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(54) **USING PREDICTION MODELS FOR SCENE DIFFICULTY IN VEHICLE ROUTING**

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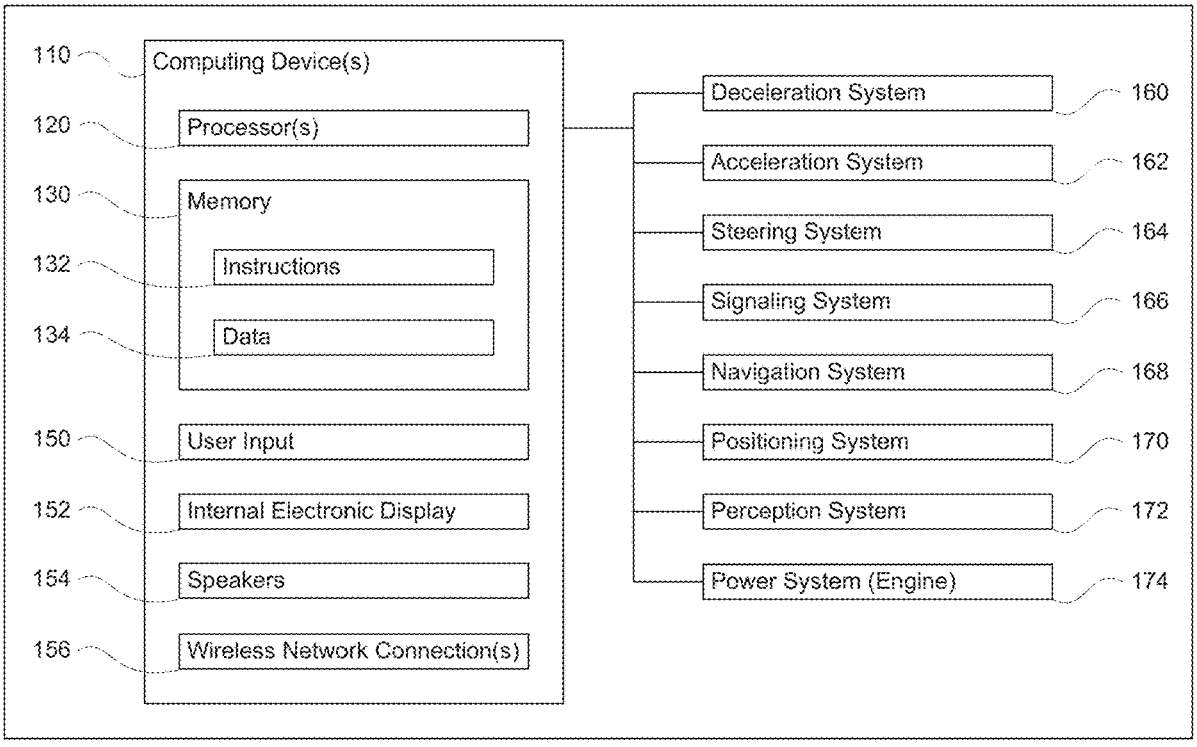
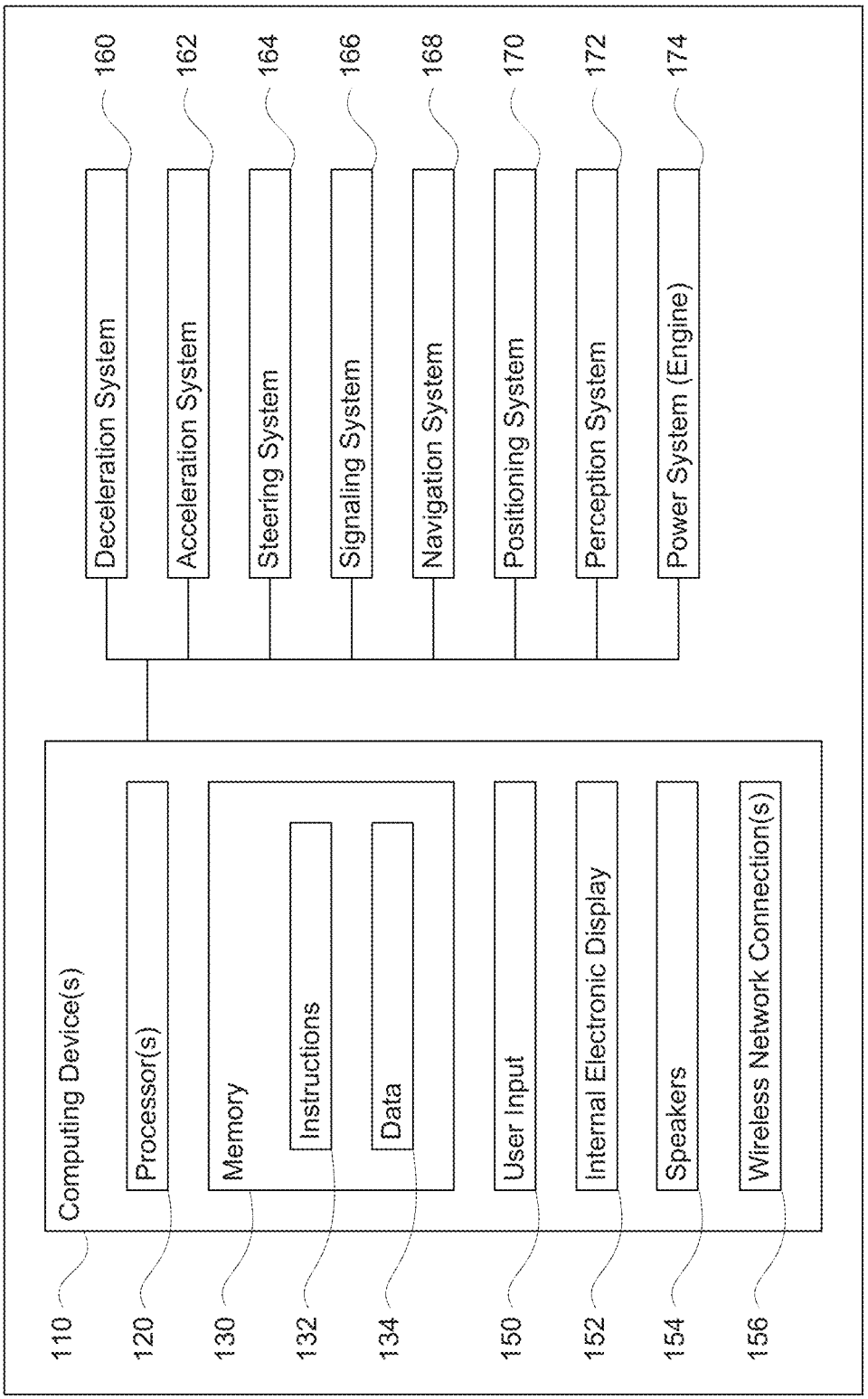
(57) **ABSTRACT**

A route is selected for travel by an autonomous vehicle based on at least a level of difficulty of traversing the driving environment along that route. Vehicle signals, provided by one or more autonomous vehicles, indicating a difficulty associated with traveling a portion of a route are collected and used to predict a most favorable driving route for a given time. The signals may indicate a probability of disengaging from autonomous driving mode, a probability of being stuck for an unduly long time, traffic density, etc. A difficulty score may be computed for each road segment of a route, and then the scores of all of the road segments of the route are added together. The scores are based on number of previous disengagements, previous requests for remote assistance, unprotected left or right turns, whether parts of the driving area are occluded, etc. The difficulty score is used to compute a cost for a particular route, which may be compared to costs computed for other possible routes. Based on such information, a route may be selected.

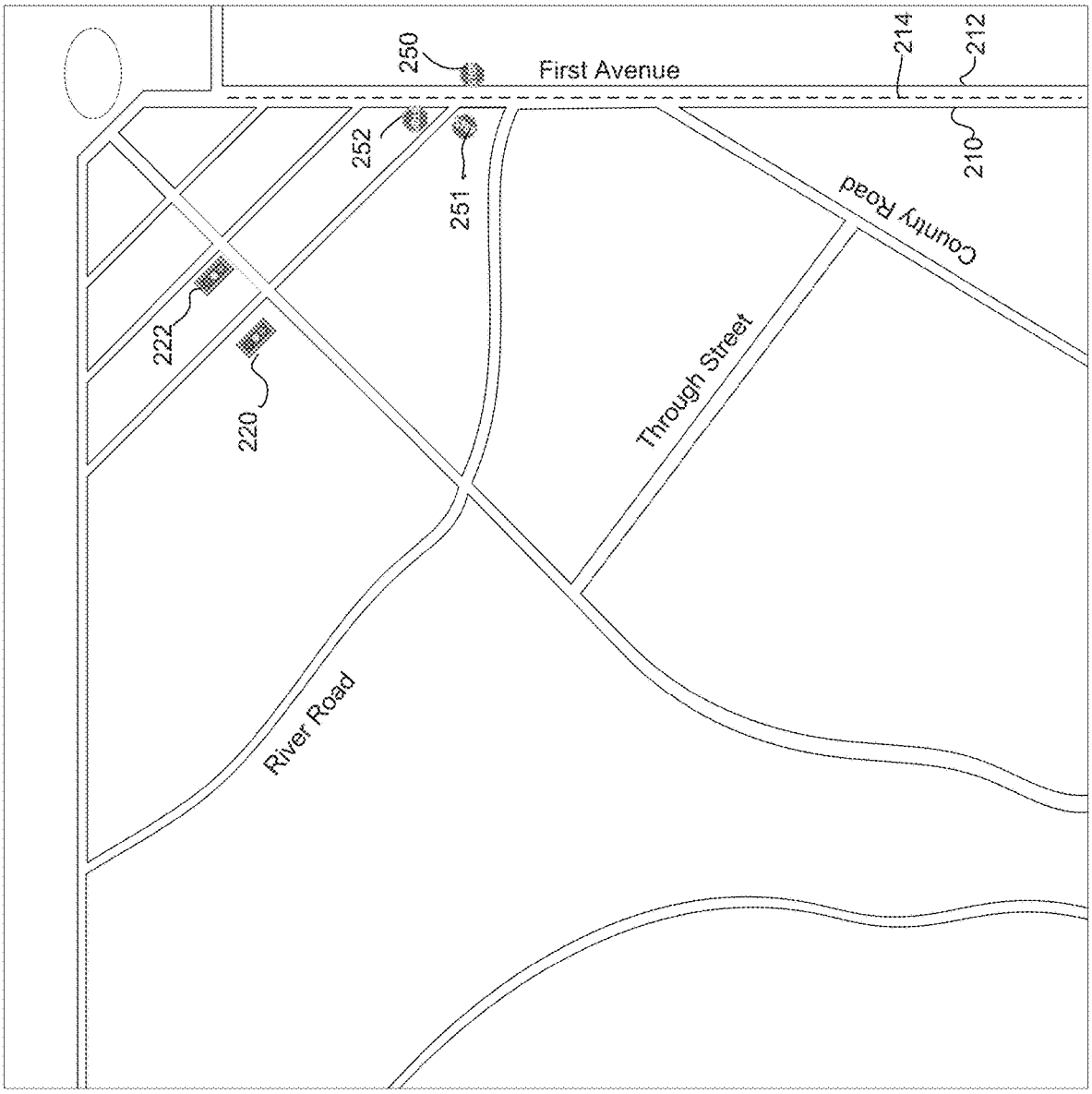



Computing Device(s)
Processor(s)
Memory
Instructions
Data
User Input
Internal Electronic Display
Speakers
Wireless Network Connection(s)
Deceleration System
Acceleration System
Steering System
Signaling System
Navigation System
Positioning System
Perception System
Power System (Engine)
110
120
130
132
134
150
152
154
156
160
162
164
166
168
170
172
174

100

FIGURE 1

FIGURE 2


First Avenue
250
214
212
210
252
251
222
220
County Road
Through Street
River Road

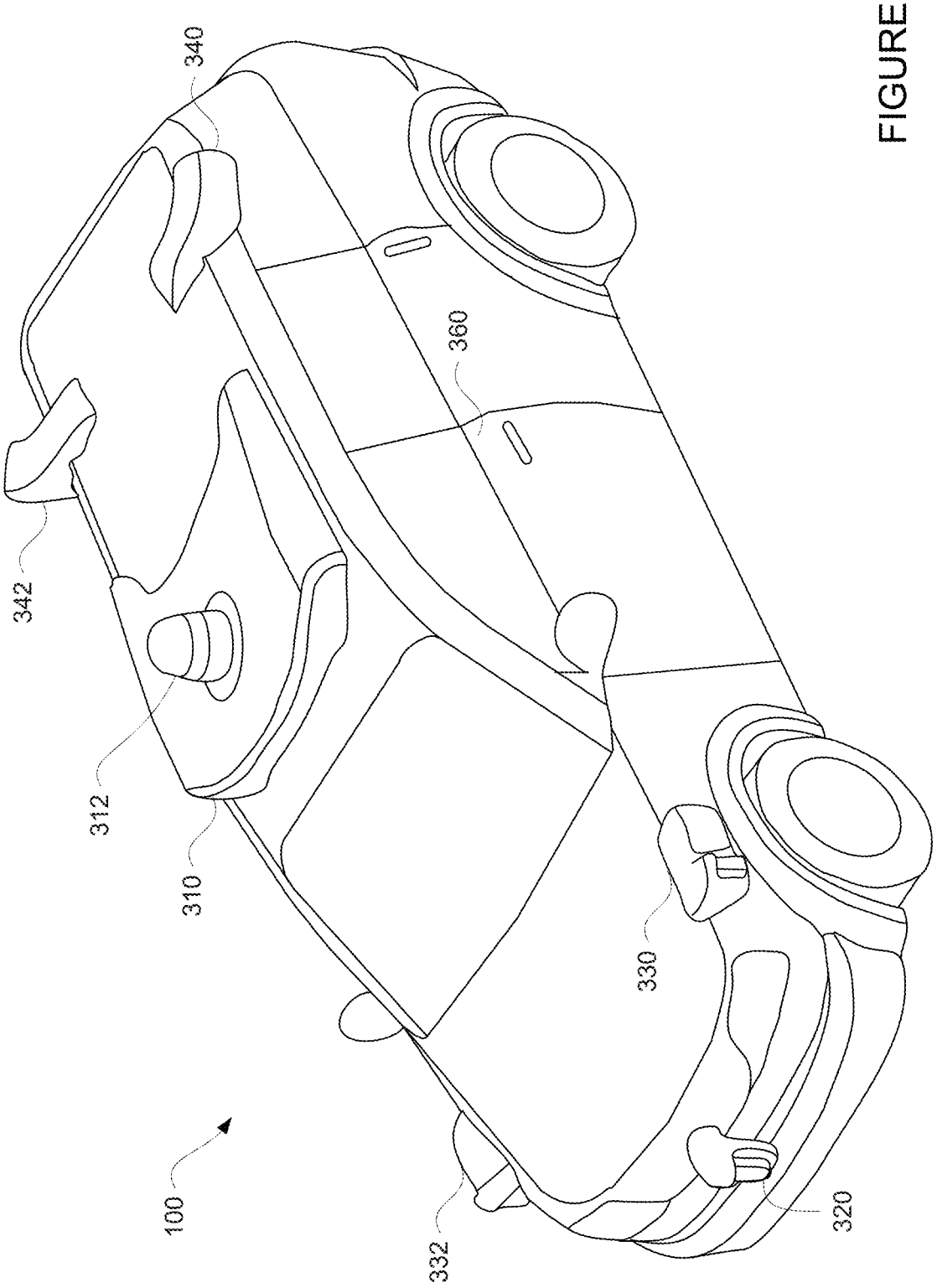
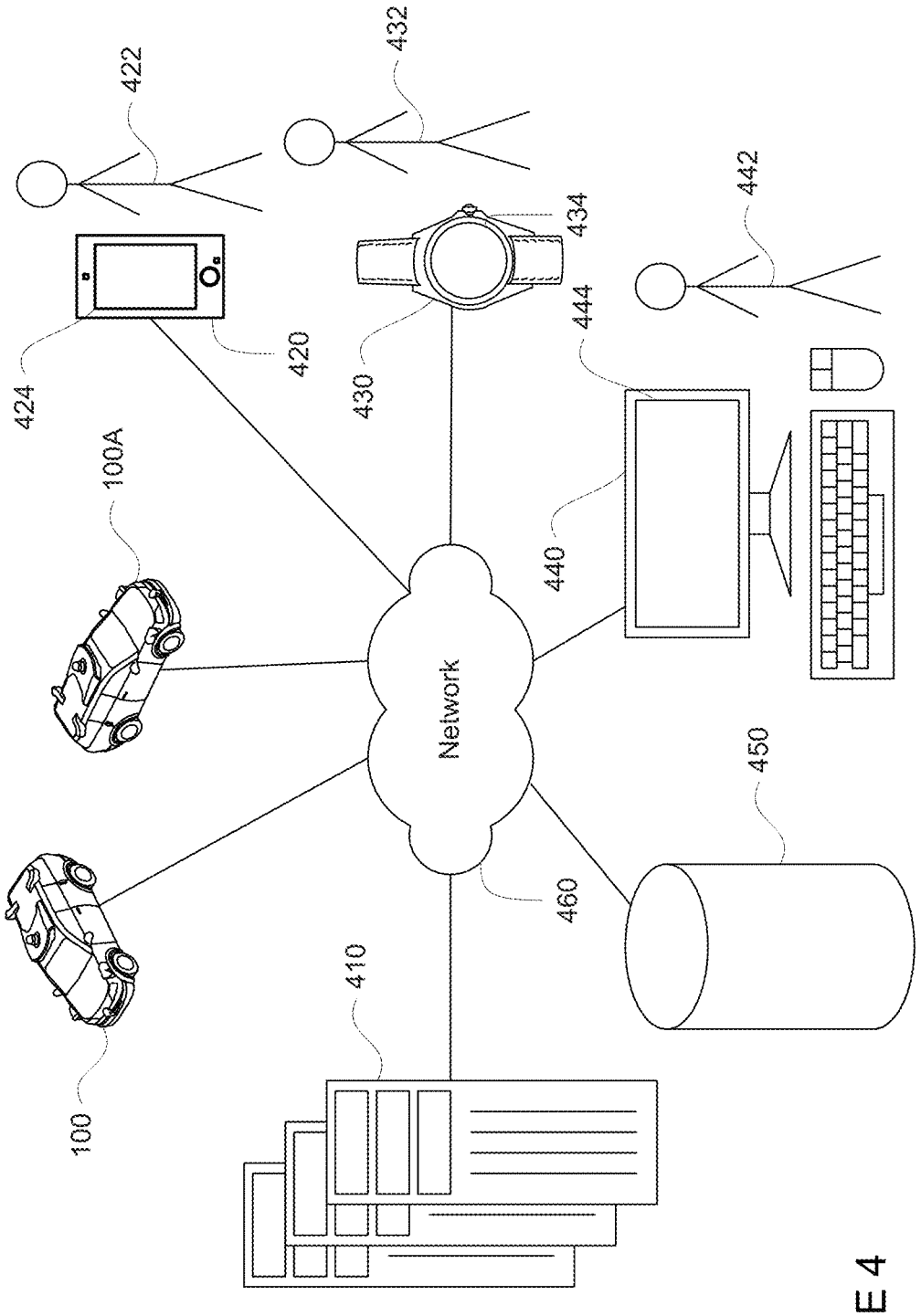


FIGURE 3


422
432
434
442
424
420
430
444
100A
440
Network
450
460
410
100

400

FIGURE 4

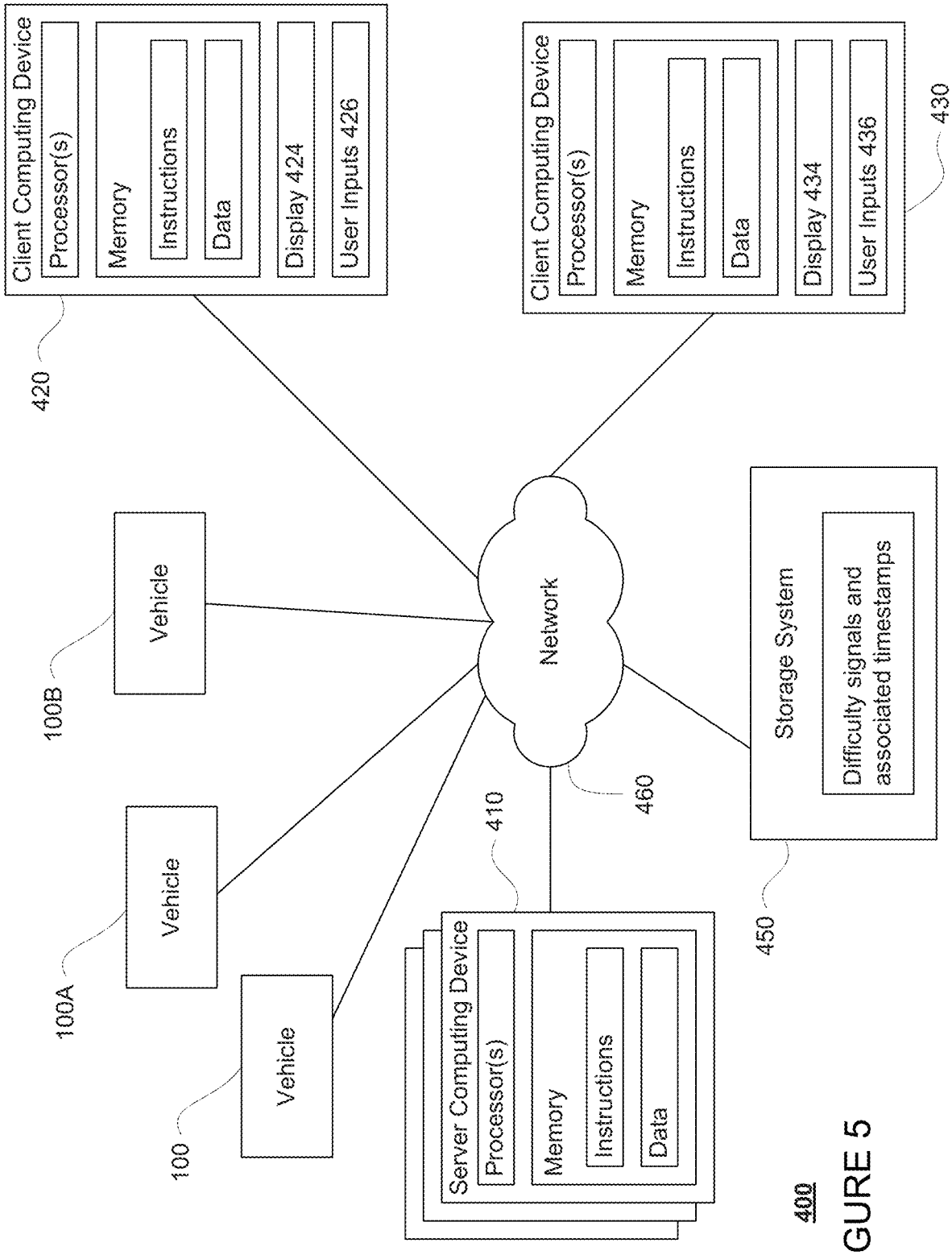

Client Computing Device
Processor(s)
Memory
Instructions
Data
Display 424
User Inputs 426
420
Client Computing Device
Processor(s)
Memory
Instructions
Data
Display 434
User Inputs 436
430
Network
460
Storage System
Difficulty signals and associated timestamps
450
Vehicle
100B
Vehicle
100A
Vehicle
100
Server Computing Device
Processor(s)
Memory
Instructions
Data
410
400

FIGURE 5

600

610 Vehicle Signal ID	620 Signal Type	630 Timestamp	640 Location
11xb2a	Manual control takeover	05:12:2017::13:36:58	05_87_322
05dp4w	Request for remote assistance	06:22:2017::05:23:32	48_23_102
47fgu1e	Extended wait	02:19:2017::00:07:44	51_309_04
89fc3q	Unprotected turn	04:01:2017::18:44:25	38_12_89
00lk5m	Occluded sensor view	09:23:2017::19:25:49	43_155_53
62vb2s	Rapid brake application	10:17:2017::08:57:12	37_64_202
59em6a	Limited sensor view	09:30:2017::11:37:05	57_24_33
78ee4d	Unprotected lane crossing	10:25:2017::15:09:39	39_88_297

FIGURE 6

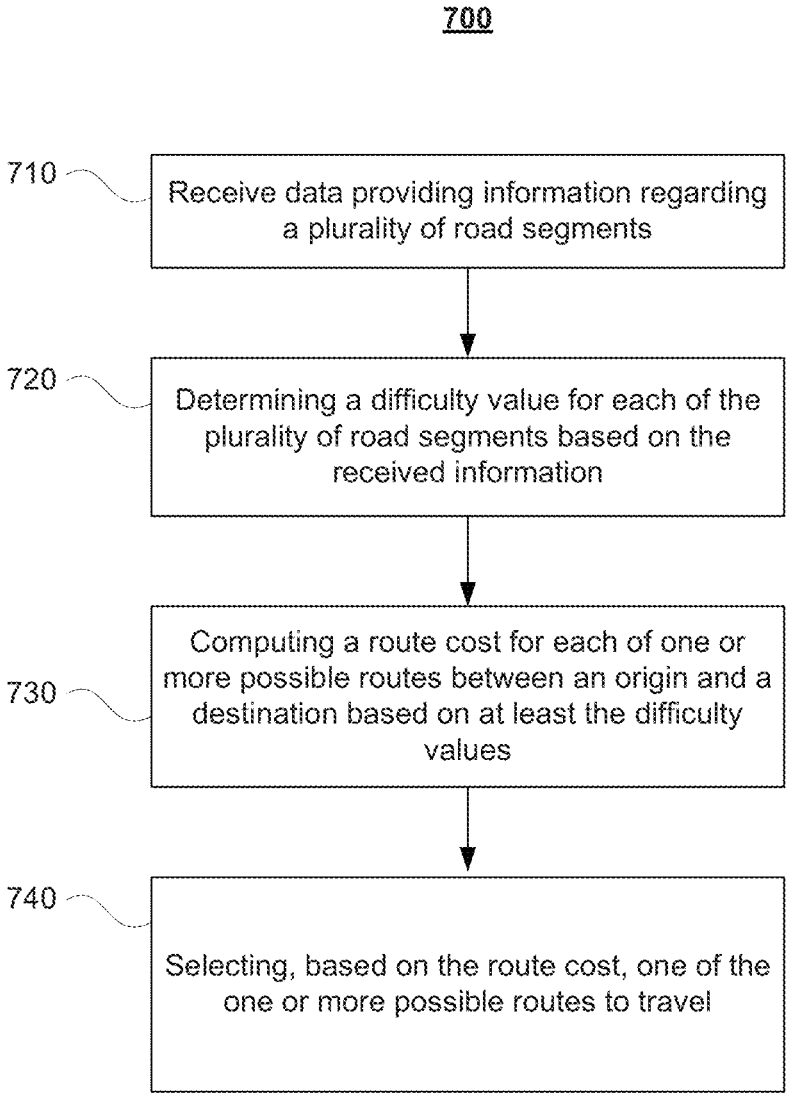

700
710
Receive data providing information regarding a plurality of road segments
720
Determining a difficulty value for each of the plurality of road segments based on the received information
730
Computing a route cost for each of one or more possible routes between an origin and a destination based on at least the difficulty values
740
Selecting, based on the route cost, one of the one or more possible routes to travel

FIGURE 7

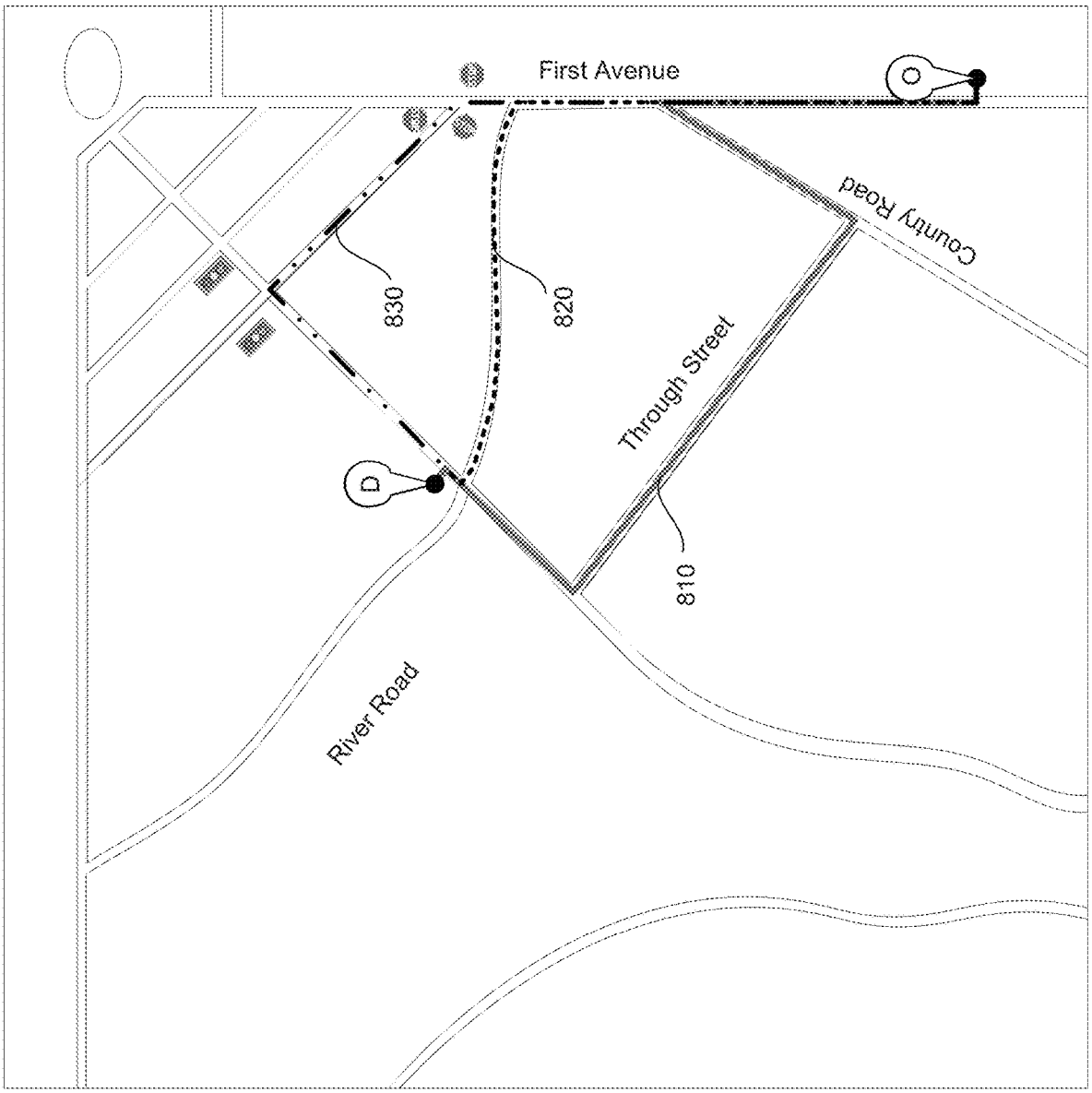

First Avenue
O
Country Road
830
820
Through Street
D
810
River Road

FIGURE 8

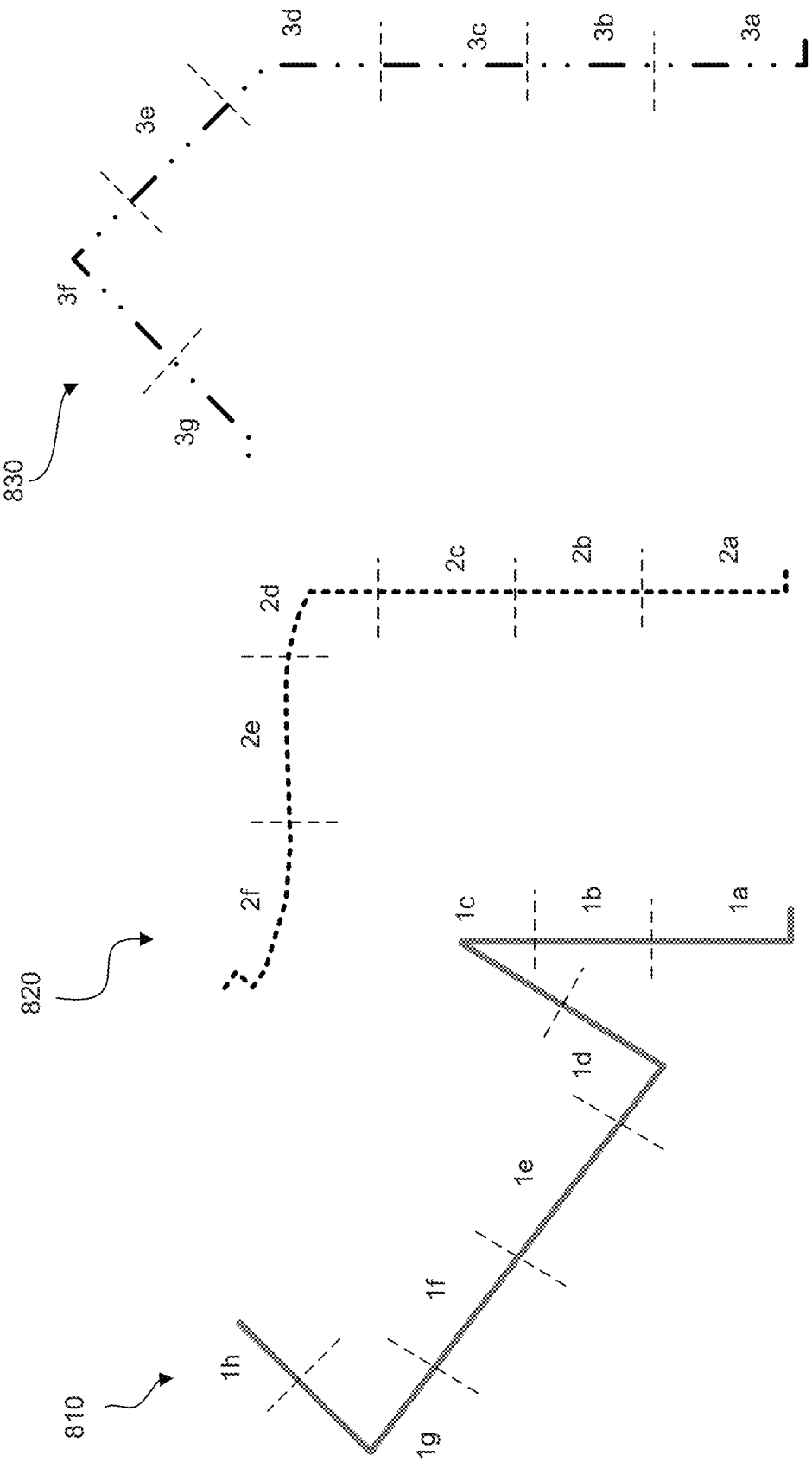

830
3g
3f
3e
3d
3c
3b
3a
820
2f
2e
2d
2c
2b
2a
810
1g
1f
1e
1d
1c
1b
1a
1h

FIGURE 9

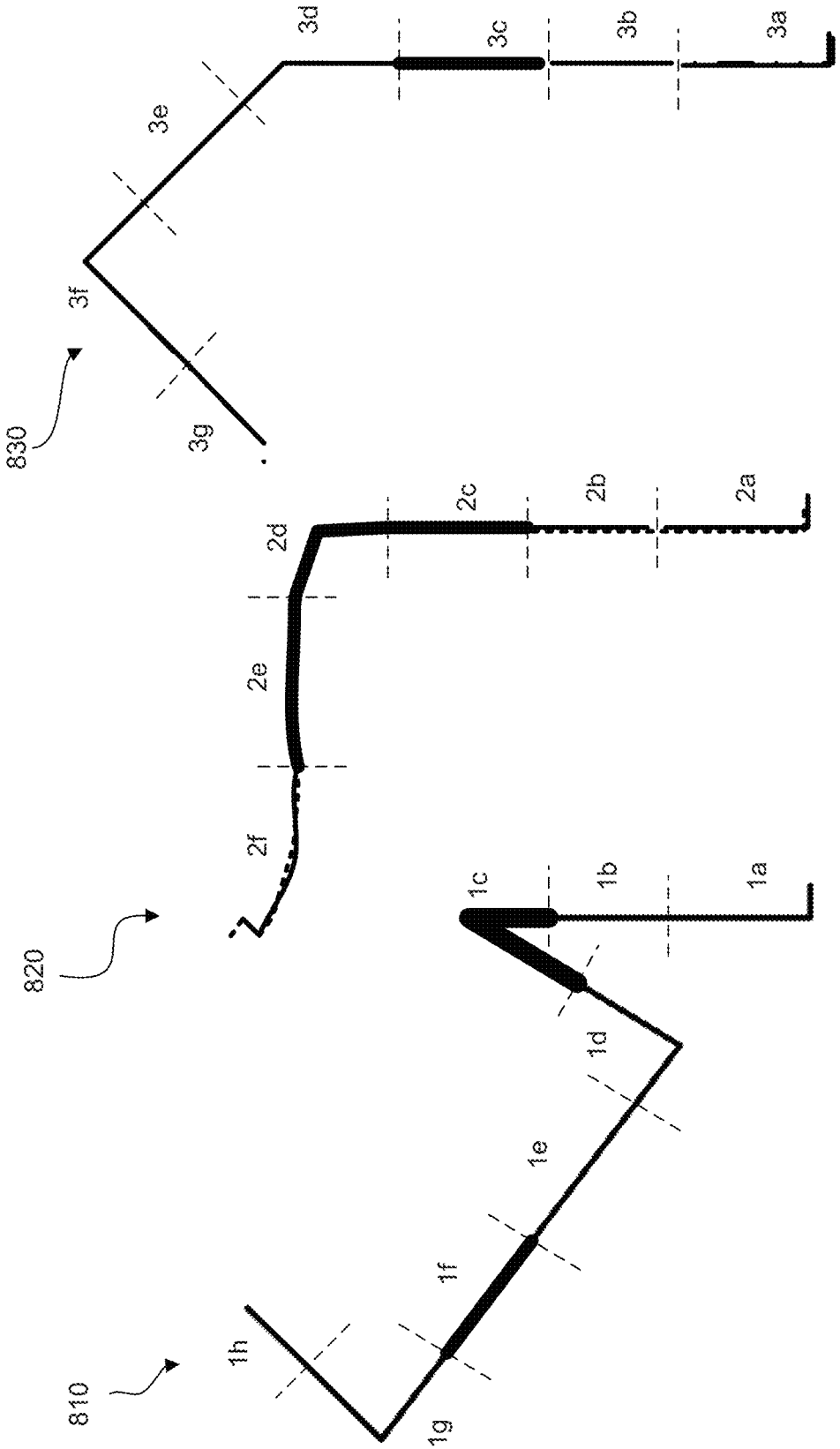

810
820
830
1a
1b
1c
1d
1e
1f
1g
1h
2a
2b
2c
2d
2e
2f
3a
3b
3c
3d
3e
3f
3g

FIGURE 10

Segment	Route 810	Route 820	Route 830
a	1	1	1
b	1	1	1
c	9	5	5
d	1	5	1
e	1	5	1
f	5	1	1
g	1	0	1
h	1	0	0
Total:	20	18	11

FIGURE 11

USING PREDICTION MODELS FOR SCENE DIFFICULTY IN VEHICLE ROUTING

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application is a continuation of U.S. patent application Ser. No. 15/843,223, filed Dec. 15, 2017, the entire disclosure of which is incorporated by reference herein.

BACKGROUND

[0002] Current navigation systems consider factors such as distance and driving time. However, such systems provide only limited options to drivers and passengers of vehicles, and particularly autonomous vehicles. Such autonomous vehicles may operate in a fully autonomous mode where passengers may provide some initial input, such as a pickup or destination location, and the vehicle maneuvers itself to that location. In other instances the vehicles may operate in a semi-autonomous or manual mode, where a human driver controls some or all aspects of the vehicle maneuvering.

BRIEF SUMMARY

[0003] One aspect of the disclosure provides a method of determining a route of travel for an autonomous vehicle. This method includes receiving, at one or more computing devices, data from one or more vehicles, the data providing information regarding a road segment traversed by the one or more vehicles, and the data including one or more difficulty signals from the one or more vehicles. The data is used to determine a difficulty value for the segment, the difficulty value based on difficulty signals from the one or more vehicles indicating disengaging from autonomous mode to a manual mode. In other examples, the difficulty signals may indicate requesting assistance from a remote operator, a number of unprotected turns along the road segment, a portion of a driving area where a field of view of the autonomous vehicle is occluded, a threshold or abnormal number of obstacles, or the like. A route cost is computed for each of one or more possible routes between an origin and a destination, wherein the route cost is based on at least the difficulty values for the road segments along that route, and it is determined which of the one or more possible routes to travel based on the route cost for each of the one or more possible routes. In some examples, the method further includes causing the autonomous vehicle to drive the determined route. The difficulty signals may be correlated with temporal features. For example, computing the difficulty value for a particular segment may include comparing a day or time of expected travel along the particular segment with a day or time correlated with the difficulty signals for the particular segment. Determining the difficulty value may include determining a probability of encountering a difficulty corresponding to at least one of the difficulty signals.

[0004] In some examples, the method may further include computing a segment cost for the road segment, wherein the segment cost is computed based on the difficulty value, distance, and time required to traverse the road segment, wherein the route cost is computed based on the segment cost for the road segments along the route. In such examples, computing the segment cost may include computing a difficulty score based on the difficulty value for the segment, computing a distance score based on the distance of the segment, computing a time score based on the time required to traverse the segment, weighting the difficulty score, the distance score, and the time score, and computing the segment cost as a function of the weighted scores. Weighting the difficulty score, the distance score, and the time score may include setting coefficients for the difficulty score, the distance score, and the time score, wherein the coefficients are modifiable to adjust relative weights. Input may be received from a passenger of the autonomous vehicle, and the coefficients may be adjusted based on the received input from the passenger.

[0005] Another aspect of the disclosure provides a system for determining a route of travel for an autonomous vehicle. The system includes one or more memories, and one or more processors in communication with the one or more memories. The one or more processors may be configured to receive data from one or more vehicles, the data providing information regarding a road segment traversed by the one or more vehicles and including difficulty signals from the one or more vehicles, and determine, based on the data, a difficulty value for the segment, the difficulty value based on difficulty signals from the one or more vehicles indicating disengaging from autonomous mode to a manual mode. In some examples, the difficulty signal may alternatively or additionally indicate requesting assistance from a remote operator, a number of unprotected turns along the road segment, a portion of a driving area where a field of view of the autonomous vehicle is occluded, a number of obstacles on the road segment, etc. The one or more processors may further compute a route cost for each of one or more possible routes between an origin and a destination, wherein the route cost is based on at least the difficulty values for the road segments along that route, and determine, based on the route cost for each of the one or more possible routes, which of the one or more possible routes to travel.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] FIG. **1** is a functional diagram of an example vehicle in accordance with an exemplary embodiment.

[0007] FIG. **2** is an example of map information in accordance with aspects of the disclosure.

[0008] FIG. **3** is an example external view of a vehicle in accordance with aspects of the disclosure.

[0009] FIG. **4** is a pictorial diagram of an example system in accordance with an exemplary embodiment.

[0010] FIG. **5** is a functional diagram of the system of FIG. **4** in accordance with aspects of the disclosure.

[0011] FIG. **6** is an example data structure in accordance with aspects of the disclosure.

[0012] FIG. **7** is an example flow diagram in accordance with aspects of the disclosure.

[0013] FIG. **8** is an example of possible route options associated with the map information of FIG. **2**.

[0014] FIG. **9** is an example of road segments for the possible route options of FIG. **8**.

[0015] FIG. **10** is an example representation of difficulty levels associated with the road segments of FIG. **9**.

[0016] FIG. **11** is an example computation of route costs for the possible route options of FIG. **8**.

DETAILED DESCRIPTION

Overview

[0017] The technology relates generally to using collected data to improve system behavior of an autonomous vehicle. In particular, such collected data can be included in a prediction model and used to determine a route to take based on time, distance, and difficulty of traveling the route.

[0018] Metrics are learned from a number of vehicles, which may include autonomous, semi-autonomous, and manually operated vehicles. These metrics are collected and considered in combination. Such metrics may include, for example, distance, time, and difficulty. The difficulty metric considers factors such as how difficult it was to make a particular turn, whether there are any obstacles such as construction, a number of pedestrian crossings, whether the roadway is rough, narrow, etc. The metrics are learned automatically from logs of previous trips, thus allowing the system to improve itself over time.

[0019] Such metrics may be associated with particular features, such as temporal features (e.g., hour of day, day of week), geographic features (e.g., precise location), and generalizing features (e.g., speed limit, nearby features such as crosswalks, intersections, schools). For example, while a particular turn may be difficult during a time corresponding to morning rush hour, the same turn may be less difficult in early afternoon and far less difficult late at night. By associating such features with the metrics, such features may be considered when determining an optimal route.

[0020] The difficulty metric may be determined based on signals indicating how difficult it is for a vehicle to traverse a particular road segment. Such signals may indicate a probability of disengaging from autonomous driving mode, a probability of being stuck for an unduly long time, traffic density, and the like. According to some examples, a difficulty score is computed for each road segment, and then the scores of all of the road segments of a route are added together. The scores may be based on number of previous disengagements, previous requests for assistance from a remote operator, unprotected left or right turns, whether parts of the driving area are occluded, user complaints, measured discomfort of passengers, fault responses in which the vehicle can no longer operate normally and need to pull over and stop, etc.

[0021] Scores may also be computed for each segment of a route based on an expected amount of time to complete travel along the segment, and a distance of the segment. These scores may be integrated with the difficulty score. For example, difficulty, time, and distance scores may all be used to compute a cost for the road segment. Such cost may be entered into a prediction model and used to determine the best route.

[0022] When determining the best route, dynamic weights can be used to adjust various trade-offs in routing, such as trade-offs between additional driving distance/time and easier driving conditions. Just as one example of a trade-off, a driver may be willing to drive some distance farther to avoid making a difficult left turn. The dynamic weights may be, for example, coefficients, which can be adjusted depending on the scenario. For example, in a first scenario where a customer is in the vehicle, the coefficients may be adjusted to be more conservative, such as providing for an easier though possible longer route. On the other hand, in a second scenario where a test driver is in the vehicle, the coefficients may be adjusted to be more adventurous, such as providing for a quicker and more difficult route.

[0023] Using the above-described model, travel routes may be selected based on not only time and distance, but also difficulty. Because this difficulty information is collected from a number of vehicle logs, it is accurate and also does not place a burden on a user for input.

Example Systems

[0024] As shown in FIG. **1**, a vehicle **100** in accordance with one aspect of the disclosure includes various components. While certain aspects of the disclosure are particularly useful in connection with specific types of vehicles, the vehicle may be any type of vehicle including, but not limited to, cars, trucks, motorcycles, buses, recreational vehicles, etc. The vehicle may have one or more computing devices, such as computing devices **110** containing one or more processors **120**, memory **130** and other components typically present in general purpose computing devices.

[0025] The memory **130** stores information accessible by the one or more processors **120**, including instructions **134** and data **132** that may be executed or otherwise used by the processor **120**. The memory **130** may be of any type capable of storing information accessible by the processor, including a computing device-readable medium, or other medium that stores data that may be read with the aid of an electronic device, such as a hard-drive, memory card, ROM, RAM, DVD or other optical disks, as well as other write-capable and read-only memories. Systems and methods may include different combinations of the foregoing, whereby different portions of the instructions and data are stored on different types of media.

[0026] The instructions **134** may be any set of instructions to be executed directly (such as machine code) or indirectly (such as scripts) by the processor. For example, the instructions may be stored as computing device code on the computing device-readable medium. In that regard, the terms "instructions" and "programs" may be used interchangeably herein. The instructions may be stored in object code format for direct processing by the processor, or in any other computing device language including scripts or collections of independent source code modules that are interpreted on demand or compiled in advance. Functions, methods and routines of the instructions are explained in more detail below.

[0027] The data **132** may be retrieved, stored or modified by processor **120** in accordance with the instructions **134**. For instance, although the claimed subject matter is not limited by any particular data structure, the data may be stored in computing device registers, in a relational database as a table having a plurality of different fields and records, XML documents or flat files. The data may also be formatted in any computing device-readable format.

[0028] The one or more processor **120** may be any conventional processors, such as commercially available CPUs. Alternatively, the one or more processors may be a dedicated device such as an ASIC or other hardware-based processor. Although FIG. **1** functionally illustrates the processor, memory, and other elements of computing devices **110** as being within the same block, it will be understood by those of ordinary skill in the art that the processor, computing device, or memory may actually include multiple processors, computing devices, or memories that may or may not be stored within the same physical housing. For example,

memory may be a hard drive or other storage media located in a housing different from that of computing devices **110**. Accordingly, references to a processor or computing device will be understood to include references to a collection of processors or computing devices or memories that may or may not operate in parallel.

[0029] Computing devices **110** may include all of the components normally used in connection with a computing device such as the processor and memory described above as well as a user input **150** (e.g., a mouse, keyboard, touch screen and/or microphone) and various electronic displays (e.g., a monitor having a screen or any other electrical device that is operable to display information). In this example, the vehicle includes an internal electronic display **152** as well as one or more speakers **154** to provide information or audio visual experiences. In this regard, internal electronic display **152** may be located within a cabin of vehicle **100** and may be used by computing devices **110** to provide information to passengers within the vehicle **100**.

[0030] Computing devices **110** may also include one or more wireless network connections **156** to facilitate communication with other computing devices, such as the client computing devices and server computing devices described in detail below. The wireless network connections may include short range communication protocols such as Bluetooth, Bluetooth low energy (LE), cellular connections, as well as various configurations and protocols including the Internet, World Wide Web, intranets, virtual private networks, wide area networks, local networks, private networks using communication protocols proprietary to one or more companies, Ethernet, WiFi and HTTP, and various combinations of the foregoing.

[0031] In one example, computing devices **110** may be control computing devices of an autonomous driving computing system or incorporated into vehicle **100**. The autonomous driving computing system may capable of communicating with various components of the vehicle in order to control the movement of vehicle **100** according to primary vehicle control code of memory **130**. For example, returning to FIG. **1**, computing devices **110** may be in communication with various systems of vehicle **100**, such as deceleration system **160**, acceleration system **162**, steering system **164**, signaling system **166**, navigation system **168**, positioning system **170**, perception system **172**, and power system **174** (i.e. the vehicle's engine or motor) in order to control the movement, speed, etc. of vehicle **100** in accordance with the instructions **134** of memory **130**. Again, although these systems are shown as external to computing devices **110**, in actuality, these systems may also be incorporated into computing devices **110**, again as an autonomous driving computing system for controlling vehicle **100**.

[0032] As an example, computing devices **110** may interact with one or more actuators of the deceleration system **160** and/or acceleration system **162**, such as brakes, accelerator pedal, and/or the engine or motor of the vehicle, in order to control the speed of the vehicle. Similarly, one or more actuators of the steering system **164**, such as a steering wheel, steering shaft, and/or pinion and rack in a rack and pinion system, may be used by computing devices **110** in order to control the direction of vehicle **100**. For example, if vehicle **100** is configured for use on a road, such as a car or truck, the steering system may include one or more actuators to control the angle of wheels to turn the vehicle. Signaling system **166** may be used by computing devices **110** in order to signal the vehicle's intent to other drivers or vehicles, for example, by lighting turn signals or brake lights when needed.

[0033] Navigation system **168** may be used by computing devices **110** in order to determine and follow a route to a location. In this regard, the navigation system **168** and/or data **132** may store detailed map information, e.g., highly detailed maps identifying the shape and elevation of roadways, lane lines, intersections, crosswalks, speed limits, traffic signals, buildings, signs, real time traffic information, vegetation, or other such objects and information.

[0034] FIG. **2** is an example of map information **200** for a geographic area, which includes a plurality of roadways. The map information **200** may include information identifying the shape, location, and other characteristics of features such as lane lines **210**, **212**, **214**, traffic signal lights **220**, **222**, stop signs **250**, **251**, **252**, and other features not shown, such as crosswalks, sidewalks, and yield signs **260**. The map information **200** may further include distance information for each of the plurality of roadways, and regulations for the various roadways, such as speed limits, prohibition of maneuvers, or the like. Just as one example of a prohibited maneuver, vehicles may be prevented from turning right on a red light between 8 am-4 pm weekdays. According to some examples, the map information may also include traffic information, such as historical traffic information. Such traffic information may be stored in association with temporal limitations, for example, indicating times of days/weeks when traffic is heavier.

[0035] Although the map information is depicted herein as an image-based map, the map information need not be entirely image based (for example, raster). For example, the map information may include one or more roadgraphs or graph networks of information such as roads, lanes, intersections, and the connections between these features. Each feature may be stored as graph data and may be associated with information such as a geographic location and whether or not it is linked to other related features, for example, a stop sign may be linked to a road and an intersection, etc. In some examples, the associated data may include grid-based indices of a roadgraph to allow for efficient lookup of certain roadgraph features.

[0036] Positioning system **170** may be used by computing devices **110** in order to determine the vehicle's relative or absolute position on a map or on the earth. For example, the position system **170** may include a GPS receiver to determine the device's latitude, longitude and/or altitude position. Other location systems such as laser-based localization systems, inertial-aided GPS, or camera-based localization may also be used to identify the location of the vehicle. The location of the vehicle may include an absolute geographical location, such as latitude, longitude, and altitude as well as relative location information, such as location relative to other cars immediately around it which can often be determined with less noise that absolute geographical location.

[0037] The positioning system **170** may also include other devices in communication with computing devices **110**, such as an accelerometer, gyroscope or another direction/speed detection device to determine the direction and speed of the vehicle or changes thereto. By way of example only, an acceleration device may determine its pitch, yaw or roll (or changes thereto) relative to the direction of gravity or a plane perpendicular thereto. The device may also track increases or decreases in speed and the direction of such changes. The

device's provision of location and orientation data as set forth herein may be provided automatically to the computing devices **110**, other computing devices and combinations of the foregoing.

[0038] The perception system **172** also includes one or more components for detecting objects external to the vehicle such as other vehicles, obstacles in the roadway, traffic signals, signs, trees, etc. For example, the perception system **172** may include lasers, sonar, radar, cameras and/or any other detection devices that record data which may be processed by computing device **110**. In the case where the vehicle is a passenger vehicle such as a minivan, the minivan may include a laser or other sensors mounted on the roof or other convenient location. For instance, FIG. **3** is an example external view of vehicle **100**. In this example, roof-top housing **310** and dome housing **312** may include a lidar sensor as well as various cameras and radar units. In addition, housing **320** located at the front end of vehicle **100** and housings **330**, **332** on the driver's and passenger's sides of the vehicle may each store a lidar sensor. For example, housing **330** is located in front of driver door **360**. Vehicle **100** also includes housings **340**, **342** for radar units and/or cameras also located on the roof of vehicle **100**. Additional radar units and cameras (not shown) may be located at the front and rear ends of vehicle **100** and/or on other positions along the roof or roof-top housing **310**.

[0039] The computing devices **110** may control the direction and speed of the vehicle by controlling various components. By way of example, computing devices **110** may navigate the vehicle to a destination location completely autonomously using data from the detailed map information and navigation system **168**. Computing devices **110** may use the positioning system **170** to determine the vehicle's location and perception system **172** to detect and respond to objects when needed to reach the location safely. In order to do so, computing devices **110** may cause the vehicle to accelerate (e.g., by increasing fuel or other energy provided to the engine by acceleration system **162**), decelerate (e.g., by decreasing the fuel supplied to the engine, changing gears, and/or by applying brakes by deceleration system **160**), change direction (e.g., by turning the front or rear wheels of vehicle **100** by steering system **164**), and signal such changes (e.g., by lighting turn signals of signaling system **166**). Thus, the acceleration system **162** and deceleration system **160** may be a part of a drivetrain that includes various components between an engine of the vehicle and the wheels of the vehicle. Again, by controlling these systems, computing devices **110** may also control the drivetrain of the vehicle in order to maneuver the vehicle autonomously.

[0040] Computing device **110** of vehicle **100** may also receive or transfer information to and from other computing devices, such as to other vehicles, control centers, databases, user devices, etc. FIGS. **4** and **5** are pictorial and functional diagrams, respectively, of an example system **400** that includes a plurality of computing devices **410**, **420**, **430**, **440** and a storage system **450** connected via a network **460**. System **400** also includes vehicle **100**, and vehicles **100**A, **100**B which may be configured the same as or similarly to vehicle **100**. Although only a few vehicles and computing devices are depicted for simplicity, a typical system may include significantly more.

[0041] As shown in FIG. **4**, each of computing devices **410**, **420**, **430**, **440** may include one or more processors, memory, data and instructions. Such processors, memories, data and instructions may be configured similarly to one or more processors **120**, memory **130**, data **132**, and instructions **134** of computing device **110**.

[0042] The network **460**, and intervening nodes, may include various configurations and protocols including short range communication protocols such as Bluetooth, Bluetooth LE, the Internet, World Wide Web, intranets, virtual private networks, wide area networks, local networks, private networks using communication protocols proprietary to one or more companies, Ethernet, WiFi and HTTP, and various combinations of the foregoing. Such communication may be facilitated by any device capable of transmitting data to and from other computing devices, such as modems and wireless interfaces.

[0043] In one example, one or more computing devices **110** may include one or more server computing devices having a plurality of computing devices, e.g., a load balanced server farm, that exchange information with different nodes of a network for the purpose of receiving, processing and transmitting the data to and from other computing devices. For instance, one or more computing devices **410** may include one or more server computing devices that are capable of communicating with computing device **110** of vehicle **100** or a similar computing device of vehicle **100**A, **100**B as well as computing devices **420**, **430**, **440** via the network **460**. For example, vehicles **100**, **100**A, **100**B may be a part of a fleet of vehicles that can be dispatched by server computing devices to various locations. In this regard, the server computing devices **410** may function as a dispatching system. In addition, the vehicles of the fleet may periodically send the server computing devices location information provided by the vehicle's respective positioning systems as well as other information relating to the status of the vehicles discussed further below, and the one or more server computing devices may track the locations and status of each of the vehicles of the fleet.

[0044] In addition, server computing devices **410** may use network **460** to transmit and present information to a user, such as user **422**, **432**, **442** on a display, such as displays **424**, **434**, **444** of computing devices **420**, **430**, **440**. In this regard, computing devices **420**, **430**, **440** may be considered client computing devices.

[0045] As shown in FIG. **4**, each client computing device **420**, **430**, **440** may be a personal computing device intended for use by a user **422**, **432**, **442**, and have all of the components normally used in connection with a personal computing device including a one or more processors (e.g., a central processing unit (CPU)), memory (e.g., RAM and internal hard drives) storing data and instructions, a display such as displays **424**, **434**, **444** (e.g., a monitor having a screen, a touch-screen, a projector, a television, or other device that is operable to display information), and user input devices **426**, **436**, **446** (e.g., a mouse, keyboard, touchscreen or microphone). The client computing devices may also include a camera for recording video streams, speakers, a network interface device, and all of the components used for connecting these elements to one another.

[0046] Although the client computing devices **420**, **430**, and **440** may each comprise a full-sized personal computing device, they may alternatively comprise mobile computing devices capable of wirelessly exchanging data with a server over a network such as the Internet. By way of example only, client computing device **420** may be a mobile phone or a

device such as a wireless-enabled PDA, a tablet PC, a wearable computing device or system, or a netbook that is capable of obtaining information via the Internet or other networks. In another example, client computing device **430** may be a wearable computing system, shown as a wrist-watch as shown in FIG. **4**. As an example the user may input information using a small keyboard, a keypad, microphone, using visual signals with a camera, or a touch screen.

[0047] As with memory **130**, storage system **450** can be of any type of computerized storage capable of storing information accessible by the server computing devices **410**, such as a hard-drive, memory card, ROM, RAM, DVD, CD-ROM, write-capable, and read-only memories. In addition, storage system **450** may include a distributed storage system where data is stored on a plurality of different storage devices which may be physically located at the same or different geographic locations. Storage system **450** may be connected to the computing devices via the network **460** as shown in FIGS. **4** and **5**, and/or may be directly connected to or incorporated into any of the computing devices **110**, **410**, **420**, **430**, etc.

[0048] Storage system **450** may store various types of information as described in more detail below. This information may be retrieved or otherwise accessed by a server computing device, such as one or more server computing devices **410**, in order to perform some or all of the features described herein. As an example, the information of storage system **450** may include reports from other vehicles regarding difficulties encountered during previous drives. Such difficulties may include, for example, obstructed sensors views, obstructed roadways, unprotected turns, rough terrain, a need for a human driver to take over control of the vehicle, requests for assistance, or any other difficulties. The reports of such difficulties may be stored in association with metadata which identifies what the particular difficulty was and a time the difficulty occurred. In some examples, the reports may further be stored in association with a value indicating a level of severity of the difficulty.

[0049] FIG. **6** provides just one example of the type and arrangement of information that may be stored in the storage system **450**. As shown, chart **600** includes a number of columns listing vehicle signal identifiers **610**, signal type **620**, timestamps **630**, and location **640**. It should be understood that additional information may also be listed, and that some of the columns may be omitted. Just as one example, the chart **600** may also store an associated difficulty value, for each signal, indicating a level of difficulty imposed by the driving environment. It should further be understood that the columns and rows are the chart **600** may be sorted in any order, or that a different organizational structure may be used altogether.

[0050] In the example chart **600**, the vehicle signal identifier **610** may identify a specific signal sent by a vehicle. Each unique signal may have a unique identifier. This identifier may be used to distinguish particular signals and to facilitate identification of particular information. The signal identifier may be included with the signal sent by the vehicle, assigned by the server computing device **410**, or composed from some combination of information from the vehicle, the serer **410**, or other sources. The signals in the chart **600** may be from one vehicle or from a plurality of different vehicles.

[0051] The signal type **620** indicates a type of difficulty encountered by the vehicle when sending the signal. A few example types of difficulties are listed in the chart **600**, including a need for a human driver to takeover control of the vehicle manually, a request for assistance from a remote operator, an extended wait (e.g., to make a turn or other maneuver), an unprotected turn, an occluded sensor view, a rapid brake application, a limited sensor view, and an unprotected lane crossing. Further examples include user complaints, measured discomfort of passengers, fault responses, etc. Other types of signals indicating a driving difficulty resulting from a driving environment may also be stored, and multiple signals of the same type may be stored.

[0052] The timestamps **630** may indicate a time the signal was sent by the vehicle. This information may be particularly useful for difficulties that are time dependent. For example, it may be determined from the signals that extended wait times to make a turn at a particular location are only experienced between 2 pm-4 pm on school days. As another example, a sensor view may only be occluded during spring and summer months, before foliage drops from a tree occluding the view. Such temporal patterns may be recognized using machine learning techniques. The timestamps **630** may also be used to update the information. For example, signals older than a predetermined threshold, such as several months or days, may be deleted or may be attributed a lower weight when determining an associated level of difficulty. While the timestamp information as shown in indicated by month:day:year::hour:minute:second, it should be understood that any other convention for indicating time may be used.

[0053] The location information **640** may identify a location from which the signal was transmitted. In the example shown, the location information is indicated by a regional identifier, a street identifier, and a segment identifier, also other formats may be used. The regional identifier may include a value indicating a particular city, state, country, or other region. The street identifier may include a value or other indicia corresponding to a particular roadway which is divided into segments for purposes of analysis. Accordingly, the segment identifier indicates a particular segment of the street. It should be understood that the location format used in chart **600** is merely an example, and that any of a variety of other formats may be used, such as geographic coordinates (e.g., latitude, longitude, altitude) or other descriptors.

[0054] In some examples, the storage system **450** may also store other information relating to difficulty of traversing a driving environment, such as a model based on the information regarding the difficulty signals. For example, the model may be a prediction model identifying which road segments are likely to present difficulty, such as requiring transition from autonomous mode to manual mode, at a given time.

[0055] The storage system **450** may also store information which can be provided to client computing devices for display to a user. For instance, the storage system **450** may store predetermined distance information for determining an area at which a vehicle is likely to stop for a given pickup or destination location. The storage system **450** may also store graphics, icons, and other items which may be displayed to a user.

[0056] The vehicle **100** may use the information from the storage system **450** to determine a route for the vehicle **100** to travel. For example, given a point of origin and a destination, several different routes may be available to the vehicle **100**. However, some routes may be more difficult to

travel than others. The information regarding difficulty of traversing the driving environments stored in the storage system **450** may be used to determine which route will present the least amount of difficulty the given time. In some examples, such difficulty information may be considered in combination with other travel information, such as time, distance, tolls, etc. The time information may take into account traffic, speed limits, and other information affecting driving time. According to some examples, the difficulty information and other travel information may be weighted. For example, a preference for easier travel despite longer travel time may be accommodated by adjusting weights accorded to difficulty information and time information, respectively. A preference for a shortest distance despite potentially difficult conditions may be accommodated by adjusting the weights accorded to distance and difficulty, respectively.

Example Methods

[0057] In addition to the operations described above and illustrated in the figures, various operations will now be described. It should be understood that the following operations do not have to be performed in the precise order described below. Rather, various steps can be handled in a different order or simultaneously, and steps may also be added or omitted.

[0058] FIG. **7** presents a flow diagram **700** illustrating an example method of selecting a route based on difficulty of driving environment. In block **710**, data is received, the data providing information regarding a plurality of road segments. The information may include signals from one or more vehicles that have traversed the road segments, such as the signals discussed above in connection with FIG. **6**. The signals may indicate a difficulty associated with traversing the road segment, wherein such difficulty is a result of the driving environment. Examples of such difficulties include requiring manual takeover, requesting assistance from remote operators, unprotected maneuvers, limited/occluded/obstructed view, or the like. In some examples, the difficulties may be signaled by user complaints, measured passenger discomfort, fault responses in which the vehicle can no longer operate normally and needs to pull over and stop, etc. Passenger discomfort may be measured by, for example, survey responses, changes in passenger heart rate, temperature, or other vitals, changes in the passenger's seating position, adjustment of controls, etc.

[0059] In block **720**, a difficulty value is determined for each of the plurality of road segments based on the received information. For example, the difficulty value may be a score or other value which may be used to compare a level of difficulty associated with traversing a first road segment to a level of difficulty of traversing a second road segment. For example, each different type of difficulty indicated by the vehicle signals may have a value. In some instances, the value for one type of difficulty may be higher than the value of another type. For example, the difficulty value associated with a request for assistance from a remote operator may be different than a difficulty value associated with an unprotected turn. In other examples, the difficulty values may be varied based on other information, such that the values for two signals having a same type are different. These difficulty values may be used to compute a difficulty value for the road segment. For example, the difficulty values of the various signals may be factored into a predictive model, which predicts a difficulty that will be encountered on a road segment if traveled. Such prediction may be time correlated, such that the predicted difficulty level may vary for a particular road segment depending on a time of day, week, season, or other temporal information. For a particular route segment, multiple difficulties may be predicted to occur at a particular time of travel. Accordingly, the difficulty value may be computed as a function of the multiple predicted difficulties.

[0060] In block **730**, a route cost for each of one or more possible routes between an origin and a destination is computed based on the difficulty values associated with the plurality of road segments. For example, the route cost may be a total of the difficulty values for each road segment along the route. In some examples, the route cost may also factor in other travel variables, such as time, distance, traffic, etc.

[0061] In block **740**, a route of travel for the autonomous vehicle is selected based on the computed route costs. Accordingly, a control system of the autonomous vehicle may cause the vehicle to travel the selected route.

[0062] FIG. **8** illustrates an example of multiple possible routes **810**, **820**, **830** between an origin O and a destination D. The routes **810-830** are shown relative to map information, such as the map information **200** of FIG. **2**.

[0063] FIG. **9** illustrates the routes **810**, **820**, **830**, wherein each route includes a plurality of road segments. For example, a first route **810** includes segments **1***a*-**1***h*, second route **820** includes segments **2***a*-**2***f*, and third route **830** includes segments **3***a*-**3***g*. The road segments may be defined for each roadway indicated on a map, or only for each possible route between an origin and a destination. The road segments may divide the roadway or route into any number of discrete subportions for analysis. For example, additional smaller segments may be used for analysis with finer granularity of potential difficulties, while fewer larger segments may be used for faster analysis consuming less memory and computing resources. In some examples, the road segments may different in size from one segment to the next. The road segments may be designated based on any factors, such as absolute distance, distance between turns, estimated travel time, etc.

[0064] FIG. **10** illustrates the possible routes **810-830** showing relative difficulty of each road segment. In this example, increased difficulty is represented by increased line thickness. Along route **810**, segments **1***a* and **1***b* have relatively low difficulty, while segment **1***c* has a very high associated level of difficulty. This may be attributed to the difficulty of maneuvering the vehicle to make such a sharp left-hand turn. Other factors may include visibility while making the turn and whether the turn is unprotected. For example, if other vehicles traveling along the roadway onto which the vehicle is turning do not have to stop or yield while the vehicle is making the sharp left-hand turn, the turn has increased difficulty. In the example shown, other difficult segments of route **810** include segment **1***f*. This may be attributed to factors other than turning, such as high pedestrian traffic, a rough terrain, limited visibility, or the like.

[0065] Along route **820**, segments **2***a* and **2***b* are also shown to have low relative difficulty. Because these segments corresponds to the same portions of roadway as the segments **1***a* and **1***b* of route **810**, it would be expected that they have the same difficulty level. Segments **2***c*-**2***e*, however, have a high level of associated difficulty, though still lower than that of segment **1***c*. Such difficulty may be a result

of having to maneuver around vehicles attempting to make the turn of segment **1***c*, waiting to make the unprotected left turn of segment **2***d*, or any of a plurality of other possibilities. The difficulty of segment **2***e* may be a result of other driving conditions, such as an obstructed view (e.g., from buildings, signs, foliage, parked cars, or any other objects), roadway construction, etc.

[0066] Along route **830**, only segment **3***c* is shown as having a level of associated difficulty. This difficulty level corresponds to that of segment **2***c*, and is likely a result of the same driving conditions. While segment **3***d* includes a left-hand turn, such turn may have a low level of associated difficulty because it is a protected turn in that vehicles traveling in opposing directions will stop pursuant to the stop signs **251**, **252**.

[0067] FIG. **11** illustrates an example calculation of route cost for each of possible routes **810**, **820**, **830**. For each route segment, a difficulty value attributed to that segment is listed. While in the example of FIG. **10** the difficulty was indicated graphically, in FIG. **11** it is represented by a numerical value. It should be understood, however, that any convention for indicating the difficulty level may be used. Consistent with FIG. **10**, segment **1***c* of the route **10** is indicated to have a highest associated difficulty level. Other segments of relatively increased difficulty includes segment **1***f* of route **810**, segments **2***c*-**2***e* of route **820**, and segment **3***c* of route **830**. Because routes **820** do not have a segment corresponding to h, those values are set to 0. The values for each segment along the routes may be summed to derive a total difficulty value for the route. For example, route **810**—has a total difficulty value of 20, route **820** has a total difficulty value of 18, and route **830** has a total difficulty value of 11. Accordingly, if solely considering difficulty, route **830** may be the most desirable route with a lowest route cost of 11. However, as mentioned above, in some examples other factors may be considered in computing route cost, such as distance, time, etc.

[0068] The foregoing examples describe an advantageous method of determining a travel route, because it expands traditional consideration of factors such as time and distance to further consider driving/riding experience. Passengers of autonomous vehicle may thus have an option of selecting a smoother or less risky drive, despite that it may take longer than other routes. This may be particularly preferable for passengers that want to read, work, or relax during the trip.

[0069] While a number of examples of different types of difficulty that may be encountered by a vehicle are described above, it should be understood that any number of further types of difficulty may also be factored into a route cost computation. For example, on particular streets, garbage collection may occur at predetermined times, such as between 7 am-8 am every Tuesday and Friday. During garbage collection times, the slow moving and frequently stopping garbage truck may present an obstacle for a vehicle traveling on that street. Moreover, presence of sanitation workers collecting the garbage requires additional caution in operation of the vehicle traveling on that street. Accordingly, difficulty signals from previous or historic drives along that street may indicate a number of obstacles (e.g., garbage truck, garbage cans, sanitation workers, etc.) above a predetermined threshold. The difficulty signals may also indicate slower driving times, increased wait times, an increased number of applications of a braking system, unexpected maneuvers (e.g., swerving), etc. Any or all of these difficulty signals may be used in computation of a cost for the particular street during the predetermined garbage collection times.

[0070] Just by way of further example, a given roadway may be near a school. As such, during school hours, and particularly during times of arrival at and dismissal from the school, an increased amount of pedestrians may be walking on or crossing the given roadway. Accordingly, during those school hours, an increased number of obstacles may be presented, requiring additional caution by vehicles traveling on the given roadway. The difficulty signals from previous vehicles having traveled the given road may indicate the presence of such additional obstacles during times corresponding to school hours. Such additional obstacles may have in some cases resulted in disengagement or a request to a remote operator for assistance. These difficulty signals indicating the presence of such additional obstacles during the particular times on the given roadway may also be used to compute a cost for the traveling the given roadway.

[0071] Unless otherwise stated, the foregoing alternative examples are not mutually exclusive, but may be implemented in various combinations to achieve unique advantages. As these and other variations and combinations of the features discussed above can be utilized without departing from the subject matter defined by the claims, the foregoing description of the embodiments should be taken by way of illustration rather than by way of limitation of the subject matter defined by the claims. In addition, the provision of the examples described herein, as well as clauses phrased as "such as," "including" and the like, should not be interpreted as limiting the subject matter of the claims to the specific examples; rather, the examples are intended to illustrate only one of many possible embodiments. Further, the same reference numbers in different drawings can identify the same or similar elements.

1. A method, comprising:

receiving, by one or more computing devices, information from one or more vehicles configured to operate in an autonomous driving mode, the information identifying different types of difficulties encountered by the one or more vehicles while operating along one or more routes in the autonomous driving mode, wherein the different types of difficulties include at least one of a sensor difficulty or a roadway condition impacting autonomous driving;

storing the information in memory along with metadata that identifies one or more details regarding each one of the different types of difficulties; evaluating, by the one or more computing devices, the stored information and the metadata in view of a plurality of route options; and

selecting, by the one or more computing devices, a given one of the plurality of route options for use by a vehicle when operating in the autonomous driving mode.

2. The method of claim **1**, wherein the information includes a vehicle signal identifier for each one of the different types of difficulties that identifies a specific signal sent by a respective one of the one or more vehicles.

3. The method of claim **2**, wherein the vehicle signal identifier is either (i) included with the specific signal sent by the respective vehicle, (ii) assigned by the one or more computing devices, or (iii) composed from a combination of information from the respective vehicle and the one or more computing devices.

4. The method of claim **1**, wherein the metadata identifies at least one of a time each one of the different types of difficulties was encountered, or location information identifying a location at which each one of the different types of difficulties was encountered.

5. The method of claim **4**, wherein the location information includes at least one of a regional identifier, a street identifier, or a road segment identifier.

6. The method of claim **4**, wherein the location information includes geographical coordinates.

7. The method of claim **1**, wherein the metadata further includes a difficulty value for each one of the different types of difficulties that indicates a level of difficulty imposed by a driving environment.

8. The method of claim **7**, further comprising weighting the difficulty values based on temporal information associated with each one of the different types of difficulties.

9. The method of claim **1**, further comprising generating a prediction model identifying which road segments are likely to present difficulty based on the information stored in the memory.

10. The method of claim **1**, wherein the information stored in the memory includes a signal type indicating a type of difficulty encountered by each of the one or more vehicles that transmitted corresponding information.

11. The method of claim **10**, wherein the type of difficulty is one of an extended wait to make a turn or other maneuver, an unprotected turn, an occluded sensor view, a rapid brake application, a limited sensor view, an unprotected lane crossing, or a driving difficulty resulting from a driving environment.

12. The method of claim **10**, wherein the type of difficulty is one of a user complaint, measured passenger discomfort, a fault response, a need for a human driver to take manual control, or a request for assistance from a remote operator.

13. The method of claim **1**, further comprising transmitting the selected route option to a particular vehicle for operating in the autonomous driving mode.

14. A method of operating a vehicle in an autonomous driving mode, the method comprising:

controlling, by one or more processors, driving operations of the vehicle in the autonomous driving mode;

receiving, by the one or more processors, sensor information from a perception system of the vehicle regarding objects or conditions in an external environment of the vehicle;

generating, by the one or more processors, information regarding a difficulty experienced while operating in the autonomous driving mode, the information identifying at least one type of difficulty encountered by the vehicle while operating along one or more routes in the autonomous driving mode, wherein the at least one type of difficulty includes at least one of a sensor difficulty for a sensor of the perception system or a roadway condition impacting autonomous driving; and

transmitting the generated information to a remote system.

15. The method of claim **14**, wherein the generated information includes a vehicle signal identifier for each one of the at least one type of difficulty.

16. The method of claim **14**, wherein the generated information includes one or both of a time or a location at which each of the at least one type of difficulty was encountered.

17. The method of claim **16**, wherein the location includes at least one of a regional identifier, a street identifier, or a road segment identifier.

18. The method of claim **14**, wherein the at least one type of difficulty encountered by the vehicle is one of an extended wait to make a turn or other maneuver, an unprotected turn, an occluded sensor view, a rapid brake application, a limited sensor view, an unprotected lane crossing, or a driving difficulty resulting from a driving environment.

19. The method of claim **14**, wherein the at least one type of difficulty encountered by the vehicle is one of a user complaint, measured passenger discomfort, a fault response, a need for a human driver to take manual control, or a request for assistance from a remote operator.

20. The method of claim **14**, further comprising:

receiving, from the remote system, a routing signal based on difficulty information obtained from one or more other vehicles; and

controlling, by the one or more processors, another driving operation of the vehicle in the autonomous driving mode according to the received routing signal.

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