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(54) **DETAILED MAP FORMAT FOR AUTONOMOUS DRIVING**

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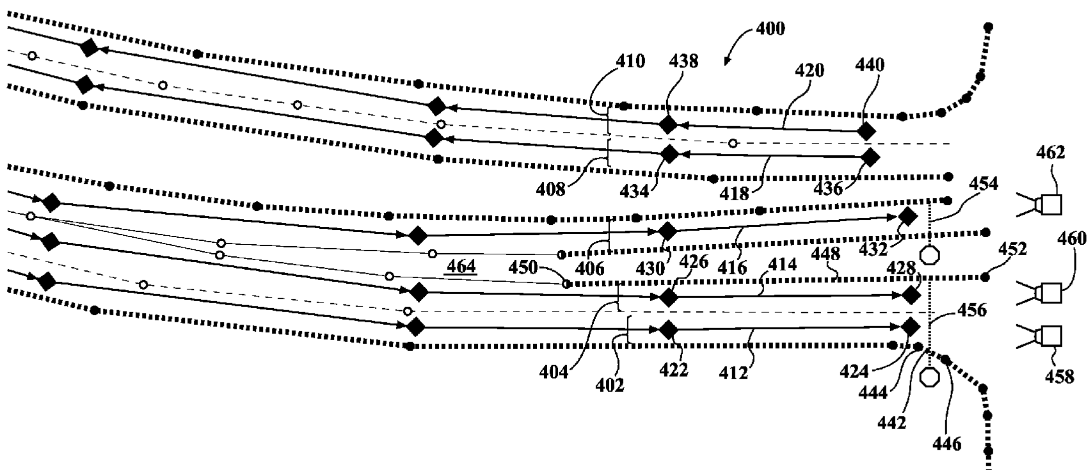
(57) **ABSTRACT**

A computer-readable detailed map format is disclosed. The detailed map format includes a lane segment and one or more border segments. A distance to an edge of the lane segment can be determined at a location along the lane segment by measuring a distance between the location and a portion of the border segment closest to the location. A lane width of the lane segment can be determined at a location along the lane segment by measuring a distance between two of the border segments positioned proximate to and on opposite sides of the lane segment.



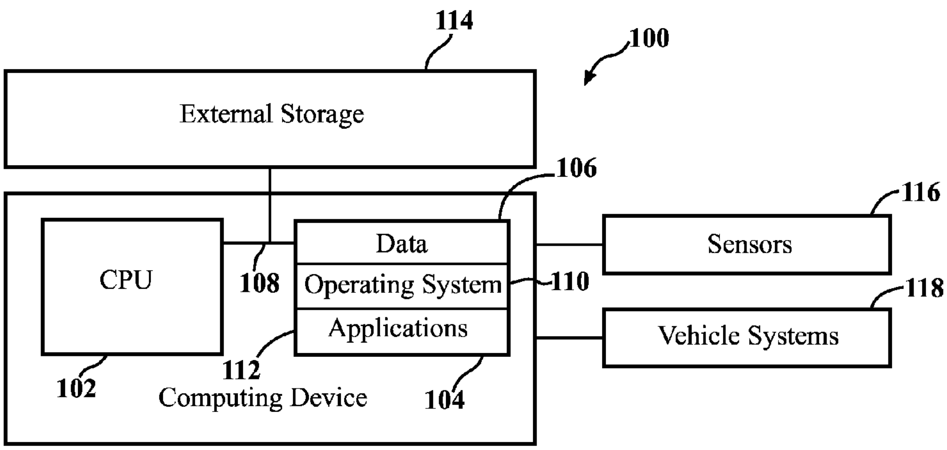
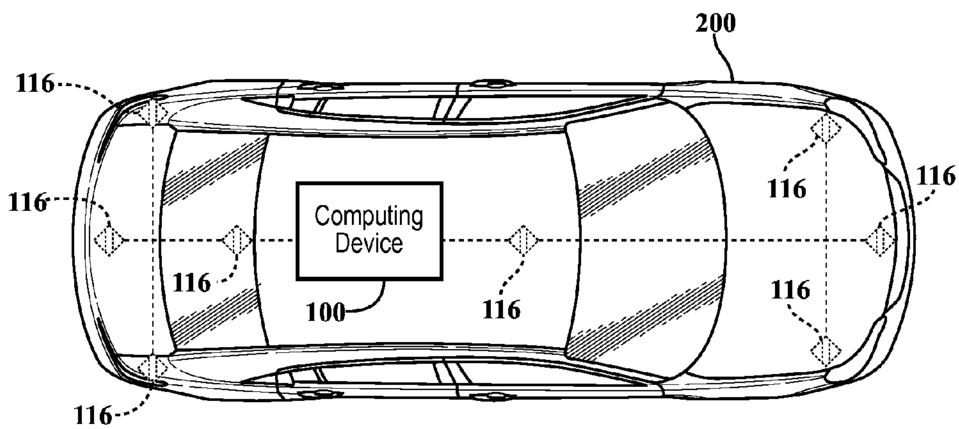

114
100
External Storage
106
116
Data
Sensors
CPU
108
Operating System
110
118
Applications
Vehicle Systems
112
102
Computing Device
104

FIG. 1


200
116
116
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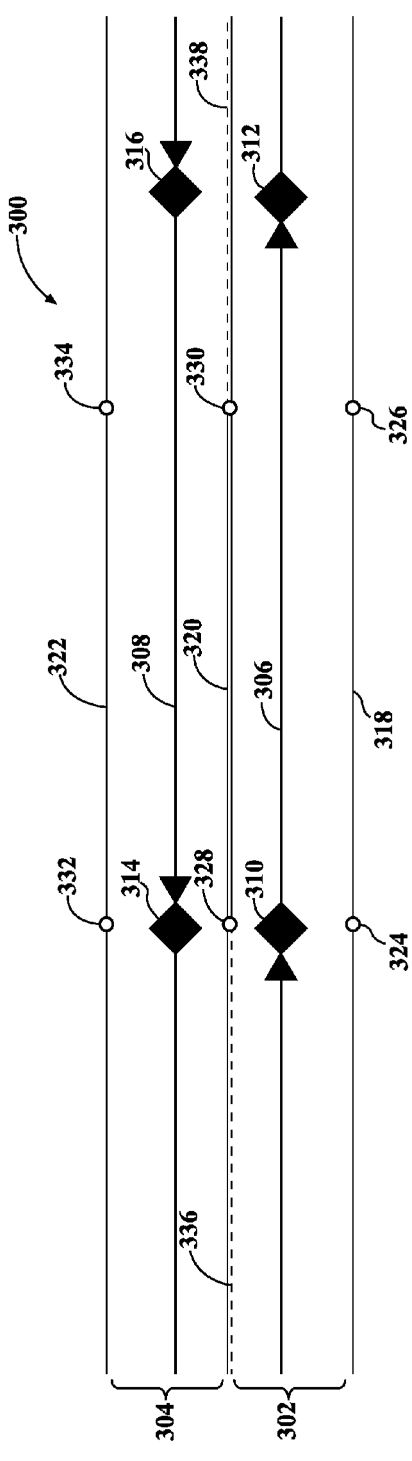
116
116
Computing Device
116
100
116
116
116

FIG. 2


300
302
304
306
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314
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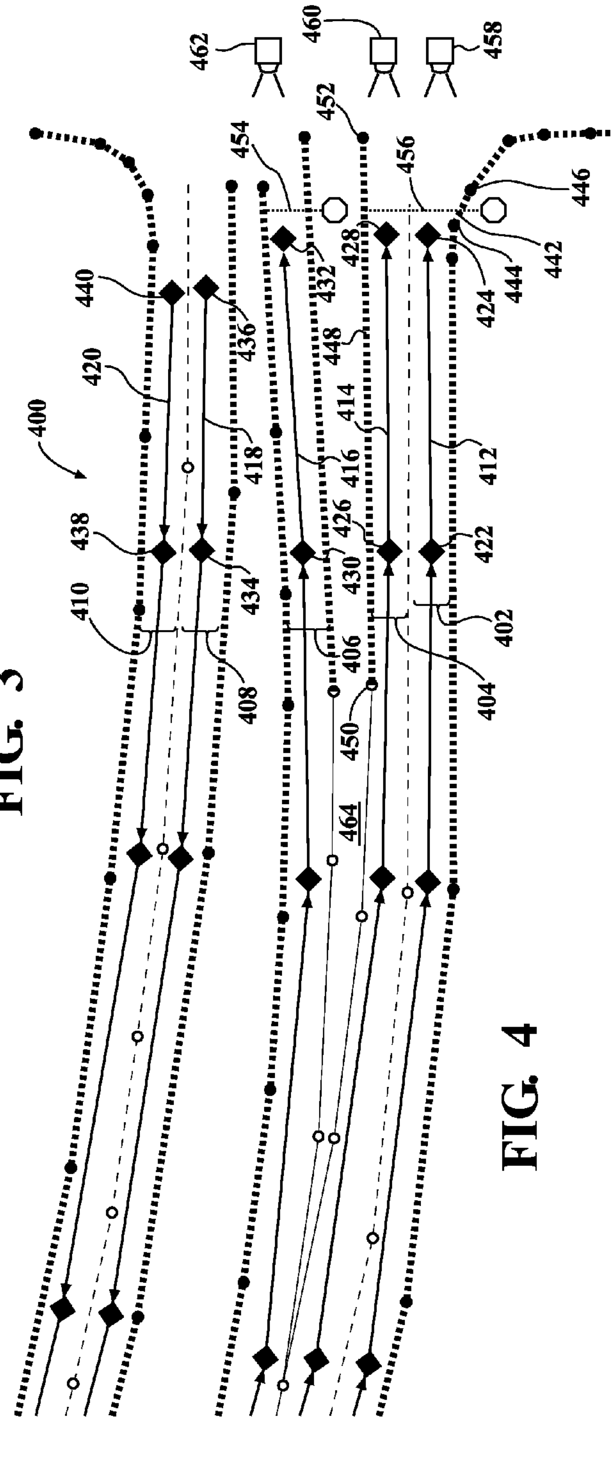
338

FIG. 3


400
402
404
406
408
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412
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424
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438
440
442
444
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454
456
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462
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FIG. 4

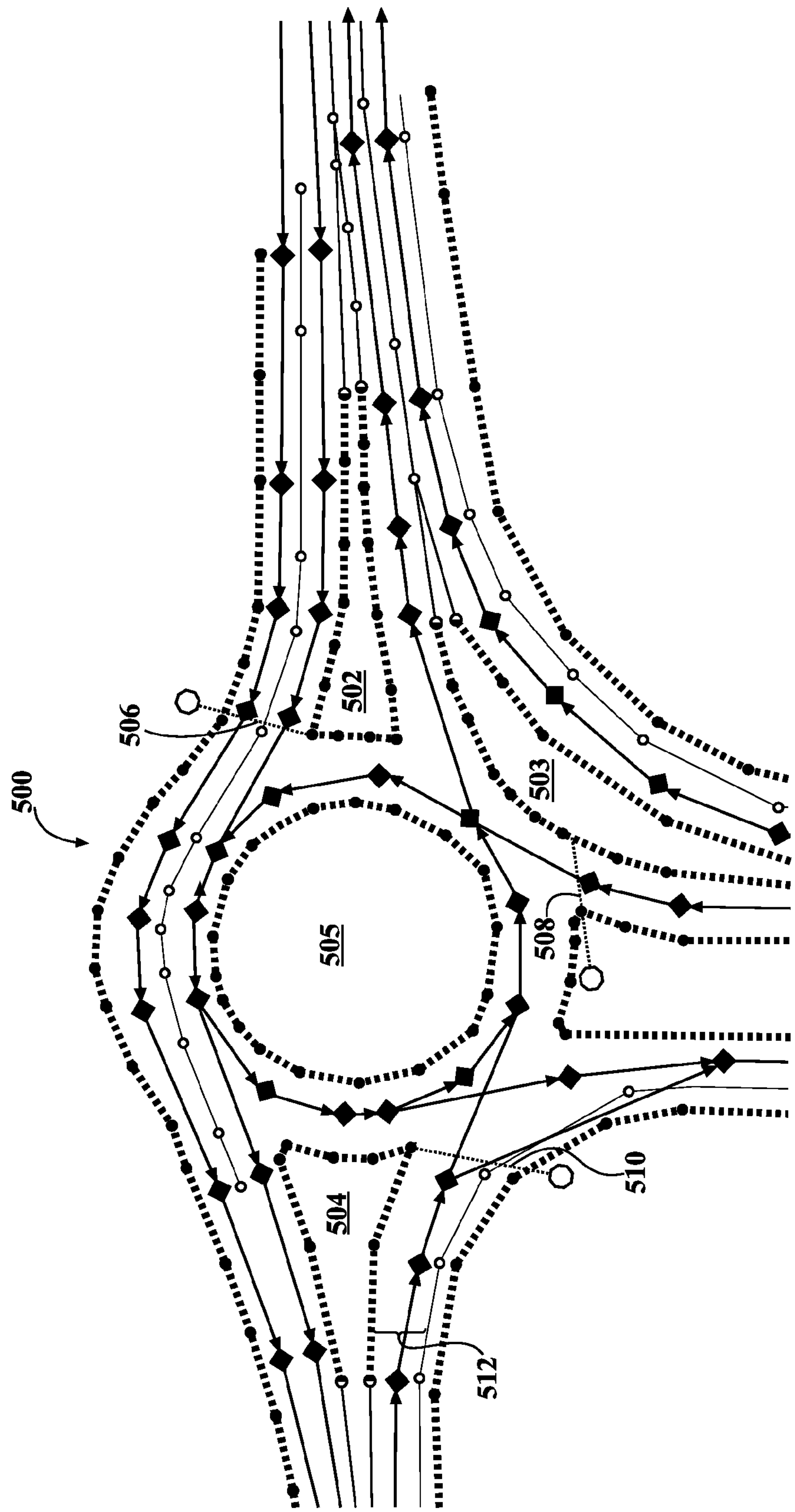

FIG. 5

DETAILED MAP FORMAT FOR AUTONOMOUS DRIVING

BACKGROUND

[0001] Fully or highly automated, e.g. autonomous or self-driven, driving systems are designed to operate a vehicle on the road either without or with low levels of driver interaction or other external controls. Autonomous driving systems require certainty in the position of and distance to geographic features surrounding the vehicle with a sufficient degree of accuracy to adequately control the vehicle. Details about the road or other geographic features surrounding the vehicle can be recorded on a detailed virtual map. The more accurate the detailed virtual map, the better the performance of the autonomous driving system. Existing virtual maps do not include sufficient or sufficiently accurate geographic feature details for optimized autonomous operation.

SUMMARY

[0002] The detailed map format described here can be used to represent the drivable area of a road, including the boundary locations of each lane, the exact width of each lane, and the location of the impassable borders of a given lane, such as curbs, medians, and islands. The detailed map format can also include information to support driving rules associated with a given lane of the road, to calculate the distance from any object within the map format to the boundary of a lane, and to identify other map features intersecting a lane, such as crosswalks and driveways. The highly detailed nature of this map format allows for improved control of a highly-automated or autonomous vehicle as well as for improved localization (exact positioning) of the autonomous vehicle in respect to the detailed map format.

[0003] Each lane within the detailed map format can include lane segments formed of waypoints. The detailed map format disclosed can also include border segments formed of borderpoints. Information associated with these border segments and borderpoints includes border type and border color. An autonomous vehicle can be controlled to operate according to driving rules based on a given border type and border color associated with the detailed map format. Border segments can also be used to determine the distance to an edge of a lane for a given lane segment or the width of the lane at any point along the lane segment, providing for more accurate control of the autonomous vehicle than is possible using lane segments formed of waypoints alone.

[0004] In one implementation, a computer-readable map format is disclosed. The map format includes at least a lane segment and a border segment. The distance to an edge of the lane segment can be determined at any location along the lane segment by measuring a distance between the chosen location and a portion of the border segment closest to the location.

[0005] In another implementation, another computer-readable map format is disclosed. The map format includes at least a lane segment and a plurality of border segments. A lane width of the lane segment can be determined at any location along the lane segment by measuring a distance between at least two of the plurality of border segments positioned proximate to and on opposite sides of the lane segment.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] The description herein makes reference to the accompanying drawings wherein like reference numerals refer to like parts throughout the several views, and wherein:

[0007] FIG. **1** is a block diagram of a computing device;

[0008] FIG. **2** is a schematic illustration of an autonomous vehicle including the computing device of FIG. **1**;

[0009] FIG. **3** shows an example two-dimensional representation of a portion of a two-lane road as represented within a detailed map format for use with the autonomous vehicle of FIG. **2**;

[0010] FIG. **4** shows an example two-dimensional representation of a portion of a four-lane road transitioning to a five-lane road at an intersection as represented within a detailed map format for use with the autonomous vehicle of FIG. **2**; and

[0011] FIG. **5** shows an example two-dimensional representation of a roundabout as represented within a detailed map format for use with the autonomous vehicle of FIG. **2**.

DETAILED DESCRIPTION

[0012] A computer-readable, highly detailed map format for an autonomous vehicle is disclosed. The detailed map format includes information representing the geographical location, travel direction, and speed limit of lanes on a given road using lane segments formed of waypoints. Beyond this basic information, the detailed map format also includes the geographical location for the borders of each lane in the form of border segments formed of borderpoints. Information associated with the border segments and border points within the detailed map format can include the border type and border color, such that driving rules can be associated with the lane segments based on the closest border segments. The detailed map format can also include stop lines linked to the end of lanes at traffic intersections to better position the autonomous vehicle for entry into a traffic intersection and to indicate where the autonomous vehicle should stop at the traffic intersection. Crosswalks can also be included in the detailed map format and associated with safety rules to be followed when the autonomous vehicle approaches the crosswalk.

[0013] FIG. **1** is a block diagram of a computing device **100**, for example, for use with autonomous driving system. The computing device **100** can be any type of vehicle-installed, handheld, desktop, or other form of single computing device, or can be composed of multiple computing devices. The processing unit in the computing device can be a conventional central processing unit (CPU) **102** or any other type of device, or multiple devices, capable of manipulating or processing information. A memory **104** in the computing device can be a random access memory device (RAM) or any other suitable type of storage device. The memory **104** can include data **106** that is accessed by the CPU **102** using a bus **108**.

[0014] The memory **104** can also include an operating system **110** and installed applications **112**, the installed applications **112** including programs that permit the CPU **102** to perform automated driving methods using the detailed map format described below. The computing device **100** can also include secondary, additional, or external storage **114**, for example, a memory card, flash drive, or any other form of computer readable medium. The installed applications **112** can be stored in whole or in part in the external storage **114** and loaded into the memory **104** as needed for processing.

[0015] The computing device **100** can also be in communication with one or more sensors **116**. The sensors **116** can capture data and/or signals for processing by an inertial measurement unit (IMU), a dead-reckoning system, a global navigation satellite system (GNSS), a light detection and ranging (LIDAR) system, a radar system, a sonar system, an image-based sensor system, or any other type of system capable of capturing information specific to the environment surrounding a vehicle for use in creating a detailed map format as described below, including information specific to objects such as features of the route being travelled by the vehicle or other localized position data and/or signals and outputting corresponding data and/or signals to the CPU **102**.

[0016] In the examples described below, the sensors **116** can capture, at least, signals for a GNSS or other system that determines vehicle position and velocity and data for a LIDAR system or other system that measures vehicle distance from lane lines (e.g., route surface markings or route boundaries), obstacles, objects, or other environmental features including traffic lights and road signs. The computing device **100** can also be in communication with one or more vehicle systems **118**, such as vehicle braking systems, vehicle propulsions systems, etc. The vehicle systems **118** can also be in communication with the sensors **116**, the sensors **116** being configured to capture data indicative of performance of the vehicle systems **118**.

[0017] FIG. **2** is a schematic illustration of an autonomous vehicle **200** including the computing device **100** of FIG. **1**. The computing device **100** can be located within the vehicle **200** as shown in FIG. **2** or can be located remotely from the vehicle **200** in an alternate location (not shown). If the computing device **100** is located remotely from the vehicle **200**, the vehicle **200** can include the capability of communicating with the computing device **100**.

[0018] The vehicle **200** can also include a plurality of sensors, such as the sensors **116** described in reference to FIG. **1**. One or more of the sensors **116** shown can be configured to capture the distance to objects within the surrounding environment for use by the computing device **100** to estimate position and orientation of the vehicle **200**, images for processing by an image sensor, vehicle position in global coordinates based on signals from a plurality of satellites, or any other data and/or signals that could be used to determine the current state of the vehicle or determine the position of the vehicle **200** in respect to its environment for use in either creating a detailed map format or comparing the vehicle's **200** position to the detailed map format. Recognized geographic features such as those described below can be used to build a detailed map format, and objects such as other vehicles can be recognized and excluded from the detailed map format.

[0019] Map formats can be constructed using geographic features captured by the vehicle **200** such as lane lines and curbs proximate the vehicle **200** as it travels a route. These geographic features can be captured using the above described LIDAR system and/or cameras in combination with an algorithm such as random sample consensus (RANSAC) to find lines, record the position of the vehicle **200**, and collect data on position from a GNSS and/or an IMU. The captured geographic features can then be manipulated using a simultaneous localization and mapping (SLAM) technique to position all of the geographic features in relation to the vehicle's **200** position. Some of the geographic features can be categorized as lane borders, and lane centers can be determined based on the lane borders. Alternatively, map formats can be constructed using overhead images (e.g. satellite images) of geographic features traced by a map editor that allows selection of different categories for each geographic feature.

[0020] FIG. **3** shows an example two-dimensional representation of a portion of a two-lane road **300** as represented within a detailed map format for use with the autonomous vehicle **200** of FIG. **2**. The two-lane road **300** in this example map format includes lanes **302**, **304**. Each of the lanes **302**, **304** can include a lane segment **306**, **308**. Each of the lane segments **306**, **308** can extend between at least two waypoints **310**, **312**, **314**, **316**, for example, the lane segment **306** extends between the waypoints **310**, **312** and the lane segment **308** extends between the waypoints **314**, **316**. Information can be associated with the waypoints **310**, **312**, **314**, **316** and stored as part of the map format. For example, each waypoint **310**, **312**, **314**, **316** can include information such as geographical location, lane speed, and lane direction.

[0021] In the example map format shown in FIG. **3**, the lane **302** is shown as having a left-to-right direction by arrows touching the waypoints **310**, **312** and the lane **304** is shown as having a right-to-left direction by arrows touching the waypoints **314**, **316**. The overall computer-readable map format can be stored in plain text, binary, or xml, for example. The basic map information can be gathered from a route network definition file (RNDF) or any other available source. However, this basic map information is not sufficient for control of the autonomous vehicle **200**.

[0022] Additional detail can be added to the map format in order to improve the map format for use with the autonomous vehicle **200**. As shown in FIG. **3**, each of the lanes **302**, **304** can be further associated with borders. Each of the borders can be formed of one or more border segments **318**, **320**, **322**. Each of the border segments **318**, **320**, **322** can extend between at least two borderpoints **324**, **326**, **328**, **330**, **332**, **334**. For example, the border segment **318** extends between the borderpoints **324**, **326** and the border segment **322** extends between the borderpoints **332**, **334**. Information can be associated with the borderpoints **324**, **326**, **328**, **330**, **332**, **334** and stored as part of the map format. For example, each borderpoint **324**, **326**, **328**, **330**, **332**, **334** can include information such as geographical location, border type, and border color.

[0023] The information associated with each borderpoint **324**, **326**, **328**, **330**, **332**, **334** can be used by the autonomous vehicle **200** in order to determine navigation routes, make decisions regarding passing other vehicles, position or localize the autonomous vehicle **200** in respect to the border segments **318**, **320**, **322**, and determine the driveable area along a given navigation route in order to support safety maneuvers or obstacle tracking. The information associated with each borderpoint **324**, **326**, **328**, **330**, **332**, **334**, can, for example, be built from data collected using a LIDAR sensor and manipulated using a SLAM technique when building the detailed map as describe above. The map information associated with the borders and lanes **302**, **304** can be stored, for example, in the form of spline points or as curves with knot vectors in the memory **104** of the computing device **100** or can be available from a remote location.

[0024] Examples of different border types that can be associated with the borderpoints **324**, **326**, **328**, **330**, **332**, **334** can include a "curb," a "single solid line," a "double solid line," a "single dashed line," a "combined dashed line and solid line," and "no line." For example, the borderpoints **324**, **326** and hence the border segment **318** extending between them can be associated with a "single solid line" border type. To represent the "single solid line" border type within the map format, borderpoints **324**, **326** are shown with an open circle representation and the border segment **318** is shown using a thin, solid line representation. Similarly, the border segment **320** extending between the borderpoints **328**, **330** can be associated with a "double solid line" border type. The partially-shown border segments **336**, **338** can be associated with a "combined dashed line and solid line" border type. In addition to border type, border color can also be associated with the borderpoints **324**, **326**, **328**, **330**, **332**, **334**. For example, border colors can include "yellow," "white," or "unknown."

[0025] Border types and border colors can be used to associate a driving rule with each of the various lane segments **306**, **308** (and/or with the waypoints **310**, **312**, **314**, **316** forming the lane segments **306**, **308**). A driving rule can be based at least in part on the border type and the border color associated with the borderpoints **324**, **326**, **328**, **330**, **332**, **334** and border segments **318**, **318**, **322**, closest to the lane segment **306**, **308**. For example, two driving rules can be associated with lane segment **306**: first, a driving rule of "no passing border" based on the border segment **320** extending between the borderpoints **328**, **330** given that the border segment **320** can be associated with a border type of "double solid line" and a border color of "yellow;" second, a driving rule of "drivable lane border" based on the border segment **318** extending between the borderpoints **324**, **326** given that the border segment **318** can be associated with a border type of "single solid line" and a border color of "white." Though the border types, border colors, and driving rules described in reference to FIG. **3** reflect commonly understood traffic rules in the United States, other traffic rules, border types, border colors, and driving rules are also possible.

[0026] Another benefit of storing information for both lane segments **306**, **308** and border segments **318**, **320**, **322** in the map format is that the distance to an edge of the lane segment **306**, **308** can be determined at any location along the lane segment **306**, **308** by measuring a distance between the location and a portion of the border segment **318**, **320**, **322** closest to the location. This allows for the autonomous vehicle **200** to be positioned within, for example, either of the lanes **302**, **304** at an optimum spacing based on the actual geographical location, border color, and border type of the border segment **318**, **320**, **322** instead of relying on fixed lane widths associated only with waypoints **324**, **326**, **328**, **330**, **332**, **334**. Knowing the actual distance to an edge of the lane segment **306**, **308** leads to greater maneuverability of the autonomous vehicle **200**. Further, the ability to localize the autonomous vehicle **200** is improved because the border segments **318**, **320**, **322** as stored within the detailed map format can be matched to images of lane borders or other geographic features captured during autonomous operation of vehicle **200**.

[0027] In some examples, border segments **318**, **320**, **322** can be positioned both proximate to and on opposite sides of a given lane segment **306**, **308**. In these cases, a lane width of the lane segment **306**, **308** can be determined at a chosen location along the lane segment **306**, **308** by measuring the distance between the two border segments **318**, **320**, **322** positioned proximate to and on opposite sides of the lane segment **306**, **308**. For example, the lane width for lane **302** can be calculated anywhere along lane segment **306** by measuring the distance between border segments **318**, **320** within the map format. Again, knowing the actual lane width at any point along the lane **302**, **304** is beneficial both for overall positioning and maneuvering of the autonomous vehicle **200**. The positioning benefit is further described in reference to FIG. **4**.

[0028] FIG. **4** shows an example two-dimensional representation of a portion of a four-lane road transitioning to a five-lane road **400** at an intersection as represented within a detailed map format for use with the autonomous vehicle **200** of FIG. **2**. The five-lane road **400** in this example map format includes lanes **402**, **404**, **406**, **408**, **410**. Each of the lanes **402**, **404**, **406**, **408**, **410** can include a lane segment **412**, **414**, **416**, **418**, **420**. Each of the lane segments **412**, **414**, **416**, **418**, **420** can extend between at least two waypoints **422**, **424**, **426**, **428**, **430**, **432**, **434**, **436**, **438**, **440**, for example, the lane segment **416** extends between the waypoints **430**, **432** and the lane segment **420** extends between the waypoints **438**, **440**. The lanes **402**, **404**, **406** proceed in a left-to-right direction as indicated by the arrows associated with the waypoints **422**, **424**, **426**, **428**, **430**, **432** and the lanes **408**, **410** proceed in a right-to-left direction as indicated by the arrows associated with the waypoints **434**, **436**, **438**, **440**.

[0029] Similar information as described above in reference to FIG. **3** is associated with the waypoints **422**, **424**, **426**, **428**, **430**, **432**, **434**, **436**, **438**, **440** shown in FIG. **4**. Each of the lanes **402**, **404**, **406**, **408**, **410** can be further associated with borders formed of one or more border segments extending between at least two borderpoints. For simplicity, only a few of the border segments and borderpoints are numbered on the example map format of the road **400** of FIG. **4**. For example, border segment **442** extends between borderpoints **444**, **446** and border segment **448** extends between borderpoints **450**, **452**. These border segments **442**, **448** are associated with lane segments **412**, **414**, respectively. As described in respect to FIG. **3**, the border segments **442**, **448** and borderpoints **444**, **446**, **450**, **452** can be associated with various border types and border colors for use in establishing driving rules.

[0030] For example, the border segments **442**, **448** can be associated with the "curb" border type, which is represented within the detailed map format using a dotted, hashed line type. The borderpoints **444**, **446**, **452** are represented using filled circles, and together, the borderpoints **444**, **446**, **452** and border segments **442**, **448** indicate an "impassable" driving rule. When the driving rule indicated is "impassable," the autonomous vehicle **200** is controlled in a manner such that the vehicle **200** will not attempt to navigate beyond the border. The borderpoint **450** is represented using a half-filled circle, indicating a transition in the border type from a "solid line" type to a "curb" type at the location of the borderpoint **450**.

[0031] Understanding the location of a transition between border types is important for autonomous control, as the vehicle **200** is physically able, if necessary, to navigate along or across a "line" type border, but is not able to safely navigate along or across a "curb" type border. The benefit of using border segments is clear in this example. A median **464** is shown as present between lane **404** and lane **406**. The left-most part of the median **464** is bordered by border segments of solid lines associated with a "drivable lane border" driving rule and a "line" type border while the right-most part of the median **464** is bordered by border segments of dotted, hashed lines associated with an "impassable" driving rule and a "curb" type border. If necessary, the vehicle **200** could navigate across only the left-most part of the median **464**.

[0032] FIG. **4** shows additional features added to the map format in order to improve the map format for use with the autonomous vehicle **200** of FIG. **2**. First, three of the lane segments **412**, **414**, **416** are associated with stop lines **454**, **456** near the traffic intersection (the traffic intersection being located on the right-most side of FIG. **4**). The stop lines **454**, **456** can be linked to the end of one or more lanes **402**, **404**, **406** and information associated with the stop lines **454**, **456** can include a geographical location of a position where the vehicle **200** must stop before the traffic intersection. In the example of FIG. **4**, the stop line **456** extends between the border segments **442**, **448**, denoting the geographical location at which the autonomous vehicle **200** should be positioned if stopping in front of the traffic intersection within either of the lanes **402**, **404**.

[0033] The additional information provided by the stop lines **454**, **456** is useful in operation of the autonomous vehicle **200** because the stop lines **454**, **456** allow the autonomous vehicle **200** to be positioned at the traffic intersection in a manner consistent with manual operation of a vehicle. For example, if the autonomous vehicle **200** approaches the traffic intersection within lane **402**, instead of stopping at the waypoint **424** denoting the end of the lane segment **412**, the autonomous vehicle **200** can be controlled to move forward to the stop line **456** and slightly around the corner of the lane **402** as denoted by the border segment **442**. This maneuver is more consistent with how a driver would manually operate a vehicle on the road **400** when making a right turn at a traffic intersection. Though not shown, crosswalks can also be included in the detailed map format in a manner similar to that used for the stop lines **454**, **456**. Information associated with the crosswalks can include a geographical location of a position of the crosswalk and a driving rule associated with the crosswalk that directs the automated vehicle system to implement additional safety protocols.

[0034] Traffic signals are another feature present within the map format shown in FIG. **4**. Each traffic signal can include information such as geographical location, traffic signal type, and traffic signal state. Traffic signal type can include information on the structure and orientation of a traffic light or traffic sign. Traffic signal structure and orientation for a traffic light can include "vertical three," "vertical three left arrow," "horizontal three," "right arrow," etc. Traffic signal state for a traffic light can include, for example, "green," "green arrow," "yellow," "blinking yellow," or "red." In the map format shown in FIG. **4**, three traffic lights **458**, **460**, **462** are shown within the traffic intersection. In this example, traffic light **458** is associated with lane **402**, and given the structure of the intersection and the shape and type of the border segments proximate lane **402**, lane **402** is understood to be a right turn lane. Similarly, traffic light **462** is associated with lane **406**, and given the structure of the intersection and shape and type of the border segments proximate lane **406**, lane **406** is understood to be a left turn lane.

[0035] FIG. **5** shows an example two-dimensional representation of a roundabout **500** as represented within a detailed map format for use with the autonomous vehicle **200** of FIG. **2**. Maneuvering the autonomous vehicle **200** through the roundabout is greatly aided by the use of lane segments, border segments, and stop lines. For example, medians **502**, **503**, **504** and center circle **505** can be identified using borderpoints and border segments and be associated with driving rules as "impassable" areas of the roundabout **500**. In another example, stop lines **506**, **508**, **510** can be used to indicate to the autonomous vehicle **200** the exact location where the autonomous vehicle **200** should stop before entering the roundabout **500**. As shown in FIG. **5**, stop line **510** indicates a position to the right and below the nearest waypoint within lane **512**. Using the stop line **510** to position the autonomous vehicle **200** at the entrance to the roundabout **500** is much closer to how a driver would operate a vehicle when compared to stopping the autonomous vehicle **200** at the final waypoint within the lane **512**.

[0036] The foregoing description relates to what are presently considered to be the most practical embodiments. It is to be understood, however, that the disclosure is not to be limited to these embodiments but, on the contrary, is intended to cover various modifications and equivalent arrangements included within the spirit and scope of the appended claims. The scope of the claims is to be accorded the broadest interpretation so as to encompass all such modifications and equivalent structures as is permitted under the law.

What is claimed is:

1. A computer-readable map format, comprising:

a lane segment; and

a border segment;

wherein a distance to an edge of the lane segment can be determined at a location along the lane segment by measuring a distance between the location and a portion of the border segment closest to the location.

2. The map format of claim **1**, wherein the lane segment is formed from a plurality of waypoints and wherein information associated with each waypoint includes at least one of a geographical location and a lane speed and a lane direction.

3. The map format of claim **1**, wherein the border segment is formed from a plurality of borderpoints and wherein information associated with each borderpoint includes at least a geographical location and a border type and a border color.

4. The map format of claim **3**, wherein information associated with the lane segment includes a driving rule and wherein the driving rule is based at least in part on the border type and the border color associated with a proximate one of the plurality of borderpoints.

5. The map format of claim **3**, wherein the border type includes at least one of a curb, a single solid line, a double solid line, a single dashed line, a combined dashed line and solid line, and no line.

6. The map format of claim **3**, wherein the border color includes at least one of yellow, white, and unknown.

7. The map format of claim **1**, further comprising:

a stop line associated with an end of the lane segment, wherein information associated with the stop line includes a geographical location, the geographical location representing a position where a vehicle must stop before a traffic intersection.

8. The map format of claim **1**, further comprising:

a traffic signal, wherein information associated with the traffic signal includes a geographical location and a traffic signal type and a traffic signal state.

9. The map format of claim **8**, wherein the traffic signal type includes information regarding structure and orientation for at least one of a traffic light and a traffic sign.

10. The map format of claim **9**, wherein the traffic signal type is a traffic light and the traffic signal state includes at least one of green, green arrow, yellow, blinking yellow, and red.

11. A computer-readable map format, comprising:

a lane segment; and

a plurality of border segments;

wherein a lane width of the lane segment can be determined at a location along the lane segment by measuring a distance between at least two of the plurality of border segments positioned proximate to and on opposite sides of the lane segment.

12. The map format of claim **11**, wherein the lane segment is formed from a plurality of waypoints and wherein information associated with each waypoint includes at least one of a geographical location and a lane speed and a lane direction.

13. The map format of claim **11**, wherein the border segment is formed from a plurality of borderpoints and wherein information associated with each borderpoint includes at least a geographical location and a border type and a border color.

14. The map format of claim **13**, wherein information associated with the lane segment includes a driving rule and wherein the driving rule is based at least in part on the border type and the border color associated with a proximate one of the plurality of borderpoints.

15. The map format of claim **13**, wherein the border type includes at least one of a curb, a single solid line, a double solid line, a single dashed line, a combined dashed line and solid line, and no line.

16. The map format of claim **13**, wherein the border color includes at least one of yellow, white, and unknown.

17. The map format of claim **11**, further comprising:

a stop line associated with an end of the lane segment, wherein information associated with the stop line includes a geographical location, the geographical location representing a position where a vehicle must stop before a traffic intersection.

18. The map format of claim **11**, further comprising:

a traffic signal, wherein information associated with the traffic signal includes a geographical location and a traffic signal type and a traffic signal state.

19. The map format of claim **18**, wherein the traffic signal type includes information regarding structure and orientation for at least one of a traffic light and a traffic sign.

20. The map format of claim **19**, wherein the traffic signal type is a traffic light and the traffic signal state includes at least one of green, green arrow, yellow, blinking yellow, and red.

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