated herein by reference in its entirety.

Statement of the Technical Field

[0002] The present disclosure relates generally to autonomous vehicles. More particularly, the present disclosure relates to implementing systems and methods for scenario dependent trajectory scoring.

Description of the Related Art

[0003] Modern day vehicles have at least one on-board computer and have internet/satellite connectivity. The software running on these on-board computers monitor and/or control operations of the vehicles. The software is configured to perform motion planning for a vehicle. The motion planning generally involves generating a trajectory for the vehicle based on processed and non-processed sensor data, and executing the generated trajectory.

SUMMARY

[0004] The present disclosure concerns implementing systems and methods for operating an autonomous vehicle. The methods comprise performing the following operations by a computing device (e.g., a vehicle on-board computing device): obtaining one or more candidate vehicle trajectories for the autonomous vehicle and context information defining a state of an environment surrounding the autonomous vehicle (e.g., intersection information, object related information, (e.g., observed sensor data for an object, prior knowledge of an object class, inferred properties of the object, predicted object trajectories), a road map, traffic information, and/or environmental information); assigning at least one class of a plurality of classes (e.g., a left turn scenario class, a right turn scenario, a passing scenario class, a driving scenario class, an

acceleration scenario class, a deceleration scenario class, a stationary scenario class, a forward driving scenario class, a reverse driving scenario class, and/or a passenger pick-up scenario class) to a scenario specified by the context information and a first candidate vehicle trajectory of the candidate vehicle trajectories; selecting at least one scoring function from a plurality of different scoring functions based on the at least one class assigned to the scenario (the plurality of different scoring functions being respectively associated with the plurality of classes); generating at least one first quality score for the first candidate vehicle trajectory using the scoring function(s); selecting a candidate vehicle trajectory from the candidate vehicle trajectory based on the first quality score associated with the first candidate vehicle trajectory and a second quality score associated with at least one second candidate vehicle trajectory; and/or causing the autonomous vehicle to perform autonomous driving operations using the selected candidate vehicle trajectory (e.g., cause the autonomous vehicle to follow the selected candidate vehicle trajectory).

[0005] The computing device may also (i) generate a feature vector using the context information and a first candidate vehicle trajectory and (ii) use the feature vector to generate the quality score for the first candidate vehicle trajectory. The first quality score for the first candidate vehicle trajectory may be produced by combining two or more scores. For example, first and second classes are assigned to the scenario specified by the context information and a first candidate vehicle trajectory. A first scoring function is selected based on the first class. A second scoring function is selected based on the second class. The second scoring function is different than the first scoring function. A first score is generated using the first scoring function and a second score is generated using the second scoring function. The first score and the second score are combined together to produce the first quality score for the first candidate vehicle trajectory. The present solution is not limited to the particulars of this example.

[0006] In those or other scenarios, the computing device selects a set of scoring functions from a plurality of different sets or weights, based on the class assigned to the scenario. The selected set of scoring functions and/or weights is(are) used to generate the at least one first quality score for the first candidate vehicle trajectory. Additionally or alternatively, the

candidate vehicle trajectory is selected from the candidate vehicle trajectories by comparing the first and second quality scores to each other or to a threshold value.

[0007] The implementing systems comprise: a processor; and a non-transitory computer-readable storage medium comprising programming instructions that are configured to cause the processor to implement the above described methods.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] The present solution will be described with reference to the following drawing figures, in which like numerals represent like items throughout the figures.

[0009] FIG. 1 is an illustration of an illustrative system.

[0010] FIG. 2 is an illustration of an illustrative architecture for a vehicle.

[0011] FIG. 3 is an illustration of an illustrative computing device.

[0012] FIG. 4 provides a block diagram of an illustrative vehicle trajectory planning process.

[0013] FIGS. 5A-5B (collectively referred to herein as “FIG. 5”) provides a flow diagram of an illustrative method for operating a vehicle.

[0014] FIG. 6 provides a flow diagram of an illustrative method generating a high quality vehicle trajectory in accordance with the present solution.

[0015] FIG. 7 provides an illustration of an illustrative system architecture implementing the present solution.

DETAILED DESCRIPTION

[0016] As used in this document, the singular forms “a,” “an,” and “the” include plural references unless the context clearly dictates otherwise. Unless defined otherwise, all technical and scientific terms used herein have the same meanings as commonly understood by one of ordinary skill in the art. As used in this document, the term “comprising” means “including, but

not limited to.” Definitions for additional terms that are relevant to this document are included at the end of this Detailed Description.

[0017] An “electronic device” or a “computing device” refers to a device that includes a processor and memory. Each device may have its own processor and/or memory, or the processor and/or memory may be shared with other devices as in a virtual machine or container arrangement. The memory will contain or receive programming instructions that, when executed by the processor, cause the electronic device to perform one or more operations according to the programming instructions.

[0018] The terms “memory,” “memory device,” “data store,” “data storage facility” and the like each refer to a non-transitory device on which computer-readable data, programming instructions or both are stored. Except where specifically stated otherwise, the terms “memory,” “memory device,” “data store,” “data storage facility” and the like are intended to include single device embodiments, embodiments in which multiple memory devices together or collectively store a set of data or instructions, as well as individual sectors within such devices.

[0019] The terms “processor” and “processing device” refer to a hardware component of an electronic device that is configured to execute programming instructions. Except where specifically stated otherwise, the singular term “processor” or “processing device” is intended to include both single-processing device embodiments and embodiments in which multiple processing devices together or collectively perform a process.

[0020] The term “vehicle” refers to any moving form of conveyance that is capable of carrying either one or more human occupants and/or cargo and is powered by any form of energy. The term “vehicle” includes, but is not limited to, cars, trucks, vans, trains, autonomous vehicles, aircraft, aerial drones and the like. An “autonomous vehicle” is a vehicle having a processor, programming instructions and drivetrain components that are controllable by the processor without requiring a human operator. An autonomous vehicle may be fully autonomous in that it does not require a human operator for most or all driving conditions and functions, or it may be semi-autonomous in that a human operator may be required in certain conditions or for

certain operations, or that a human operator may override the vehicle's autonomous system and may take control of the vehicle.

[0021] In this document, when terms such as “first” and “second” are used to modify a noun, such use is simply intended to distinguish one item from another, and is not intended to require a sequential order unless specifically stated. In addition, terms of relative position such as “vertical” and “horizontal”, or “front” and “rear”, when used, are intended to be relative to each other and need not be absolute, and only refer to one possible position of the device associated with those terms depending on the device's orientation.

[0022] An Autonomous Vehicle (AV) has at least one on-board computer and wireless communication connectivity. The software running on these on-board computers monitor and/or control operations of the vehicle. The software is configured to perform motion planning for the vehicle. The main task of motion planning is to generate a high quality trajectory for the AV to follow. For this goal, the on-board computer of the AV comprises a trajectory scoring module to evaluate the quality of multiple candidate trajectories based on a novel scoring scheme. The novel scoring scheme generally involves: determining a quality score for each candidate trajectory; and selecting the candidate trajectory with the best or most desirable quality score (e.g., the highest score, the lowest score, the score which exceeds a threshold value, or the score within or outside of boundary values).

[0023] The trajectory scoring module comprises a trajectory feature generator, a scenario classifier, scoring functions, and an aggregator. The trajectory feature generator is configured to analyze a candidate trajectory and context information to derive a feature vector. The context information includes, but is not limited to, intersection information, object related information (e.g., observed sensor data for an object, prior knowledge of an object class, inferred properties of the object, predicted object trajectories), a road map, traffic information and/or environmental information. The feature vector is then used to assign a score to the candidate trajectory. The feature vector helps to ensure that the solution works in different scenarios (e.g., when the AV is at an intersection, making a turn, driving straight, or driving close to a bicyclist). The scenario classifier is generally configured to classify given context information into at least one of a

plurality of scenarios (e.g., track behind a lead vehicle, pass the object from the left, pass the object from the right, etc.). The context information generally defines a state of (e.g., circumstances and/or conditions) of an environment surrounding the autonomous vehicle. The scenario classification can be discrete or continuous. In the discrete case, the context information is classified as one of the plurality of scenarios. In the continuous case, a probability value is provided for each of a plurality of scenarios. Each scoring function is generally configured to generate a score for a candidate vehicle trajectory. The scoring function(s) can be the same as or different for each scenario classification. The aggregator is generally configured to aggregate the outputs from the scoring functions to produce the quality score for the given candidate trajectory.

[0024] The present solution is being described herein in the context of an autonomous vehicle. The present solution is not limited to autonomous vehicle applications. The present solution can be used in other applications such as robotic application, radar system application, metric applications, and/or system performance applications

[0025] Illustrative Systems

[0026] Referring now to FIG. 1, there is provided an illustration of an illustrative system **100**. System **100** comprises a vehicle **102₁** that is traveling along a road in a semi-autonomous or autonomous manner. Vehicle **102₁** is also referred to herein as an AV. The AV **102₁** can include, but is not limited to, a land vehicle (as shown in FIG. 1), an aircraft, a spacecraft or a watercraft.

[0027] AV **102₁** is generally configured to detect objects **102₂**, **114**, **116** in proximity thereto. The objects can include, but are not limited to, a vehicle **102₂**, a cyclist **114** (such as a rider of a bicycle, electric scooter, motorcycle, or the like) and/or a pedestrian **116**. This object detection can be made, for example, by analyzing sensor data generated by at least one sensor device on the AV **102₁** and/or information received from a communication device (e.g., a transceiver, a beacon and/or a smart phone) of the object via communication link(s) **150**, **152**, **154**. The communication link(s) **150**, **152**, **154** can include, but are not limited to, V2X communication links. The term “V2X” refers to a communication between a vehicle and any entity that may

affect, or may be affected by, the vehicle. The information can include, but is not limited to: information specifying actions or operations have been performed, being performed and/or are to be performed by the object; and/or information specifying future intentions of the object (e.g., a driving intention, a parking intention, a passenger pick-up intention, a delivery intention, etc.).

[0028] When such a detection is made, AV **102₁** performs operations to: generate one or more possible object trajectories for the detected object; determine one or more object classifications, goals and/or future intentions for the detection object; and use the at least one of the generated possible object trajectories, object classifications, goals and future intentions to facilitate a determination of a vehicle trajectory. The AV **102₁** may then perform operations to follow the vehicle trajectory.

[0029] In some scenarios, the AV **102₁** performs additional operations to determine whether or not there is an undesirable level of risk that a collision will occur between the AV and object in a threshold period of time (e.g., 1 minute). If so, the AV **102₁** performs operations to determine whether the collision can be avoided if the vehicle trajectory is followed by the AV **102₁** and any one of a plurality of dynamically generated emergency maneuvers is performed in pre-defined time period (e.g., *N* milliseconds). If the collision can be avoided, then the AV **102₁** takes no action or optionally performs a cautious maneuver (e.g., mildly slows down). In contrast, if the collision cannot be avoided, then the AV **102₁** immediately takes an emergency maneuver (e.g., brakes and/or changes direction of travel).

[0030] Referring now to FIG. 2, there is provided an illustration of an illustrative system architecture **200** for a vehicle. Vehicles **102₁** and/or **102₂** of FIG. 1 can have the same or similar system architecture as that shown in FIG. 2. Thus, the following discussion of system architecture **200** is sufficient for understanding vehicle(s) **102₁**, **102₂** of FIG. 1.

[0031] As shown in FIG. 2, the vehicle **200** includes an engine or motor **202** and various sensors **204-218** for measuring various parameters of the vehicle. In gas-powered or hybrid vehicles having a fuel-powered engine, the sensors may include, for example, an engine temperature sensor **204**, a battery voltage sensor **206**, an engine Rotations Per Minute (RPM) sensor **208**, and a throttle position sensor **210**. If the vehicle is an electric or hybrid vehicle, then

the vehicle may have an electric motor, and accordingly will have sensors such as a battery monitoring system **212** (to measure current, voltage and/or temperature of the battery), motor current **214** and voltage **216** sensors, and motor position sensors such as resolvers and encoders **218**.

[0032] Operational parameter sensors that are common to both types of vehicles include, for example: a position sensor **236** such as an accelerometer, gyroscope and/or inertial measurement unit; a speed sensor **238**; and an odometer sensor **240**. The vehicle also may have a clock **242** that the system uses to determine vehicle time during operation. The clock **242** may be encoded into the vehicle on-board computing device, it may be a separate device, or multiple clocks may be available.

[0033] The vehicle also will include various sensors that operate to gather information about the environment in which the vehicle is traveling. These sensors may include, for example: a location sensor **260** (e.g., a Global Positioning System (GPS) device); object detection sensors such as one or more cameras **262**; a LiDAR sensor system **264**; and/or a radar and/or a sonar system **266**. The sensors also may include environmental sensors **268** such as a precipitation sensor and/or ambient temperature sensor. The object detection sensors may enable the vehicle to detect objects that are within a given distance range of the vehicle **200** in any direction, while the environmental sensors collect data about environmental conditions within the vehicle's area of travel.

[0034] During operations, information is communicated from the sensors to an on-board computing device **220**. The on-board computing device **220** analyzes the data captured by the sensors and optionally controls operations of the vehicle based on results of the analysis. For example, the on-board computing device **220** may control: braking via a brake controller **232**; direction via a steering controller **224**; speed and acceleration via a throttle controller **226** (in a gas-powered vehicle) or a motor speed controller **228** (such as a current level controller in an electric vehicle); a differential gear controller **230** (in vehicles with transmissions); and/or other controllers.

[0035] Geographic location information may be communicated from the location sensor **260** to the on-board computing device **220**, which may then access a map of the environment that corresponds to the location information to determine known fixed features of the environment such as streets, buildings, stop signs and/or stop/go signals. Captured images from the cameras **262** and/or object detection information captured from sensors such as LiDAR **264** is communicated from those sensors to the on-board computing device **220**. The object detection information and/or captured images are processed by the on-board computing device **220** to detect objects in proximity to the vehicle **200**. Any known or to be known technique for making an object detection based on sensor data and/or captured images can be used in the embodiments disclosed in this document.

[0036] LiDAR information is communicated from LiDAR sensor **264** to the on-board computing device **220**. Additionally, captured images are communicated from the camera(s) **262** to the on-board computing device **220**. The LiDAR information and/or captured images are processed by the on-board computing device **220** to detect objects in proximity to the vehicle **200**.

[0037] When the on-board computing device **220** detects a moving object, the on-board computing device **220** will generate one or more possible object trajectories for the detected object, and use the possible object trajectories to determine a vehicle trajectory for the AV. The on-board computing device **220** then performs operations to cause the AV to follow the defined vehicle trajectory. For example, the on-board computing device **220** uses the object trajectory information to decide what space has been occupied by the object, and then generates a vehicle trajectory in which the AV is not planned to travel to that space.

[0038] In some scenarios, the on-board computing device **220** analyzes the possible object trajectories and the vehicle trajectory to assess the risk of a collision between the object and the AV. If the risk exceeds an acceptable threshold, the on-board computing device **220** performs operations to determine whether the collision can be avoided if the AV follows a vehicle trajectory and/or implements one or more dynamically generated emergency maneuvers is performed in a pre-defined time period (e.g., *N* milliseconds). If the collision can be avoided,

then the on-board computing device **220** may cause the vehicle **200** to perform a cautious maneuver (e.g., mildly slow down, accelerate, or swerve). In contrast, if the collision cannot be avoided, then the on-board computing device **220** will cause the vehicle **200** to take an emergency maneuver (e.g., brake and/or change direction of travel).

[0039] Referring now to FIG. 3, there is provided an illustration of an illustrative architecture for a computing device **300**. The computing device **110** of FIG. 1 and/or the vehicle on-board computing device **220** of FIG. 2 is/are the same as or similar to computing device **300**. As such, the discussion of computing device **300** is sufficient for understanding the computing device **110** of FIG. 1 and the vehicle on-board computing device **220** of FIG. 2.

[0040] Computing device **300** may include more or less components than those shown in FIG. 3. However, the components shown are sufficient to disclose an illustrative solution implementing the present solution. The hardware architecture of FIG. 3 represents one implementation of a representative computing device configured to operate a vehicle, as described herein. As such, the computing device **300** of FIG. 3 implements at least a portion of the method(s) described herein.

[0041] Some or all components of the computing device **300** can be implemented as hardware, software and/or a combination of hardware and software. The hardware includes, but is not limited to, one or more electronic circuits. The electronic circuits can include, but are not limited to, passive components (e.g., resistors and capacitors) and/or active components (e.g., amplifiers and/or microprocessors). The passive and/or active components can be adapted to, arranged to and/or programmed to perform one or more of the methodologies, procedures, or functions described herein.

[0042] As shown in FIG. 3, the computing device **300** comprises a user interface **302**, a Central Processing Unit (CPU) **306**, a system bus **310**, a memory **312** connected to and accessible by other portions of computing device **300** through system bus **310**, a system interface **360**, and hardware entities **314** connected to system bus **310**. The user interface can include input devices and output devices, which facilitate user-software interactions for controlling operations of the computing device **300**. The input devices include, but are not limited to, a

physical and/or touch keyboard **350**. The input devices can be connected to the computing device **300** via a wired or wireless connection (e.g., a Bluetooth® connection). The output devices include, but are not limited to, a speaker **352**, a display **354**, and/or light emitting diodes **356**. System interface **360** is configured to facilitate wired or wireless communications to and from external devices (e.g., network nodes such as access points, etc.).

[0043] At least some of the hardware entities **314** perform actions involving access to and use of memory **312**, which can be a Random Access Memory (RAM), a disk drive, flash memory, a Compact Disc Read Only Memory (CD-ROM) and/or another hardware device that is capable of storing instructions and data. Hardware entities **314** can include a disk drive unit **316** comprising a computer-readable storage medium **318** on which is stored one or more sets of instructions **320** (e.g., software code) configured to implement one or more of the methodologies, procedures, or functions described herein. The instructions **320** can also reside, completely or at least partially, within the memory **312** and/or within the CPU **306** during execution thereof by the computing device **300**. The memory **312** and the CPU **306** also can constitute machine-readable media. The term "machine-readable media", as used here, refers to a single medium or multiple media (e.g., a centralized or distributed database, and/or associated caches and servers) that store the one or more sets of instructions **320**. The term "machine-readable media", as used here, also refers to any medium that is capable of storing, encoding or carrying a set of instructions **320** for execution by the computing device **300** and that cause the computing device **300** to perform any one or more of the methodologies of the present disclosure.

[0044] Referring now to FIG. 4, there is provided a block diagram that is useful for understanding how movement of an AV is achieved in accordance with the present solution. All of the operations performed in blocks **402-410** can be performed by the on-board computing device of a vehicle (e.g., AV **102₁** of FIG. 1).

[0045] In block **402**, a location of the AV (e.g., AV **102₁** of FIG. 1) is detected. This detection can be made based on sensor data output from a location sensor (e.g., location sensor

260 of FIG. 2) of the AV. This sensor data can include, but is not limited to, GPS data. The detected location of the AV is then passed to block **406**.

[0046] In block **404**, an object (e.g., vehicle **102₂** of FIG. 1) is detected within proximity of the AV (e.g., < 100+ meters). This detection is made based on sensor data output from a camera (e.g., camera **262** of FIG. 2) of the AV, a LiDAR system (e.g., LiDAR system **264** of FIG. 2) of the AV, and/or a radar/sonar system (e.g., radar/sonar system **266** of FIG. 2) of the AV. For example, image processing is performed to detect an instance of an object of a certain class (e.g., a vehicle or pedestrian) in an image. LiDAR point clouds can additionally or alternatively be analyzed to detect the object of the certain class. Track information generated by the radar/sonar system can additionally or alternatively be used to detect the object. The sensor data (e.g., images, LiDAR point clouds and radar/sonar data) processing/object detection can be achieved in accordance with any known or to be known image processing/object detection algorithm.

[0047] Additionally, a predicted trajectory is determined in block **404** for the object. The object's trajectory is predicted in block **404** based on, for example, the object's class, a cuboid geometry, radar track information and/or contents of a map **414** (e.g., sidewalk locations, lane locations, lane directions of travel, driving rules, etc.). The cuboid geometry may be determined using a LiDAR dataset and the map **414**. Techniques for predicting object trajectories based on cuboid geometries and/or the other listed information are well known in the art. For example, one technique involves predicting that the object is moving on a linear path in the same direction as the heading direction of the cuboid. The predicted object trajectories can include, but are not limited to, the following trajectories: a trajectory defined by the object's actual speed (e.g., 1 mile per hour) and actual direction of travel (e.g., west); a trajectory defined by the object's actual speed (e.g., 1 mile per hour) and another possible direction of travel (e.g., south, south-west, or X (e.g., 40°) degrees from the object's actual direction of travel in a direction towards the AV) for the object; a trajectory defined by another possible speed for the object (e.g., 2-10 miles per hour) and the object's actual direction of travel (e.g., west); and/or a trajectory defined by another possible speed for the object (e.g., 2-10 miles per hour) and another possible direction of travel (e.g., south, south-west, or X (e.g., 40°) degrees from the object's actual direction of

travel in a direction towards the AV) for the object. The possible speed(s) and/or possible direction(s) of travel may be pre-defined for objects in the same class and/or sub-class as the object. The cuboid defines a full extent of the object and a heading of the object. The heading defines a direction in which the object's front is pointed, and therefore provides an indication as to the actual and/or possible direction of travel for the object.

[0048] Information **412** specifying the object's predicted trajectory and/or the cuboid geometry is provided to block **406**. In some scenarios, a classification of the object is also passed to block **406**. In block **406**, a high quality vehicle trajectory **420** is generated using the information from blocks **402** and **404**. The high quality vehicle trajectory is selected from a plurality of candidate vehicle trajectories. Techniques for determining candidate vehicle trajectories are well known in the art. For example, in some scenarios, such a technique involves determining a candidate trajectory for the AV that would pass the object when the object is in front of the AV, the cuboid has a heading direction that is aligned with the direction in which the AV is moving, and the cuboid has a length that is greater than a threshold value. The present solution is not limited to the particulars of this scenario. Each candidate vehicle trajectory can be determined based on the location information from block **402**, the object detection information from block **404**, and/or map information **428** (which is pre-stored in a data store of the vehicle). A quality score is determined for each candidate vehicle trajectory. The candidate vehicle trajectory with the best or most desirable quality score (e.g., the highest score, the lowest score, or the score which exceeds a threshold value) is then selected as the high quality vehicle trajectory **420**. The manner in which the candidate vehicle trajectories are scored and/or selected will be described in more detail below.

[0049] The high quality vehicle trajectory **420** may represent a smooth path that does not have abrupt changes that would otherwise provide passenger discomfort. For example, the vehicle trajectory is defined by a path of travel along a given lane of a road in which the object is not predicted travel within a given amount of time. The high quality vehicle trajectory **420** is then provided to block **408**.

[0050] In block **408**, a steering angle and velocity command is generated based on the vehicle trajectory **420**. The steering angle and velocity command is provided to block **410** for vehicle dynamics control, i.e., the steering angle and velocity command causes the AV to follow the vehicle trajectory **408**.

[0051] Illustrative Methods

[0052] Referring now to FIG. 5, there is provided a flow diagram of an illustrative method **500** for operating a vehicle (e.g., vehicle **102₁** of FIG. 1). Method **500** can be implemented by the vehicle on-board computing device **220** of FIG. 2 and/or the computing device **300** of FIG. 3. Method **500** is performed for each object (e.g., vehicle **102₂** of FIG. 1, cyclist **114** of FIG. 1, and/or pedestrian **116** of FIG. 1) that has been detected to be within a distance range from the vehicle at any given time.

[0053] Method **500** comprises a plurality of operations **502-530**. The present solution is not limited to the particular order of operations **502-530** shown in FIG. 5. For example, the operations of **504** can be performed subsequent to **506**, rather than before as shown in FIG. 5A. Additionally or alternatively, the operations of **520** can be performed in parallel with the operations of **504-518**, rather than subsequent to the same as shown in FIG. 5.

[0054] As shown in FIG. 5A, method **500** begins with **502** and continues with **504** where a high quality vehicle trajectory (e.g., vehicle trajectory **420** of FIG. 4) for an AV is generated. The manner in which the high quality vehicle trajectory is generated will be described below in relation to FIG. 6. The high quality vehicle trajectory may represent a smooth path that does not have abrupt changes that would otherwise provide passenger discomfort, or may represent an emergency maneuver to avoid a collision. In some scenarios, the high quality vehicle trajectory is determined based on location information generated by a location sensor (e.g., location sensor **260** of FIG. 2) of the AV, object detection information generated by the on-board computing device (e.g., on-board computing device **220** of FIG. 2) of the AV, images captured by at least one camera (e.g., camera **262** of FIG. 2) of the AV, LiDAR datasets generated by a LiDAR system (e.g., LiDAR system **264** of FIG. 2) of the AV, radar/sonar data generated by a

radar/sonar system (e.g., radar/sonar system **266** of FIG. 2) of the AV, map information stored in a memory (e.g., memory **412** of FIG. 4) of the AV, and/or lane information.

[0055] In **505**, the AV performs operations to detect an object that is in proximity thereto. Object detection algorithms are well known in the art. Any known or to be known object detection algorithm can be used here. The object detection is then used to facilitate at least one autonomous driving operation (e.g., object tracking operations, object trajectory prediction operations, vehicle trajectory determination operations, and/or collision avoidance operations).

[0056] Accordingly, method **500** continues with **506** where one or more possible object trajectories (e.g., possible object trajectories **412** of FIG. 4) are determined for the object (e.g., vehicle **102**, cyclist **114** or pedestrian **116** of FIG. 1) detected in **505**. Techniques for determining trajectories for detected objects are well known. In some scenarios, sensor data is used to determine the object trajectories. Other information may be alternatively or additionally used to determine the object trajectories. This other information can include, but is not limited to, information received from a communication device (e.g., a transceiver, a beacon and/or a smart phone) of the object via wireless communication link(s) (e.g., link(s) **150**, **152**, **154** of FIG. 1). This information can specify actions or operations that have been performed, are being performed and/or are going to be performed by the object. (e.g., turn right/left, change lanes, accelerate/decelerate, a path of travel, etc.).

[0057] Next in **510**, a determination is made as to whether the vehicle trajectory generated in **504** and the possible object trajectory generated in **506** intersect each other. If they do not intersect each other [**511:NO**], then **512** is performed where method **500** returns to **504**.

[0058] In contrast, if they do intersect each other [**511:YES**], then method **500** continues to **514** where a time value is determined. This time value represents a time at which a collision will occur if the high quality vehicle trajectory is followed by the AV and the possible object trajectory of travel is followed by the object (e.g., which has been classified as a driving vehicle and has a drive intention). The time value determined in **514** is then compared to a threshold time value, as shown by **516**. The threshold time value is selected in accordance with a given application (e.g., one or more seconds). If the time value is greater than the threshold time value

[516:NO], then 518 is performed where method 500 returns to 504. If the time value is equal to or less than the threshold time value [516:YES], then method 500 continues with 520-522. 520-522 involve: dynamically generating one or more emergency maneuver profiles based on the high quality vehicle trajectory and the possible object trajectory/predicted path of travel; and determine whether the collision can be avoided if the high quality vehicle trajectory is followed by the AV and any one of the emergency maneuvers is performed in a pre-defined time period (e.g., *N* milliseconds). Upon completing 522, method 500 continues with 524 of FIG. 5B.

[0059] Referring now to FIG. 5B, if the collision cannot be avoided in the pre-defined time period [524:NO], then 526 is performed where the AV is caused to immediately take an emergency maneuver. The emergency maneuver can include, but is not limited to, one of the dynamically generated emergency maneuvers discussed above in relation to 520. Techniques for causing an AV to take emergency maneuvers are well known in the art. Subsequently, 530 is performed where method 500 ends or other processing is performed.

[0060] In contrast, if the collision can be avoided in the pre-defined time period [524:YES], then 528 is performed where the AV is optionally caused to perform a cautious maneuver (e.g., mildly slow down). Techniques for causing an AV to take a cautious maneuver such as slowing down are well known in the art. Subsequently, 530 is performed where method 500 ends or other processing is performed.

[0061] Referring now to FIG. 6, there is provided a flow diagram of an illustrative method 600 generating a high quality vehicle trajectory in accordance with the present solution. Method 600 can be performed in block 406 of FIG. 4 and/or block 504 of FIG. 5. Method 600 can be implemented by the vehicle on-board computing device 220 of FIG. 2 and/or the computing device 300 of FIG. 3.

[0062] As shown in FIG. 6, method 600 begins with 602 and continues with 604 where the computing device obtains candidate vehicle trajectory(ies) and context information from a data store (e.g., memory 312 of FIG. 3). The context information generally defines circumstances and/or conditions of an environment surrounding the autonomous vehicle. The context information can include, but is not limited to, predicted trajectories for detected objects, a map

(e.g., 3D road map), traffic information (e.g., traffic flow, traffic jams, slow moving, delays, road closure, roadwork, construction, accident, etc.), environmental information (e.g., rain, snow, fog, etc.), and/or other information (e.g., information received over communication link(s) **150**, **152**, **154** of FIG. 1). A candidate vehicle trajectory is selected in **606**. The selected candidate vehicle trajectory and the context information is used in **608** to generate a feature vector.

[0063] The feature vector is determined using known or to be known geometric algorithms, deep learning techniques (e.g., variational auto encoder), and/or other feature extraction algorithms. The feature vector can include, but is not limited to, a value specifying the closest detected object (e.g., pedestrian) to the vehicle, the closest distance from detected object (e.g., light, stop sign, etc.) to the vehicle, and/or whether the vehicle is blocking an intersection. The feature vector may also include, but is not limited to, the following information for a detected object: a foreground/background classification, a position, and a delta value (i.e., height above ground).

[0064] The selected candidate vehicle trajectory and the context information is also used in **610** to classify a scenario specified thereby into one or more scenario classes. The scenario classification can be discrete or continuous. In the discrete case, the context is classified as one of the scenarios. In the continuous case, the scenario classifier given a probability of each possible scenario. The scenario space itself can be discrete or continuous. In the discrete case, there are a finite number of scenario. In the continuous case, the scenario space is a multi-dimensional vector space where each scenario is represented by a multi-dimensional real-valued vector.

[0065] The scenario classes can include, but are not limited to, a left turn scenario class, a right turn scenario, a passing scenario class, a driving scenario class, an acceleration scenario class, a deceleration scenario class, a stationary scenario class, a forward driving scenario class, a reverse driving scenario class, and/or a passenger pick-up scenario class. In some scenarios, a machine learning algorithm is employed in which machine learned models are used to determine scenario classifications. In those or other scenarios, the classification criteria is pre-defined to specify possible scenario classifications. For example, if the select candidate vehicle trajectory

and map of the context information indicate that the AV is to take a left or right turn, then the scenario may be classified as a left or right turn scenario. If the selected candidate vehicle trajectory, a predicted trajectory for a detected object, road map and traffic information indicate that the AV is to pass the detected object, then the scenario may be classified as a passing scenario. If the selected candidate vehicle trajectory indicates that the AV is stationary and the context information indicates that individual(s) is(are) in proximity to the AV, then the scenario may be classified as a passenger pick-up scenario. The present solution is not limited to the particulars of this example.

[0066] The machine-learning algorithm can employ supervised machine learning, semi-supervised machine learning, unsupervised machine learning, and/or reinforcement machine learning. Each of these listed types of machine-learning algorithms is well known in the art. In some scenarios, the machine-learning algorithm includes, but is not limited to, a decision tree learning algorithm, an association rule learning algorithm, an artificial neural network learning algorithm, a deep learning algorithm, an inductive logic programming based algorithm, a support vector machine based algorithm, a Bayesian network based algorithm, a representation learning algorithm, a similarity and metric learning algorithm, a sparse dictionary learning algorithm, a genetic algorithm, a rule-based machine-learning algorithm, and/or a learning classifier system based algorithm. The machine-learning process implemented by the present solution can be built using Commercial-Off-The-Shelf (COTS) tools (e.g., SAS available from SAS Institute Inc. of Cary, North Carolina).

[0067] For each scenario class determined in **610**, the computing device selects in **612** (i) a scoring function from a plurality of different scoring functions $SF_1, SF_2, \dots, SF_N$, (ii) a set of scoring functions from a plurality of different sets (e.g., $ST_1 = [SF_1, SF_2, SF_{10}]$, $ST_2 = [SF_2, SF_3, SF_{10}, SF_N]$ and/or $ST_3 = [SF_6, SF_8]$), and/or (iii) weights w_Z for the at least one scoring function. N and Z are integers. The scoring functions can include, but are not limited to, a linear regression function, a non-linear regression function, a Quadratic function features in feature vector, and/or a polynomial function of features in feature vector. An illustrative scoring function $SF(f)$ is defined by the following mathematical equation (2).

$$SF(f) = w \cdot f \quad (2)$$

where $SF(f)$ is the inner product of the feature vector f and a weight w of the associated scenario.

[0068] The scoring function(s) is(are) performed in **614** to generate quality score(s) s_X for the candidate vehicle trajectory. X is an integer. One or more quality scores can be generated for each scenario class associated with the candidate vehicle trajectory. For example, a first quality score s_1 is generated for a first scenario class (e.g., a right turn scenario class) determined in **610** for the candidate vehicle trajectory. A second quality score s_2 and a third quality score s_3 are generated for a second scenario class (e.g., a passenger pick-up scenario class) determined in **610** for the candidate vehicle trajectory. The present solution is not limited to the particulars of this example.

[0069] If only one quality score was generated for all of the scenario classes **[616:NO]**, then method **600** continues with **622** as shown by **618**. In **622**, the quality scores for all the scenario classes are combined together to produce a final quality score s_{final} . The final quality score s_{final} may be defined, for example, by the following mathematical equation (3), mathematical equation (4) or mathematical equation (5).

$$s_{final} = s_{1-class1} + s_{2-class2} + \dots + s_{X-classX} \quad (3)$$

$$s_{final} = \text{avg} (s_{1-class1} + s_{2-class2} + \dots + s_{X-classX}) \quad (4)$$

$$s_{final} = (w_1 \cdot s_{1-class1}) + (w_2 \cdot s_{2-class2}) + \dots + (w_X \cdot s_{X-classX}) \quad (5)$$

where $s_{1-class1}$ represents a quality score generated for a first scenario class, $s_{2-class2}$ represents a quality score generated for a second scenario class, $s_{X-classX}$ represents a quality score generated for the X^{th} scenario class, and $w_1, w_2, \dots, w_X$ each represent a weight.

[0070] If two or more quality scores were generated for at least one scenario class **[616:YES]**, then method **600** continues with **620** where the quality scores are combined together to produce an aggregate quality score $s_{aggregate}$ for the given scenario class. For example, if two quality scores $s_{1-classX}$ and $s_{2-classX}$ were generated for a given class X , then the aggregate quality

score for the given class may be defined by the following mathematical equation (5), mathematical equation (6), mathematical equation (7) or mathematical equation (8).

$$S_{aggregate-classX} = S_{1-classX} + S_{2-classX} \quad (5)$$

$$S_{aggregate-classX} = \text{avg} (S_{1-classX}, S_{2-classX}) \quad (6)$$

$$S_{aggregate-classX} = (w_1 \cdot S_{1-classX}) + (w_1 \cdot S_{2-classX}) \quad (7)$$

$$S_{aggregate-classX} = S_{1-classX} + S_{2-classX} + S_{classX-previous} \quad (8)$$

where $S_{classX-previous}$ represents a previous quality score generated for the given class. The present solution is not limited to the particulars of these mathematical equations. The aggregation function can be a (weighted) average, max out, or any other real-valued vector function. The aggregation function can be static or dynamic. The dynamic aggregation functions can include, but is not limited to, filtering and other smoothing functions to smooth the transition between different scenarios, and/or a function of any historical values of the quality score (e.g., the quality score calculated in previous cycle(s) or a certain amount of time ago).

[0071] The aggregated quality score may be combined with the quality score(s)/aggregate quality score(s) for the other scenario classes to generate the final quality score s_{final} for the given candidate vehicle trajectory, as shown by 622. Accordingly, the final quality score s_{final} may be alternatively defined by the following mathematical equation (8), (9), (10), (11), (12), (13) or (14).

$$S_{final} = S_{Xaggregate-classX} \quad (8)$$

$$S_{final} = S_{1-class1} + S_{2-class2} + \dots + S_{Xaggregate-classX} \quad (9)$$

$$S_{final} = \text{avg} (S_{1-class1} + S_{2-class2} + \dots + S_{Xaggregate-classX}) \quad (10)$$

$$S_{final} = (w_1 \cdot S_{1-class1}) + (w_2 \cdot S_{2-class2}) + \dots + (w_X \cdot S_{Xaggregate-classX}) \quad (11)$$

$$S_{final} = S_{1aggregate-class1} + S_{2aggregate-class2} + \dots + S_{Xaggregate-classX} \quad (12)$$

$$S_{final} = \text{avg} (S_{1aggregate-class1} + S_{2aggregate-class2} + \dots + S_{Xaggregate-classX}) \quad (13)$$

$$s_{final} = (w_1 \cdot s_{1aggregate-class1}) + (w_2 \cdot s_{2aggregate-class2}) + \dots + (w_X \cdot s_{Xaggregate-classX}) \quad (14)$$

where $s_{1aggregate-class1}$ represents an aggregate quality score for a first class, $s_{2aggregate-class2}$ represents an aggregate quality score for a second class.

[0072] Once the final quality score s_{final} for the given candidate trajectory has been generated, method 600 may return to 606 so that the process is repeated for a next candidate vehicle trajectory as shown by optional 624. In 626, a candidate vehicle trajectory is selected based on the final quality score(s) representing the quality of the candidate vehicle trajectory(ies). For example, the candidate vehicle trajectory with the highest or lowest final quality score is selected in 616. Alternatively or additionally, the candidate vehicle trajectory is selected as the one with the quality score that is greater than or less than a given threshold. If two or more candidate vehicle trajectories have a quality score that is greater than or less than the given threshold, then the candidate vehicle trajectory is selected as the one with the greatest or lowest quality score. A linear/non-linear function could be used to selected the candidate vehicle trajectory based on the final quality scores. Subsequently, 628 is performed where method 600 ends or other operations are performed. For example, the computing device may consider the selected candidate vehicle trajectory as a high quality vehicle trajectory, and therefore perform operations to cause the AV to follow the same (e.g., provided that there is no risk of collision with an object).

[0073] Referring now to FIG. 7, there is provided a schematic illustration of an illustrative system architecture 700 for implementing the present solution (e.g., method 600 of FIG. 6). System 700 may be implemented in hardware, software or a combination thereof.

[0074] As shown in FIG. 7, system 700 comprises a trajectory sampler 706, a feature vector generator 708, a scenario classifier 710, a scoring function/weight selector 712, score generators 716, 718, ..., 720, optional combiners 722, 724, ..., 726, a final score generator 728, and a candidate vehicle trajectory selector 730. The trajectory sampler 706 is configured to sample a candidate vehicle trajectory 702 input into system 700. The trajectory sampler 706 can be deterministic or stochastic. The sampled candidate vehicle trajectory 704 is then passed to the scenario classifier 710 and the feature vector generator 708. The scenario classifier 710 is

configured to analyze the vehicle trajectory **704** and context information **705** to classify a scenario specified thereby into one or more scenario classes. The scenario classes can include, but are not limited to, a left turn scenario class, a right turn scenario, a passing scenario class, and/or a passenger pick-up scenario class. In some scenarios, the scenario classifier **710** employs a machine learning algorithm in which machine learned models are used to determine scenario classifications. In those or other scenarios, the scenario classifier **710** uses pre-defined classification criteria to determine scenario classifications.

[0075] The scenario classification(s) **711** is(are) passes to the scoring function/weight selector **712**. Based on the scenario classification(s), the scoring function/weight selector **712** selects (i) a scoring function from a plurality of different scoring functions $SF_1, SF_2, \dots, SF_N$, (ii) a set of scoring functions from a plurality of different sets (e.g., $ST_1 = [SF_1, SF_2, SF_{10}]$, $ST_2 = [SF_2, SF_5, SF_{10}, SF_N]$ and/or $ST_3 = [SF_6, SF_8]$), and/or (iii) weights w_z for the at least one scoring function. The scoring functions can include, but are not limited to, a linear regression function, a non-linear regression function, a Quadratic function features in feature vector, and/or a polynomial function of features in feature vector. A control signal **715** is then sent from the scoring function/weight selector **712** to the score generator(s) associated with the selected scoring function(s) or the selected set of scoring functions. The control signal **715** causes an enablement of the selected scoring function generator(s) or scoring function(s) of the selected set. The control signal **715** may also specify selected weights that are to be used by the scoring function(s).

[0076] When enabled, a scoring function generator **716**, **718**, **720** processes a feature vector **714** to generate one or more quality scores for a given scenario classification associated with the given candidate vehicle trajectory **704**. For example, score generator(s) **716** generate(s) quality score(s) $s_{X-class1}$ for a first scenario associated with the given candidate vehicle trajectory **704**. Score generator **718** generate(s) quality score(s) $s_{X-class2}$ for a second scenario associated with the given candidate vehicle trajectory **704**. Score generator **720** generate(s) quality score(s) $s_{X-classN}$ for an N^{th} scenario associated with the given candidate vehicle trajectory **704**. The present

solution is not limited to the particulars of this example. The same or different score generator(s) **716**, **718**, **720** can be enabled for different candidate vehicle trajectories.

[0077] The quality scores are output from the score generator(s) **716**, **718**, **720**, and passed to optional combiner(s) **722**, **724**, **726** and/or final score generator **728**. Each combiner **722**, **724**, **726** is configured to produce an aggregate quality score for a respective scenario. For example, combiner **722** is configured to combine the quality scores output from the first scenario score generator(s) **716** to produce an aggregated quality score $s_{aggregate-class1}$. Combiner **724** is configured to combine the quality scores output from the second scenario score generator(s) **718** to produce an aggregated quality score $s_{aggregate-class2}$. Combiner **726** is configured to combine the scores output from the N^{th} scenario score generator(s) **720** to produce an aggregated quality score $s_{aggregate-classN}$.

[0078] The quality score(s) output from the score generator(s) **716-720** and/or the quality aggregated score(s) output from the combiner(s) **722-726** is(are) passed to the final score generator **728**. The final score generator **728** determines a final quality score s_{final} based on the received quality score(s) and/or aggregated quality score(s). The final quality score s_{final} is then passed to the candidate vehicle trajectory selector **730**. The operations of blocks **706-728** are performed for each candidate vehicle trajectory contained in the candidate vehicle trajectories **702**.

[0079] The final quality scores are then used by the candidate vehicle trajectory selector **730** to select a candidate vehicle trajectory from the candidate vehicle trajectories **702**. For example, the candidate vehicle trajectory with the highest or lowest final quality score is selected by the candidate vehicle trajectory selector **730**. Alternatively or additionally, the candidate vehicle trajectory is selected by the candidate vehicle trajectory selector **730** as the one with the quality score that is greater than or less than a given threshold. If two or more candidate vehicle trajectories have a quality score that is greater than or less than the given threshold, then the candidate vehicle trajectory is selected by the candidate vehicle trajectory selector **730** as the one with the greatest or lowest quality score. A linear/non-linear function could be used by the

candidate vehicle trajectory selector **730** to select the candidate vehicle trajectory based on the final quality scores.

[0080] As evident from the above discussion, the present solution may utilize a scenario classifier and an aggregator for trajectory scoring, which introduces more structure and transparency to a scoring calculation. The present solution may use multiple scoring functions with the same and/or different types of scenarios. The present solution has many advantages. For example, the present solution is relatively easy to tune to focus on particular scenario(s). The present solution also enables parallelism in development where each team member can tune part of the scoring function in parallel. Use of the scenario classifier reduces the required complexity of the feature vector generator.

[0081] Although the present solution has been illustrated and described with respect to one or more implementations, equivalent alterations and modifications will occur to others skilled in the art upon the reading and understanding of this specification and the annexed drawings. In addition, while a particular feature of the present solution may have been disclosed with respect to only one of several implementations, such feature may be combined with one or more other features of the other implementations as may be desired and advantageous for any given or particular application. Thus, the breadth and scope of the present solution should not be limited by any of the above described embodiments. Rather, the scope of the present solution should be defined in accordance with the following claims and their equivalents.

CLAIMS

What is claimed is:

1. A method for operating an autonomous vehicle, comprising:
 - obtaining, by a computing device, one or more candidate vehicle trajectories for the autonomous vehicle and context information defining a state of an environment surrounding the autonomous vehicle;
 - assigning, by the computing device, at least one class of a plurality of classes to a scenario specified by the context information and a first candidate vehicle trajectory of the candidate vehicle trajectories;
 - selecting, by the computing device, at least one scoring function from a plurality of different scoring functions based on the at least one class assigned to the scenario, the plurality of different scoring functions being respectively associated with the plurality of classes;
 - generating, by the computing device, at least one first quality score for the first candidate vehicle trajectory using the at least one selected scoring function;
 - selecting, by the computing device, a candidate vehicle trajectory from the candidate vehicle trajectories based on the first quality score associated with the first candidate vehicle trajectory and a second quality score associated with at least one second candidate vehicle trajectory; and
 - causing, by the computing device, the autonomous vehicle to perform autonomous driving operations using the selected candidate vehicle trajectory.
2. The method according to claim 1, wherein the context information comprises at least one of intersection information, object related information, a road map, traffic information, and environmental information.
3. The method according to claim 1, further comprising performing operations, by the computing device, to (i) generate a feature vector using the context information and a first

candidate vehicle trajectory of the candidate vehicle trajectories and (ii) use the feature vector to generate the quality score for the first candidate feature vector.

4. The method according to claim 1, further comprising combining a first score and a second score to produce the first quality score for the first candidate feature vector.

5. The method according to claim 1, wherein

a first class and a second class are assigned to the scenario specified by the context information and a first candidate vehicle trajectory,

a first scoring function is selected based on the first class and a second scoring function is selected based on the second class, the second scoring function being different than the first scoring function,

a first score is generated using the first scoring function and a second score is generated using the second scoring function, and

the first score and the second score are combined together to produce the first quality score for the first candidate vehicle trajectory.

6. The method according to claim 1, wherein the plurality of classes comprise at least one of a left turn scenario class, a right turn scenario, a passing scenario class, a driving scenario class, an acceleration scenario class, a deceleration scenario class, a stationary scenario class, a forward driving scenario class, a reverse driving scenario class, and/or a passenger pick-up scenario class.

7. The method according to claim 1, further comprising selecting, by the computing device based on the at least one class, a set of scoring functions from a plurality of different sets or weights.

8. The method according to claim 7, wherein the selected set of scoring functions or weights is used to generate the at least one first quality score for the first candidate vehicle trajectory.

9. The method according to claim 1, wherein the candidate vehicle trajectory is selected from the candidate vehicle trajectories by comparing the first and second quality scores to each other or to a threshold value.

10. The method according to claim 1, wherein the autonomous driving operations comprise causing the autonomous vehicle to follow the selected candidate vehicle trajectory.

11. A system, comprising:

a processor;

a non-transitory computer-readable storage medium comprising programming instructions that are configured to cause the processor to implement a method for operating an autonomous vehicle, wherein the programming instructions comprise instructions to:

obtain one or more candidate vehicle trajectories for the autonomous vehicle and context information defining a state of an environment surrounding the autonomous vehicle;

assign at least one class of a plurality of classes to a scenario specified by the context information and a first candidate vehicle trajectory of the candidate vehicle trajectories;

select at least one scoring function from a plurality of different scoring functions based on the at least one class assigned to the scenario, the plurality of different scoring functions being respectively associated with the plurality of classes;

generate at least one first quality score for the first candidate vehicle trajectory using the at least one selected scoring function;

select candidate vehicle trajectory from the candidate vehicle trajectories based on the first quality score associated with the first candidate vehicle trajectory and a second quality score associated with at least one second candidate vehicle trajectory; and

cause the autonomous vehicle to perform autonomous driving operations using the selected candidate vehicle trajectory.

12. The system according to claim 11, wherein the context information comprises at least one of intersection information, object related information, a road map, traffic information, and environmental information.

13. The system according to claim 11, wherein the programming instructions further comprise instructions to (i) generate a feature vector using the context information and a first candidate vehicle trajectory of the candidate vehicle trajectories and (ii) use the feature vector to generate the quality score for the first candidate feature vector.

14. The system according to claim 11, wherein the programming instructions further comprise instructions to combine a first score and a second score to produce the first quality score for the first candidate feature vector.

15. The system according to claim 11, wherein

a first class and a second class are assigned to the scenario specified by the context information and a first candidate vehicle trajectory,

a first scoring function is selected based on the first class and a second scoring function is selected based on the second class, the second scoring function being different than the first scoring function,

a first score is generated using the first scoring function and a second score is generated using the second scoring function, and

the first score and the second score are combined together to produce the first quality score for the first candidate vehicle trajectory.

16. The system according to claim 11, wherein the plurality of classes comprise at least one of a left turn scenario class, a right turn scenario, a passing scenario class, a driving scenario class, an acceleration scenario class, a deceleration scenario class, a stationary scenario class, a forward driving scenario class, a reverse driving scenario class, and/or a passenger pick-up scenario class.

17. The system according to claim 11, wherein the programming instructions further comprise instructions to select a set of scoring functions from a plurality of different sets or weights, based on the at least one class.

18. The system according to claim 17, wherein the set of scoring functions or weights is used to generate the at least one first quality score for the first candidate vehicle trajectory.

19. The system according to claim 11, wherein the candidate vehicle trajectory is selected from the candidate vehicle trajectories by comparing the first and second quality scores to each other or to a threshold value.

20. A non-transitory computer-readable medium that stores instructions that are configured to, when executed by at least one computing device, cause the at least one computing device to perform operations comprising:

obtaining one or more candidate vehicle trajectories for an autonomous vehicle and context information defining a state of an environment surrounding the autonomous vehicle;

assigning at least one class of a plurality of classes to a scenario specified by the context information and a first candidate vehicle trajectory of the candidate vehicle trajectories;

selecting at least one scoring function from a plurality of different scoring functions based on the at least one class assigned to the scenario, the plurality of different scoring functions being respectively associated with the plurality of classes;

generating at least one first quality score for the first candidate vehicle trajectory using the at least one selected scoring function;

selecting a candidate vehicle trajectory from the candidate vehicle trajectories based on the first quality score associated with the first candidate vehicle trajectory and a second quality score associated with at least one second candidate vehicle trajectory; and

causing, the autonomous vehicle to perform autonomous driving operations using the selected candidate vehicle trajectory.

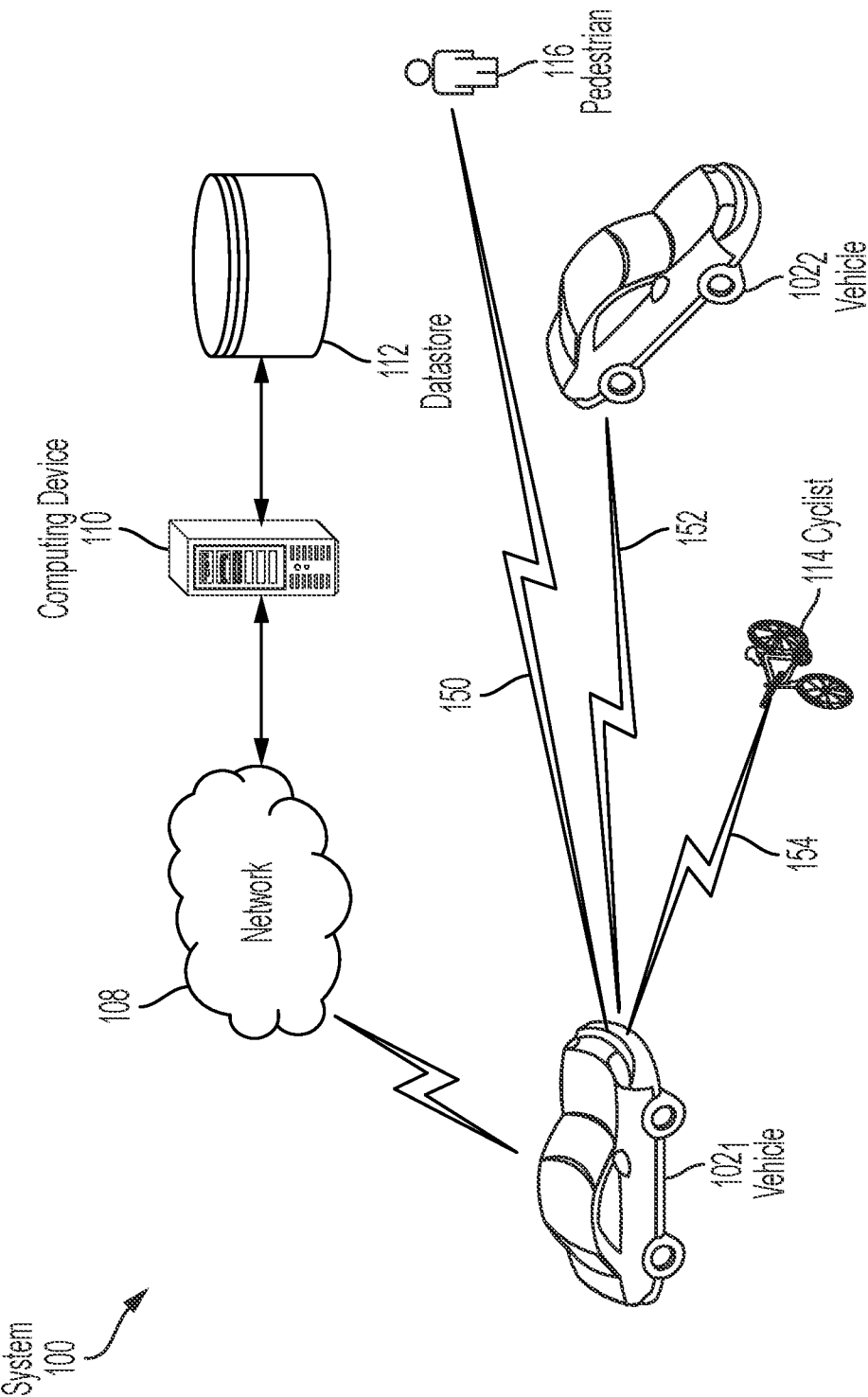


FIG. 1

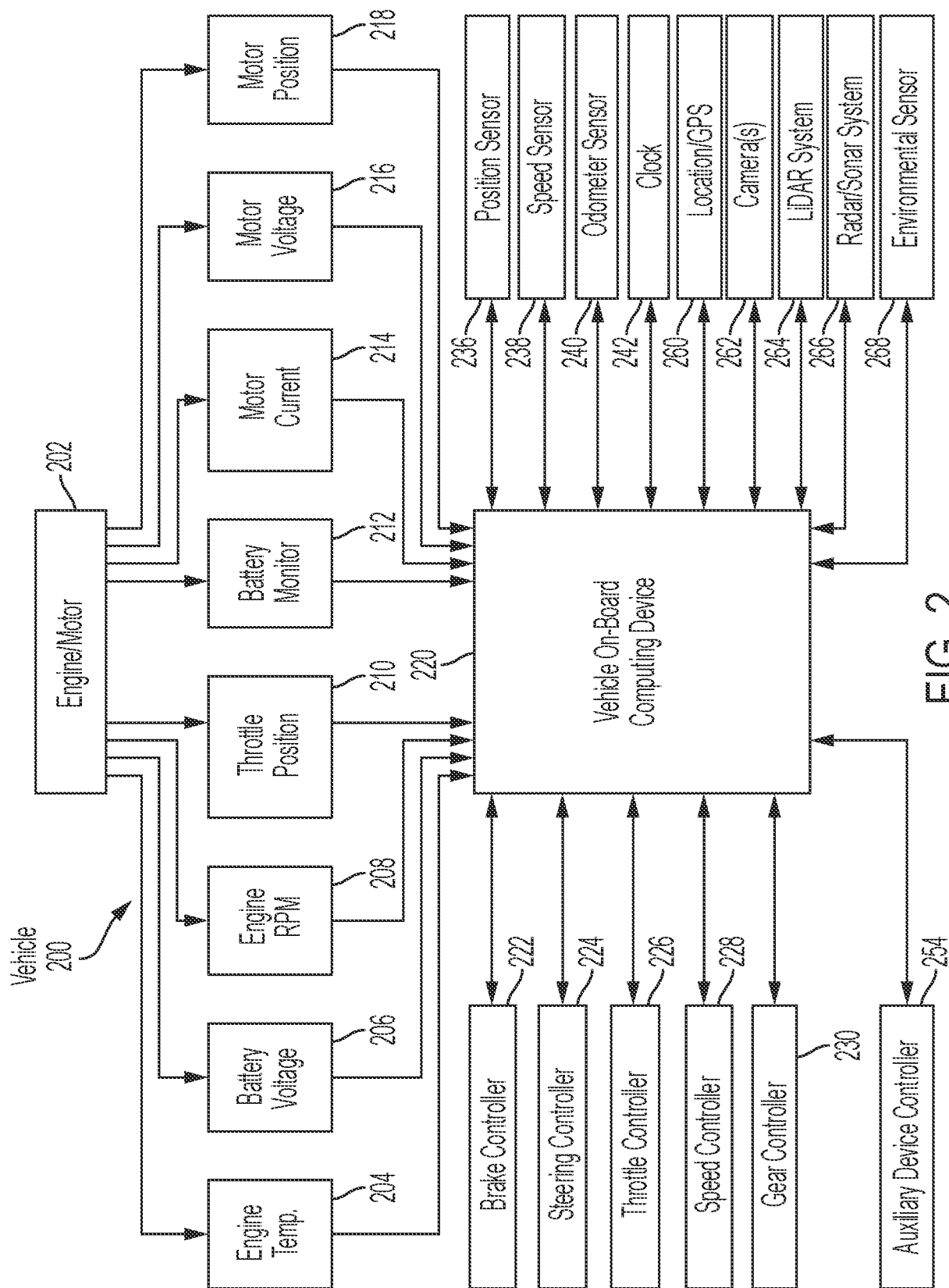


FIG. 2

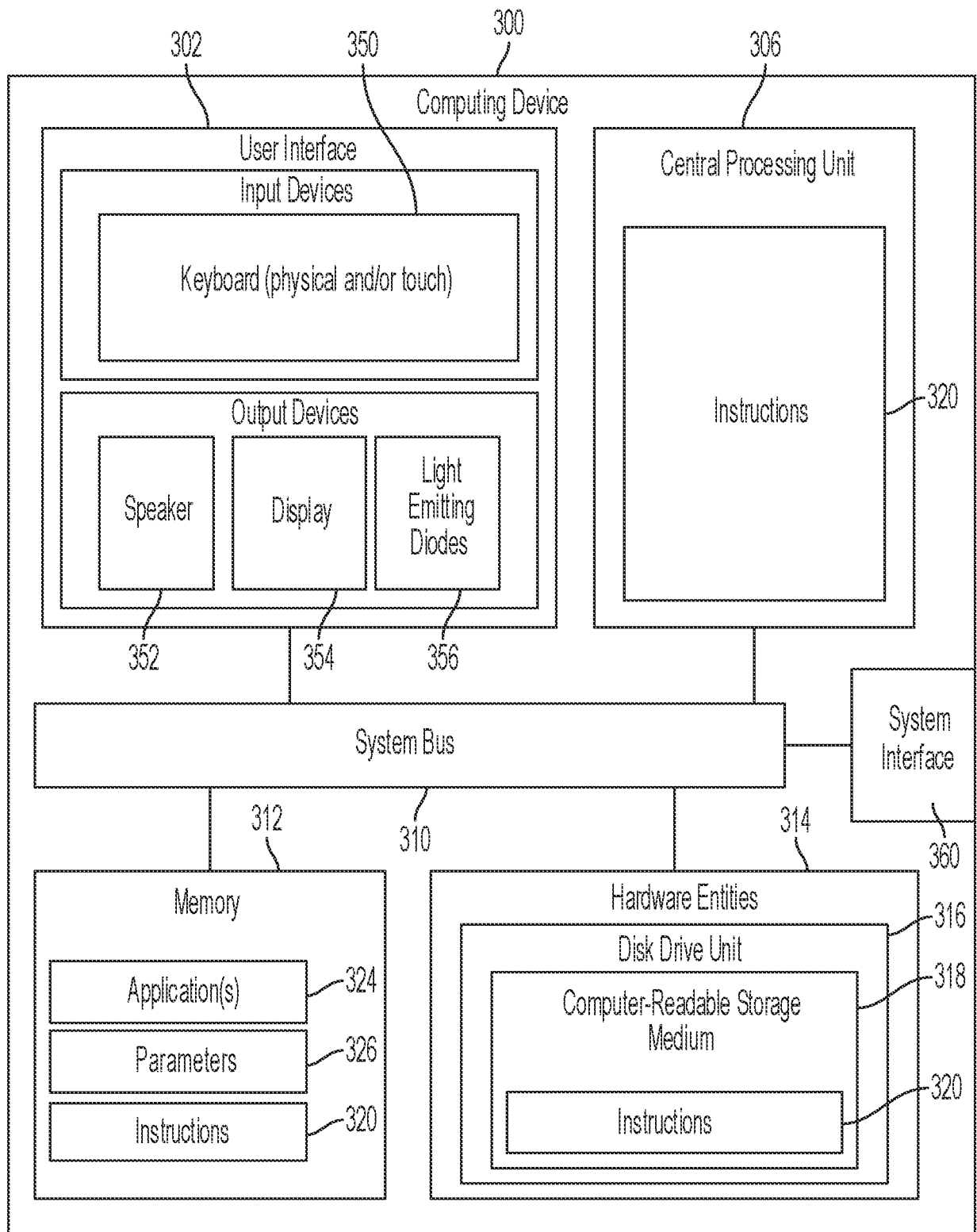


FIG. 3

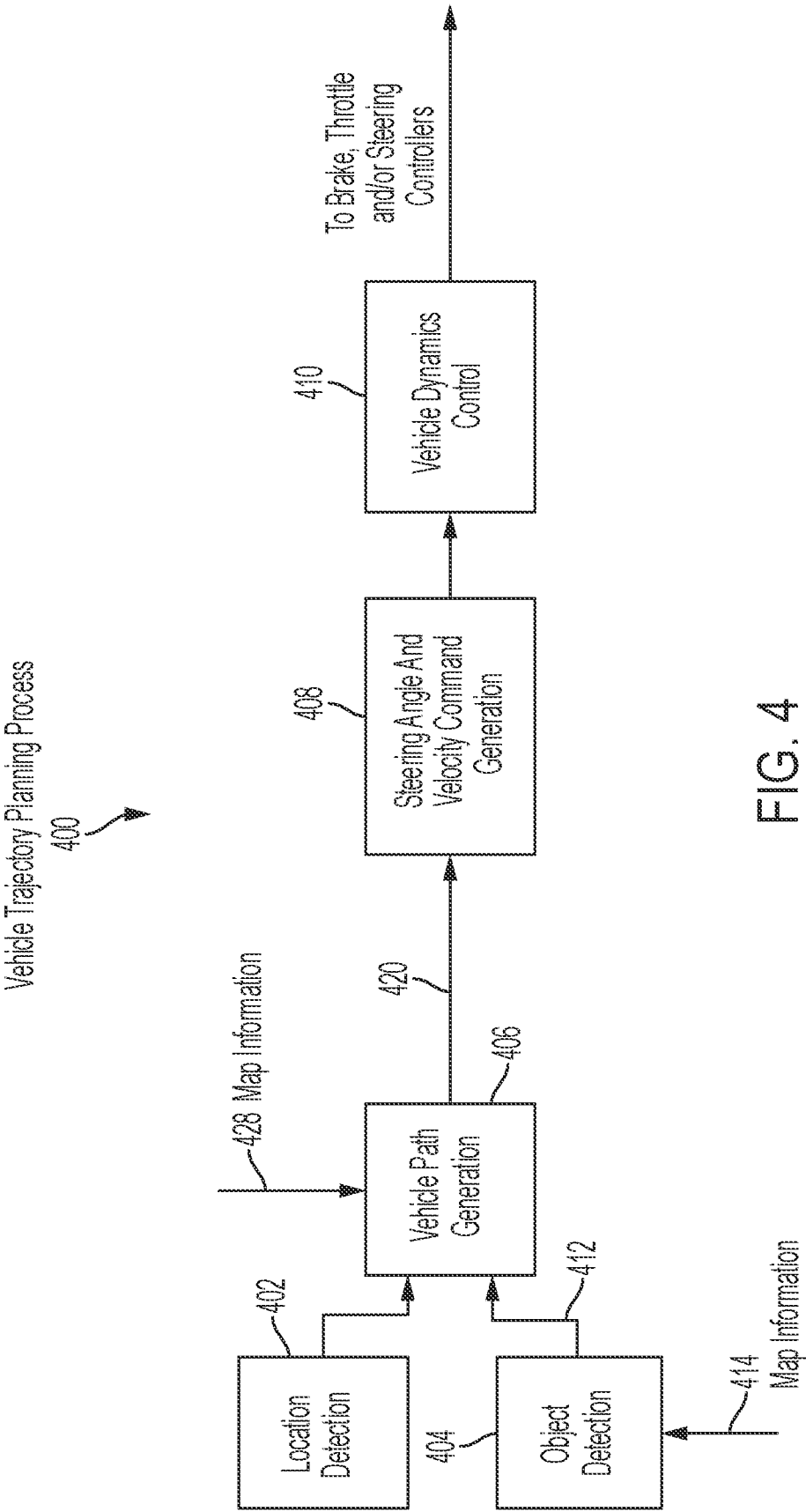
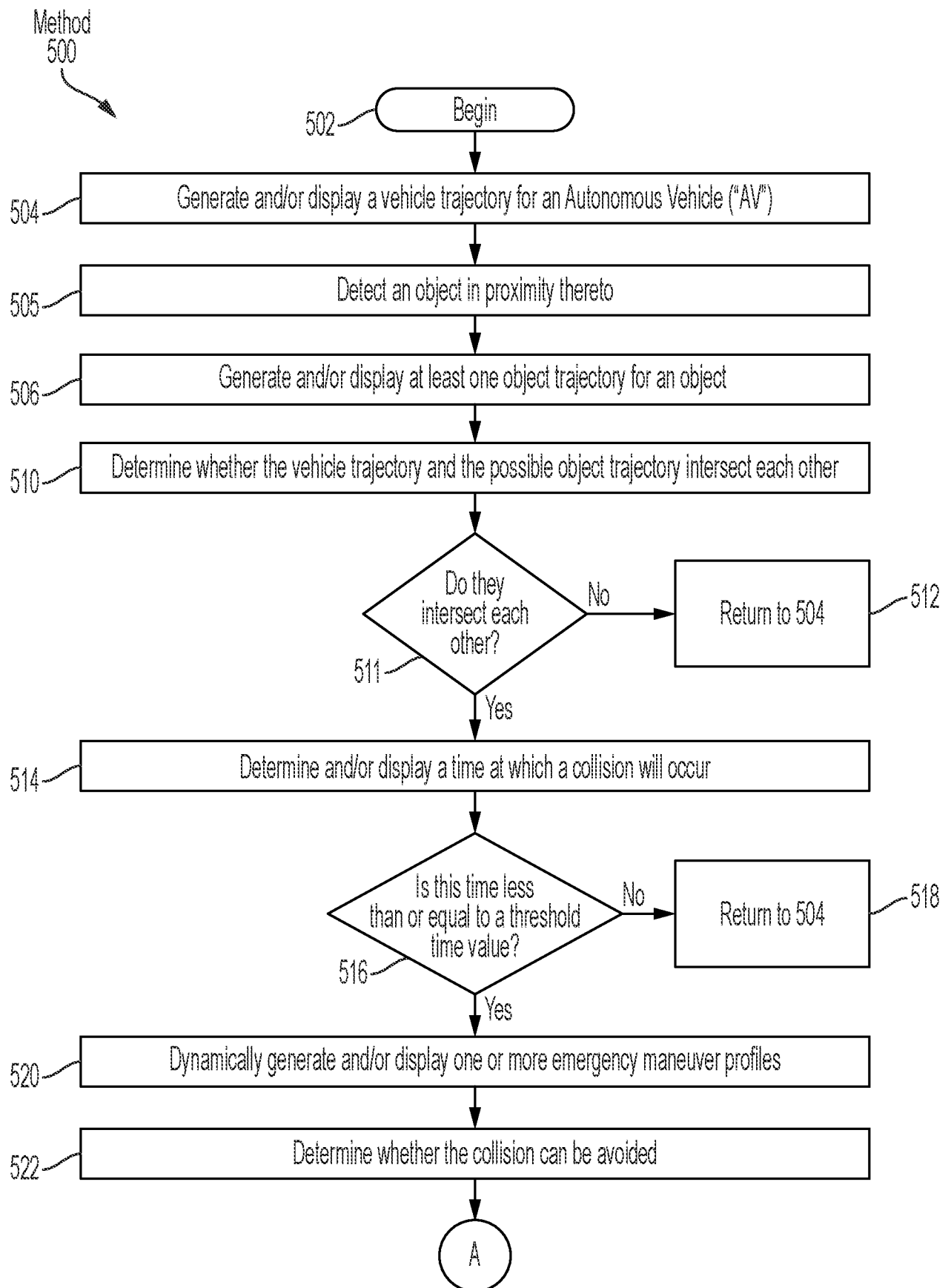


FIG. 4



TO FIG. 5B
FIG. 5A

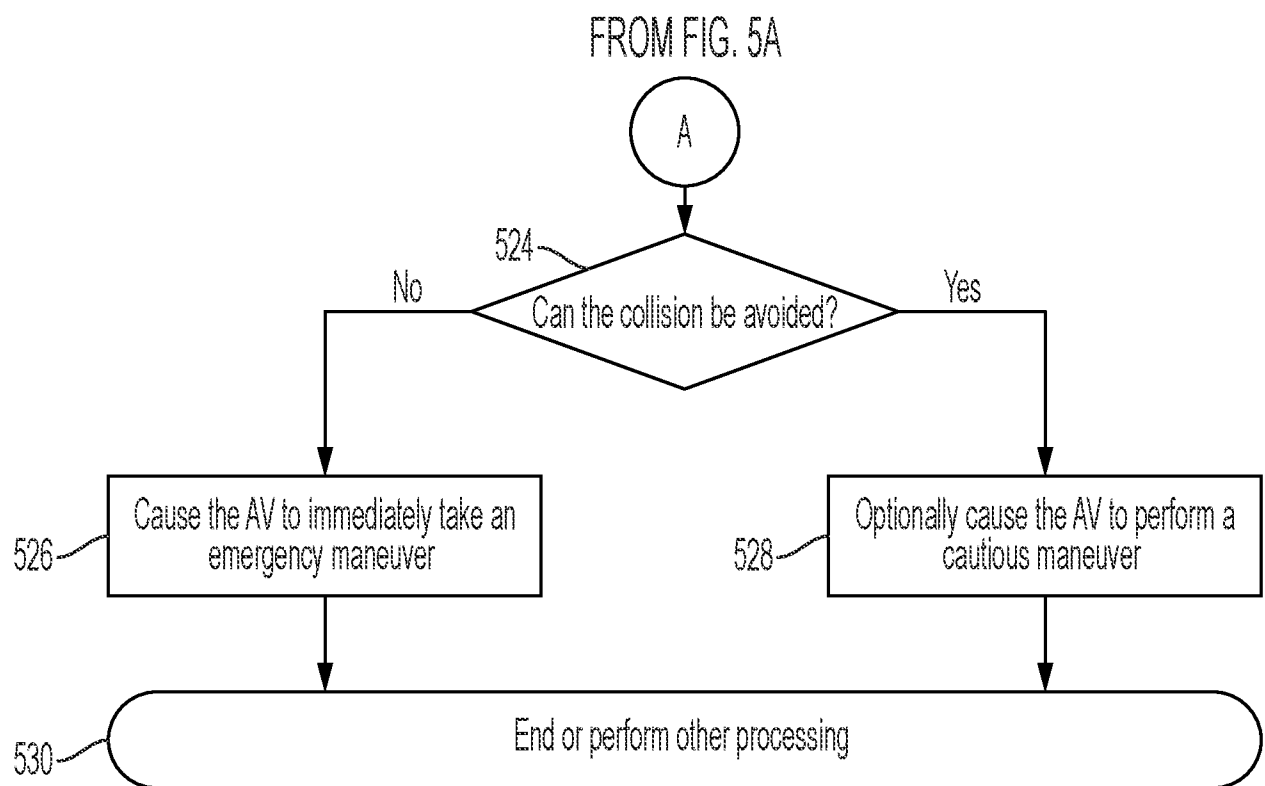


FIG. 5B

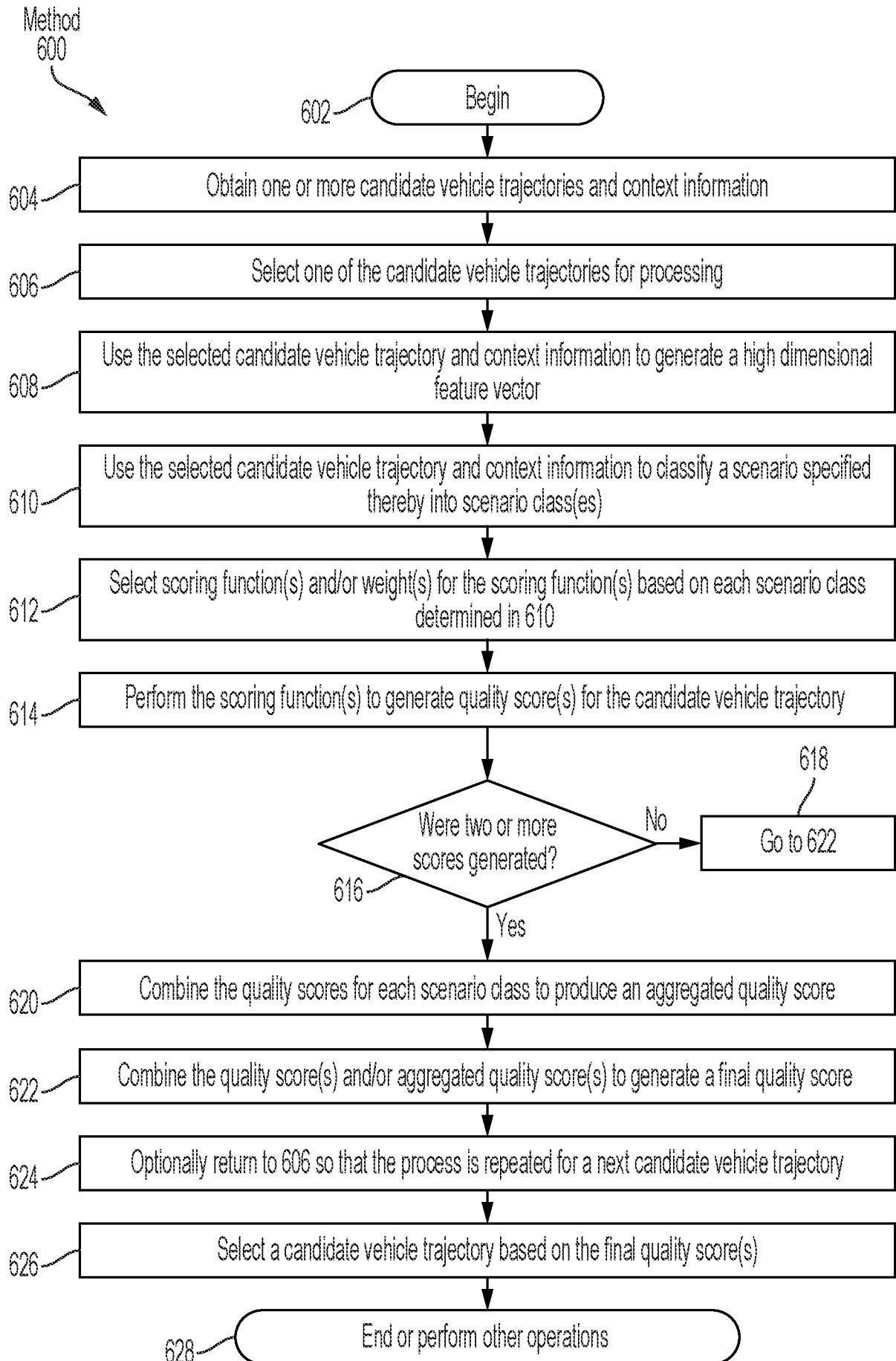


FIG. 6

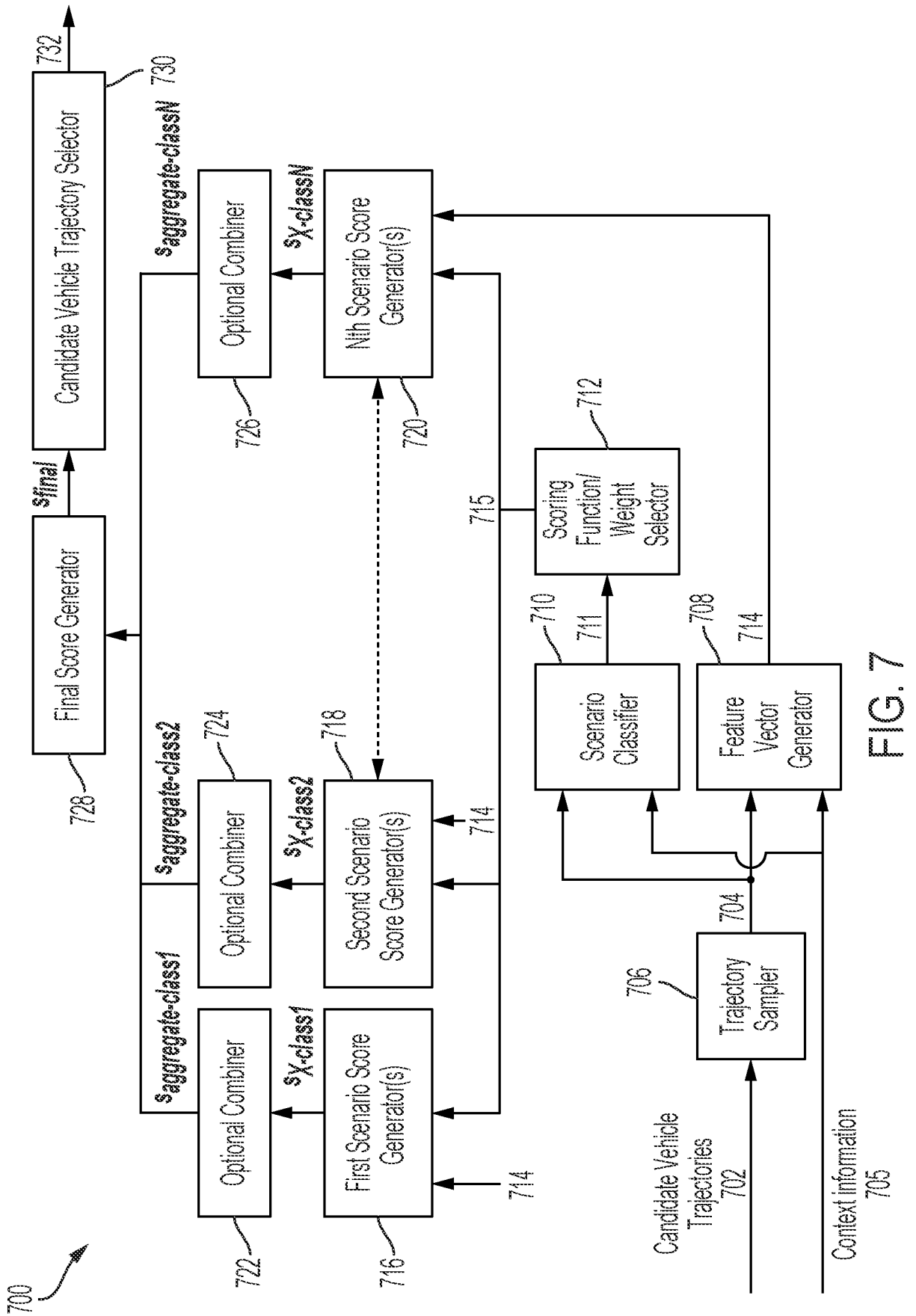


FIG. 7

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2021/073112

A. CLASSIFICATION OF SUBJECT MATTER**B60W 60/00**(2020.01)i; **B60W 40/02**(2006.01)i; **B60W 50/00**(2006.01)i

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

B60W 60/00(2020.01); B60W 30/09(2012.01); B60W 30/095(2012.01); B60W 30/182(2012.01); B60W 50/08(2006.01); G01C 21/34(2006.01); G01C 22/00(2006.01); G05D 1/00(2006.01); G05D 1/02(2006.01)

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

Korean utility models and applications for utility models
Japanese utility models and applications for utility models

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

eKOMPASS(KIPO internal) & Keywords: autonomous vehicle, one or more candidate vehicle trajectories, context information, at least one class, scenario, at least one scoring function, at least one first quality score, selected candidate vehicle trajectory

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2019-0286151 A1 (GM GLOBAL TECHNOLOGY OPERATIONS LLC.) 19 September 2019 (2019-09-19) paragraphs [0001]-[0042]; claims 15-20; and figures 1-4	1-20
Y	US 10421453 B1 (WAYMO LLC.) 24 September 2019 (2019-09-24) column 1, line 47 – column 4, line 14, column 13, line 52 – column 15, line 7; and figure 9	1-20
A	US 10452070 B2 (UBER TECHNOLOGIES, INC.) 22 October 2019 (2019-10-22) claims 1-17; and figures 6-7	1-20
A	US 2019-0369637 A1 (MOBILEYE VISION TECHNOLOGIES LTD.) 05 December 2019 (2019-12-05) claims 1-27; and figure 19	1-20
A	KR 10-2195935 B1 (LG ELECTRONICS INC.) 30 December 2020 (2020-12-30) claims 13-27; and figures 1-21	1-20



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents:

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“E” earlier application or patent but published on or after the international filing date

“L” document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

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“P” document published prior to the international filing date but later than the priority date claimed

“T” later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

“X” document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

“Y” document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

“&” document member of the same patent family

Date of the actual completion of the international search

30 March 2022

Date of mailing of the international search report

30 March 2022

Name and mailing address of the ISA/KR

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.

PCT/US2021/073112

Patent document cited in search report			Publication date (day/month/year)	Patent family member(s)			Publication date (day/month/year)
US	2019-0286151	A1	19 September 2019	CN	110271556	A	24 September 2019
				DE	102019105874	A1	19 September 2019
US	10421453	B1	24 September 2019	US	10899345	B1	26 January 2021
				US	9248834	B1	02 February 2016
				US	9669827	B1	06 June 2017
				US	9914452	B1	13 March 2018
US	10452070	B2	22 October 2019	EP	3665539	A1	17 June 2020
				JP	2020-534202	A	26 November 2020
				US	10571922	B2	25 February 2020
				US	2019-0086924	A1	21 March 2019
				US	2019-0384301	A1	19 December 2019
				WO	2019-055413	A1	21 March 2019
US	2019-0369637	A1	05 December 2019	CN	110462544	A	15 November 2019
				EP	3566106	A1	13 November 2019
				US	11181926	B2	23 November 2021
				WO	2018-172849	A1	27 September 2018
KR	10-2195935	B1	30 December 2020	KR	10-2019-0101925	A	02 September 2019
				US	2020-0033147	A1	30 January 2020