as location relative to other cars immediately around it which can often be determined with greater accuracy than absolute geographical location.

[0038] 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.

[0039] 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 devices 110. In the case where the vehicle is a small passenger vehicle such as a car, the car may include a laser or other sensors mounted on the roof or other convenient location. For instance, a vehicle's perception system may use various sensors, such as LIDAR, sonar, radar, cameras, etc. to detect objects and their characteristics such as location, orientation, size, shape, type, direction and speed of movement, etc. The raw data from the sensors and/or the aforementioned characteristics can be quantified or arranged into a descriptive function or vector for processing by the computing devices 110. As discussed in further detail below, 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.

[0040] FIGURES 2A-2D are examples of external views of vehicle 100 having a width dimension W1 (as shown in FIGURE 2C), a length dimension L1 (as shown in FIGURES 2A and 2D), and a height dimension H1 (as shown in FIGURES 2A and 2C). As can be seen, vehicle 100 includes many features of a typical vehicle such as headlights 202, windshield 203, taillights/turn signal lights 204, rear windshield 205, doors 206, side view mirrors 208, wheels 210, and turn signal/parking lights 212. Headlights 202, taillights/turn signal lights 204, and turn signal/parking lights 212 may be associated with the signaling system 166. Light bar 207 may also be associated with the signaling system 166.

[0050] As the vehicle 100 is traveling, the sensors of the perception system 172 may detect various objects in the vehicle's environment. FIGURE 4 is a representation of objects detected by the perception system 172 along roadway 400 and the position of vehicle 100 corresponding to the view of roadway 300 in FIGURE 3. In this example, the perception system 172 may detect lanes lines 401, 402, 403, 404, 405, and 406 which define lanes 410, 412, 414, and 416. In this example, lanes 410, 412, 414, and 416 may correspond to each of northbound lanes 310 and 312 and southbound lanes 314 and 316, respectively. In addition, perception system 172 has also detected vehicle 320.

[0051] For each object, the vehicle's perception system may use segmentation to identify specific sensor data points corresponding to an object. This may also include determining a bounding box representing the dimensions of that object. This may be achieved using any known segmentation and/or bounding box techniques. For instance, as shown in FIGURE 4, the location of vehicle 320 is represented by bounding box 420 which includes data points that the perception system 172 has determined to correspond to an object. FIGURE 5A depicts a top down view of the relative positions of vehicle 100 and bounding box 420 as shown in FIGURE 4. Arrow 510 represents the current or observed heading of vehicle 320 and therefore the heading of bounding box 420. FIGURE 5B depicts a side view of the bounding box 420. Arrows 520 and 522 identify the corresponding sides of the bounding box 420 of FIGURES 5A and 5B. The distances X, Y, and Z represent the width, length and height of the bounding box 420.

[0052] The characteristics of the identified objects as well as the segmentation information identifying the sensor data points (and in some cases, bounding boxes) for those objects may be provided to the computing devices 110 by the perception system 172. As an example, these characteristics may include the location (GPS coordinates and/or relative to the vehicle), size, shape, dimensions, speed, orientation, elevation, type (passenger vehicle, tractor trailer, bicycle, pedestrian), features of the road surface (lane lines, etc.), and more. In addition, the perception system may provide information identifying sensor data points around the object, but not specifically associated with the object according to the segmentation.

[0053] The perception system and/or the vehicle's computing devices may use prior observations of the object to predict a future trajectory of the object. For instance, an object's speed, orientation/heading, location, state (i.e. turn signal, etc.), or prior estimated trajectory may be used to predict a series of locations and times in the future where the object is likely

wheel is to the vehicle's sensors, the more sensor data points are likely to be received from wheel surface and the more accurate the estimation may be.

[0063] The estimation may be used as an indication of the curvature of the future path of the vehicle (the change in orientation over distance) or yaw rate (the change in orientation over time). For example, combining the future wheel orientation with the object's speed, a trajectory of the object can be determined. In this regard, the estimation may be used to determine a future heading for an object, a future trajectory for an object, or alternatively, increase or decrease a likelihood or confidence in different future trajectories for an object.

[0064] The predicted heading or trajectory may then be used to make driving decisions for the vehicle. For instance, when the object is in an adjacent lane, the predicted heading may be a very early indication that the object is going to move towards the vehicle's lane. As an example, turning to FIGURE 8, where the angle Θ is relatively large, such as 15 degrees or more or less, this may indicate a future heading or future trajectory 810 of the bounding box 420 which takes the object (vehicle 320) towards the northbound lane 410. In this example, the future trajectory (heading and speed over a future period of time) of the bounding box may indicate that the object will enter into lane 410 within a predetermined period of time, for instance 1 second or more or less. In response, the vehicle's computing devices may control the vehicle to speed up, slow down, or even change lanes as appropriate to avoid a collision or even getting too close to vehicle 320. In extreme cases, such as where the object appears to be changing headings erratically, the vehicle's computing devices may even notify a passenger of the vehicle to take control of the steering, braking, or acceleration if possible. Alternatively, if the vehicle is being controlled in a semi-autonomous or manual mode, the notification may be provided in order to assist the driver of the vehicle.

[0065] Alternatively, the area may be determined by using a model of wheel locations. In this regard, the size, location, and shape of the bounding box as well as the locations of the data points, may be used to fit a model which provides the orientation of the wheel using a simple fixed wheel radius for the wheel or more complex wheel radius that depends upon the size of the bounding box. In this example, the model may be trained using machine learning where operators mark and identify data points corresponding to wheels as positive examples for training data for the model.

[0066] The features described above may relate to laser data points which provide distance, direction and intensity information. In this regard, the intensity information may be used as a cue to indicate the outer rim of the wheel (i.e. a black wheel would have low

reflectivity and therefore low intensity). In this regard, the area may be estimated using one or more images of the object and thereafter, the laser data may be used to identify the orientation of the wheel.

[0067] Similarly, if the perception system provides camera data, the location of a black object above the road surface and proximate to the location of the bounding box may be used as a cue to indicate a location of a wheel. In some cases, an image alone may be sufficient to recognize a possible wheel location and even estimate an orientation of a vehicle's wheel, for instance, using a 3D model estimation from two or more images of the wheel and/or 3D model data generated for the image using laser data. Another way to compute wheel orientation from an image may include determining the aspect ratio of wheel width and height in the image. This aspect ratio may correspond to a wheel orientation. Combining this with the orientation of the object, as determined from other sensor data, image processing of the image or multiple images of the wheel, the relative wheel orientation can be computed.

Estimating the wheel orientation can even be useful for very slow moving and even stopped vehicles. For instance, an object that is ready to move out of a parking spot may have angled the object's wheels to move out of the parking spot, but may not actually have begun moving. Thus, using the angle of the wheel to estimate a future trajectory of an object is more likely to predict accurately the object's trajectory as otherwise, the computing devices would likely predict that the object would remain stationary. In another example, a given vehicle is stopped in an adjacent lane may attempting to change into the lane of the vehicle 100, for instance, because the driver of that car has changed his mind and wants to change his route and use the lane. In such cases, the wide angle of the wheel relative to the side of the given vehicle may provide more information about where the given vehicle is going to go than the given vehicle's prior trajectory. Such stationary lane changes or low-speed lane changes are common cases where the front wheels are angled significantly.

[0068] FIGURE 9 is an example flow diagram 900 in accordance which may be performed by one or more processors of one or more computing devices of a vehicle, such as computing devices 110 of vehicle 100 in order to determine a future heading of an object. In this example, sensor data, including information identifying a bounding box representing an object in a vehicle's environment and locations of sensor data points corresponding to the object, is received at block 910. An area corresponding to a front wheel of the object based on the size of the bounding box is identified at block 920. An orientation of the wheel is