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(54) **RADAR-BASED ANALYTICS**

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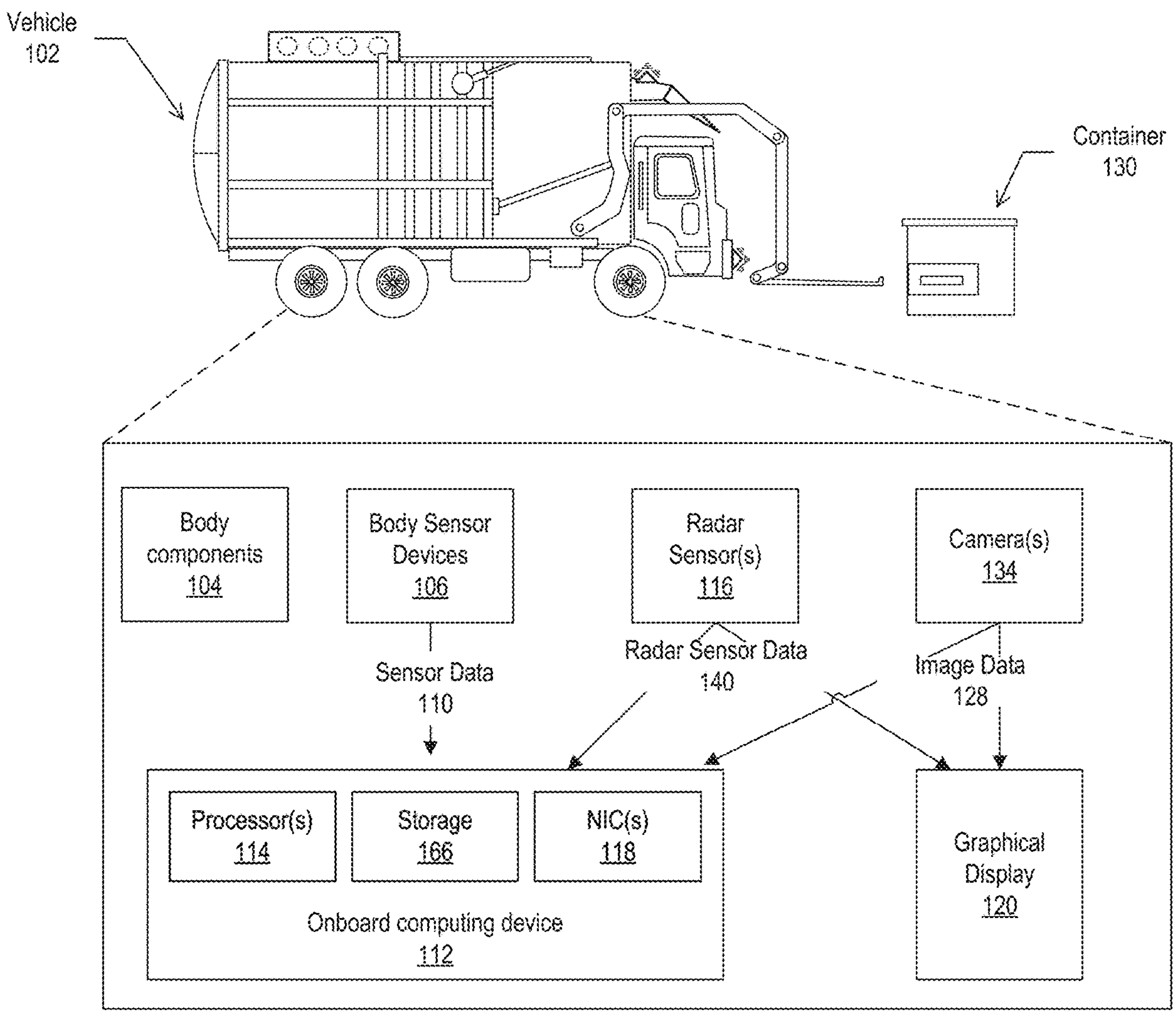
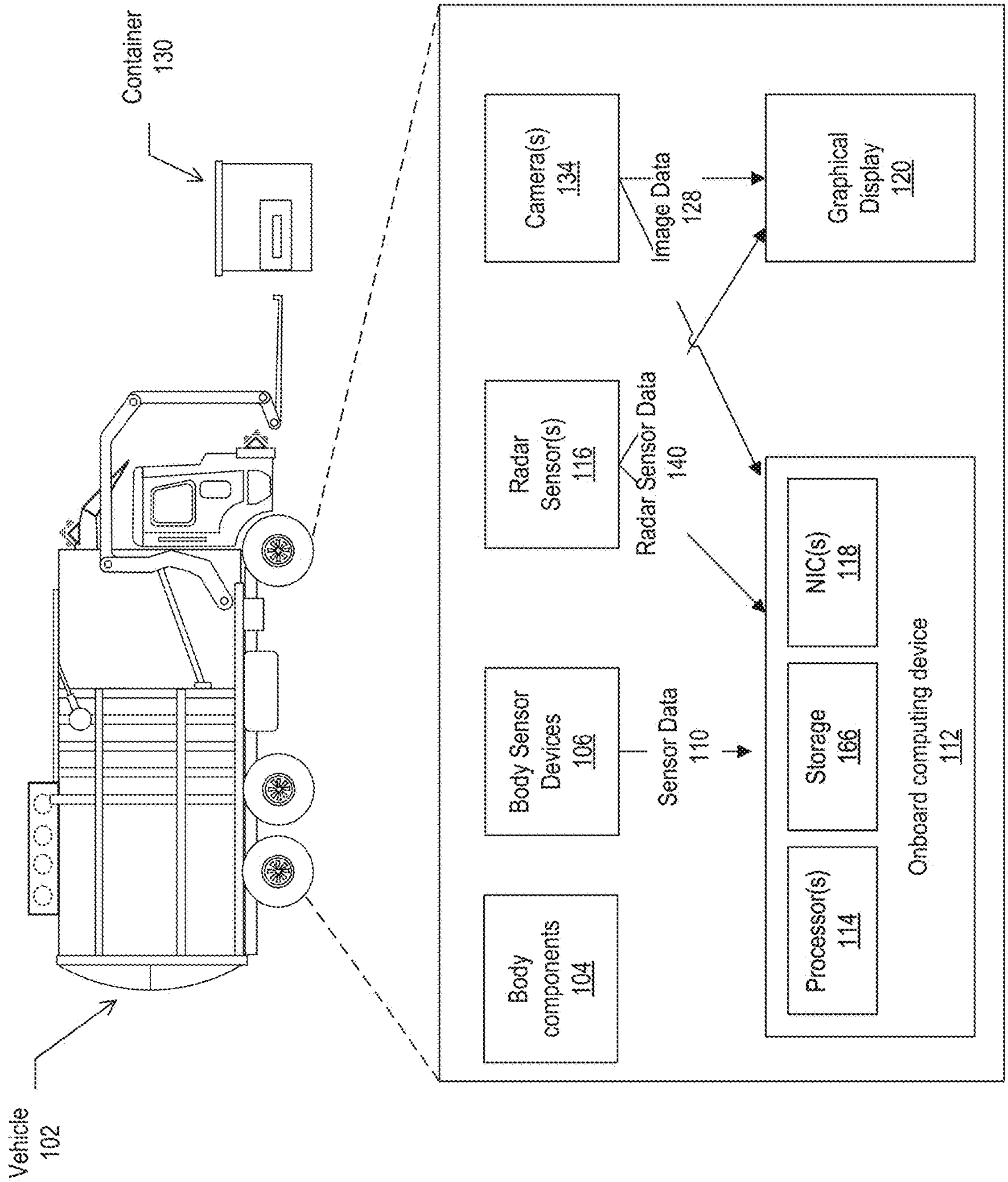
(57) **ABSTRACT**

Systems and methods for operating a refuse collection vehicle include detecting, using at least one radar sensor coupled to the refuse collection vehicle, a hazard positioned within a detection distance of the at least one radar sensor; transmitting, from the at least one radar sensor to a computing device, a signal indicating the hazard detected by the at least one radar sensor; and in response to receiving the signal, controlling the refuse collection vehicle to prevent damage to the refuse collection vehicle resulting from contact between the hazard and the refuse collection vehicle.





Vehicle
102
Container
130
Body components
104
Body Sensor Devices
106
Sensor Data
110
Radar Sensor(s)
116
Radar Sensor Data
140
Camera(s)
134
Image Data
128
Graphical Display
120
Processor(s)
114
Storage
166
NIC(s)
118
Onboard computing device
112

FIG. 1

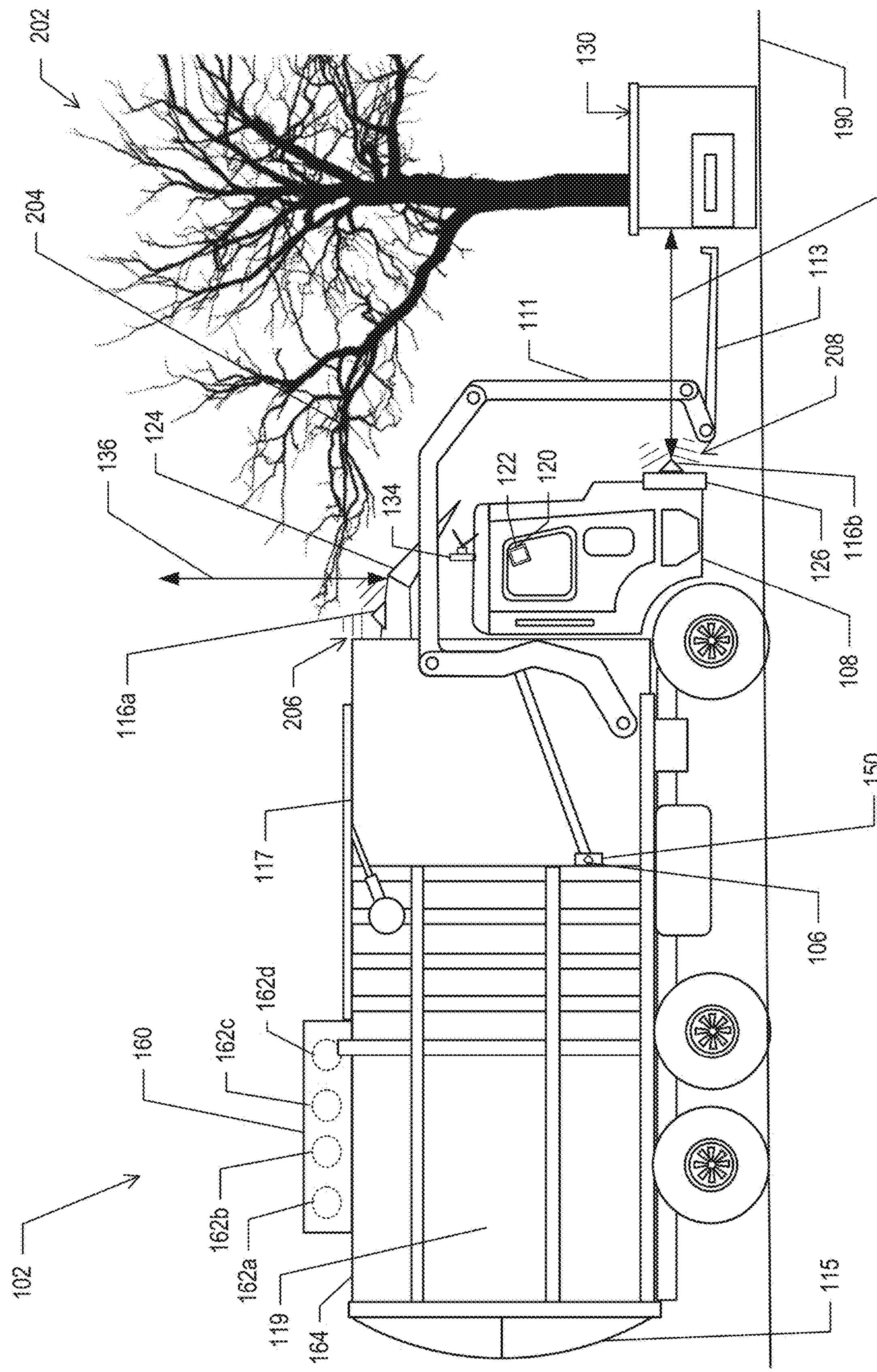

202
204
130
190
138
113
111
208
124
136
134
122
120
126
116b
108
116a
206
150
117
106
162d
162c
160
162b
162a
119
164
115
102

FIG. 2

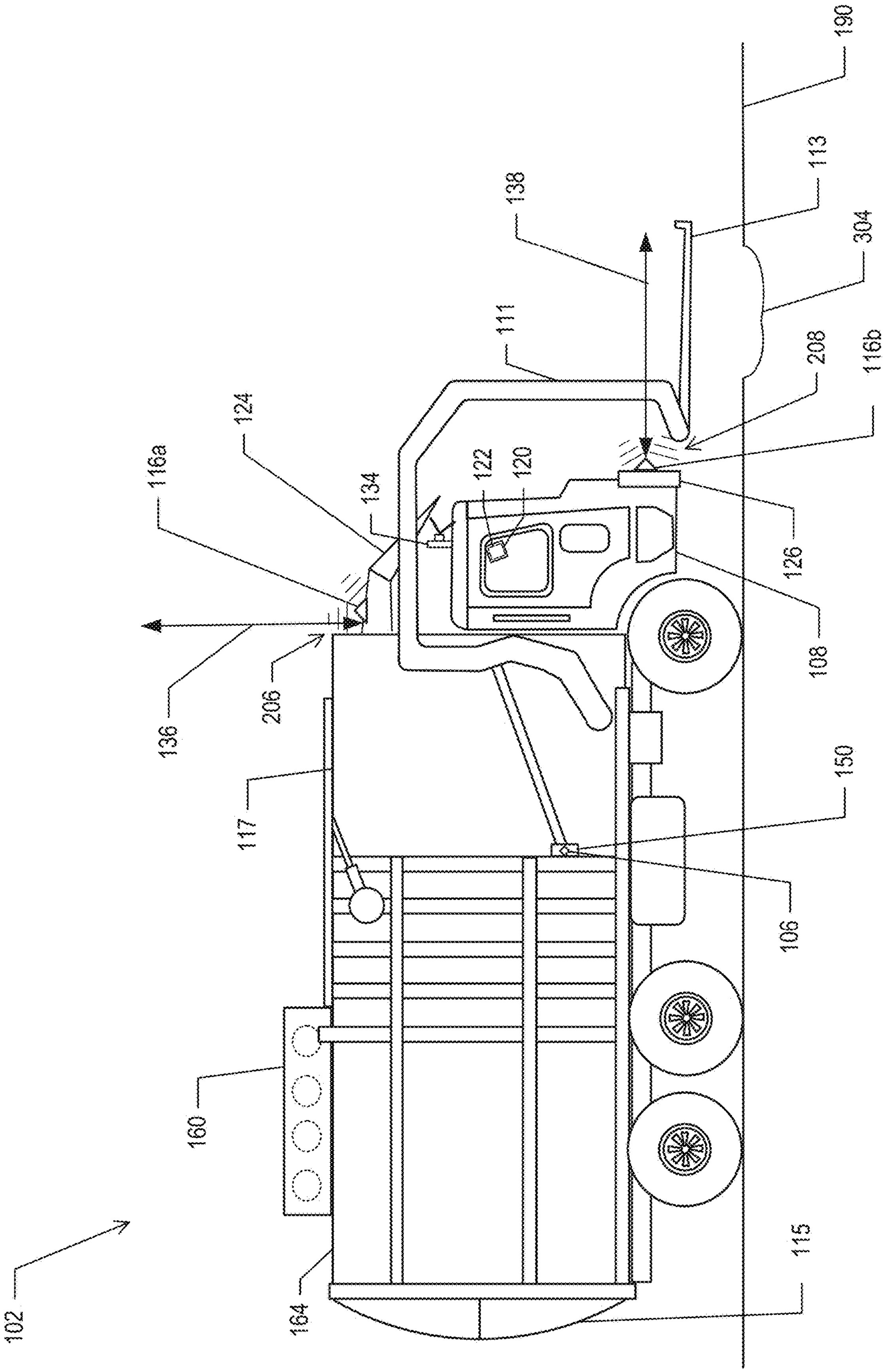

102
164
115
160
117
136
206
116a
124
134
122
120
111
138
113
190
304
208
116b
126
108
150
106

FIG. 3

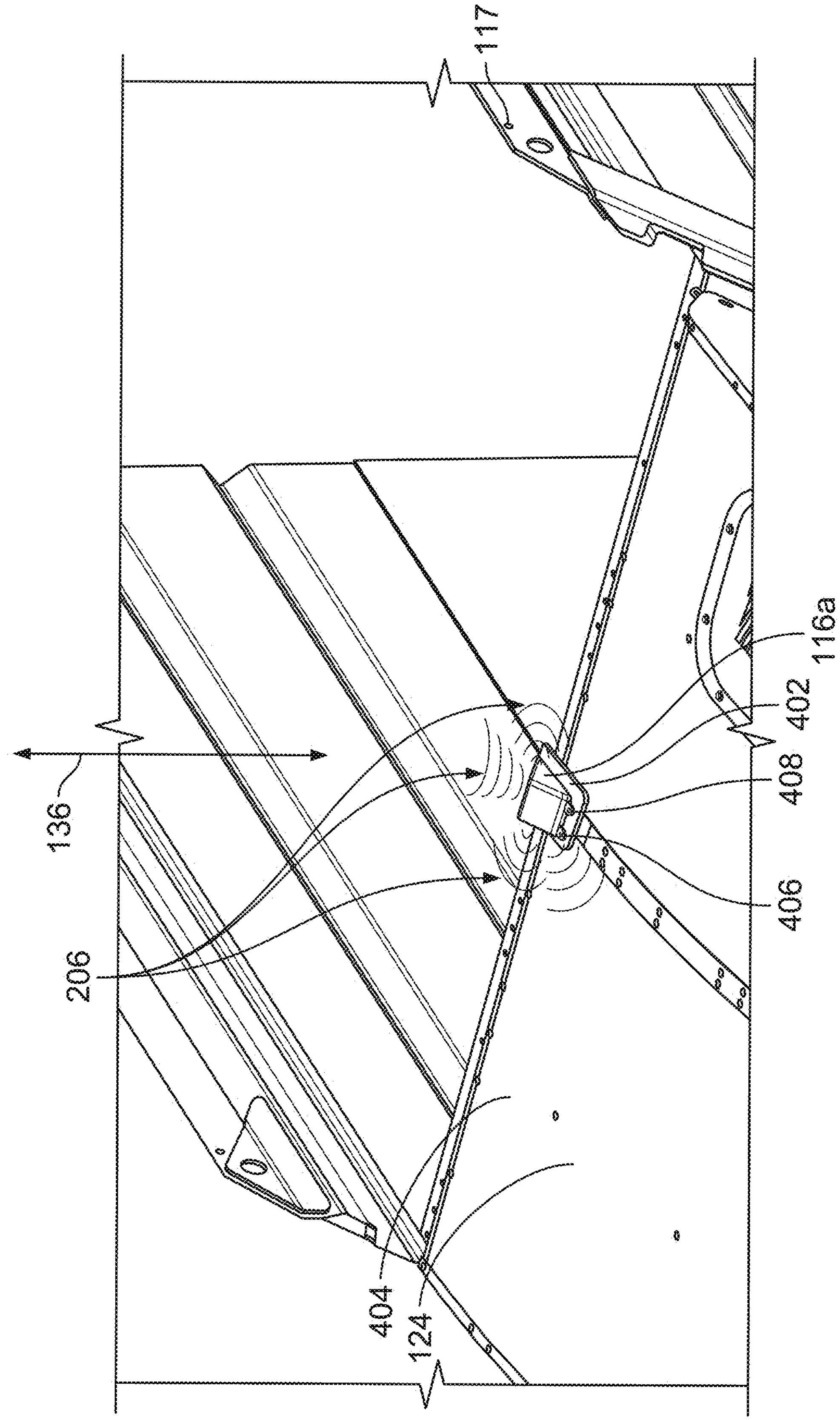


FIG. 4

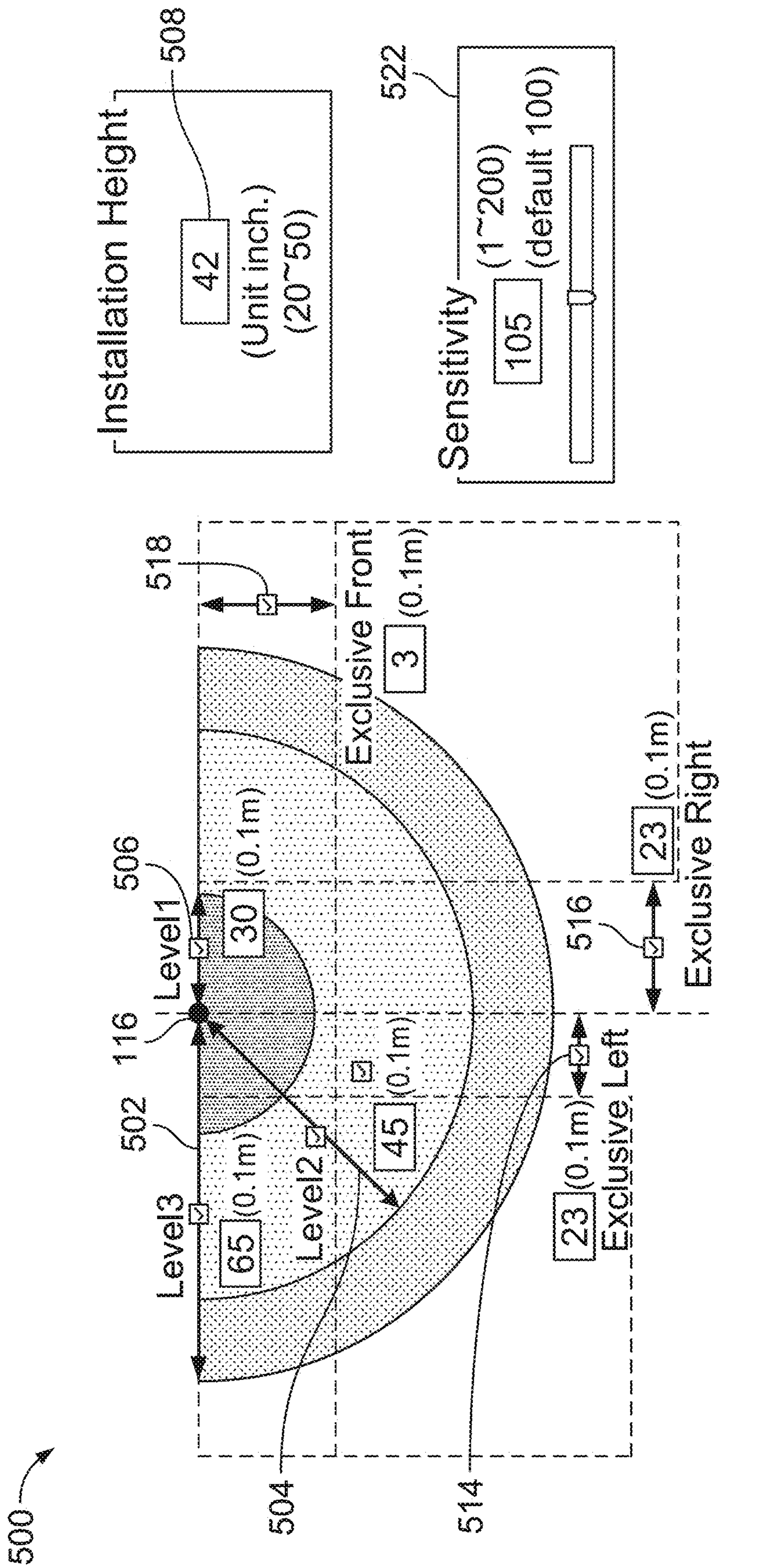

500
Installation Height
42
(Unit inch.)
(20~50)
508
Sensitivity
105
(1~200)
(default 100)
522
518
Exclusive Front
3 (0.1m)
506
Level1
30 (0.1m)
116
502
Level3
65 (0.1m)
Level2
45 (0.1m)
516
Exclusive Right
23 (0.1m)
Exclusive Left
23 (0.1m)
504
514

FIG. 5

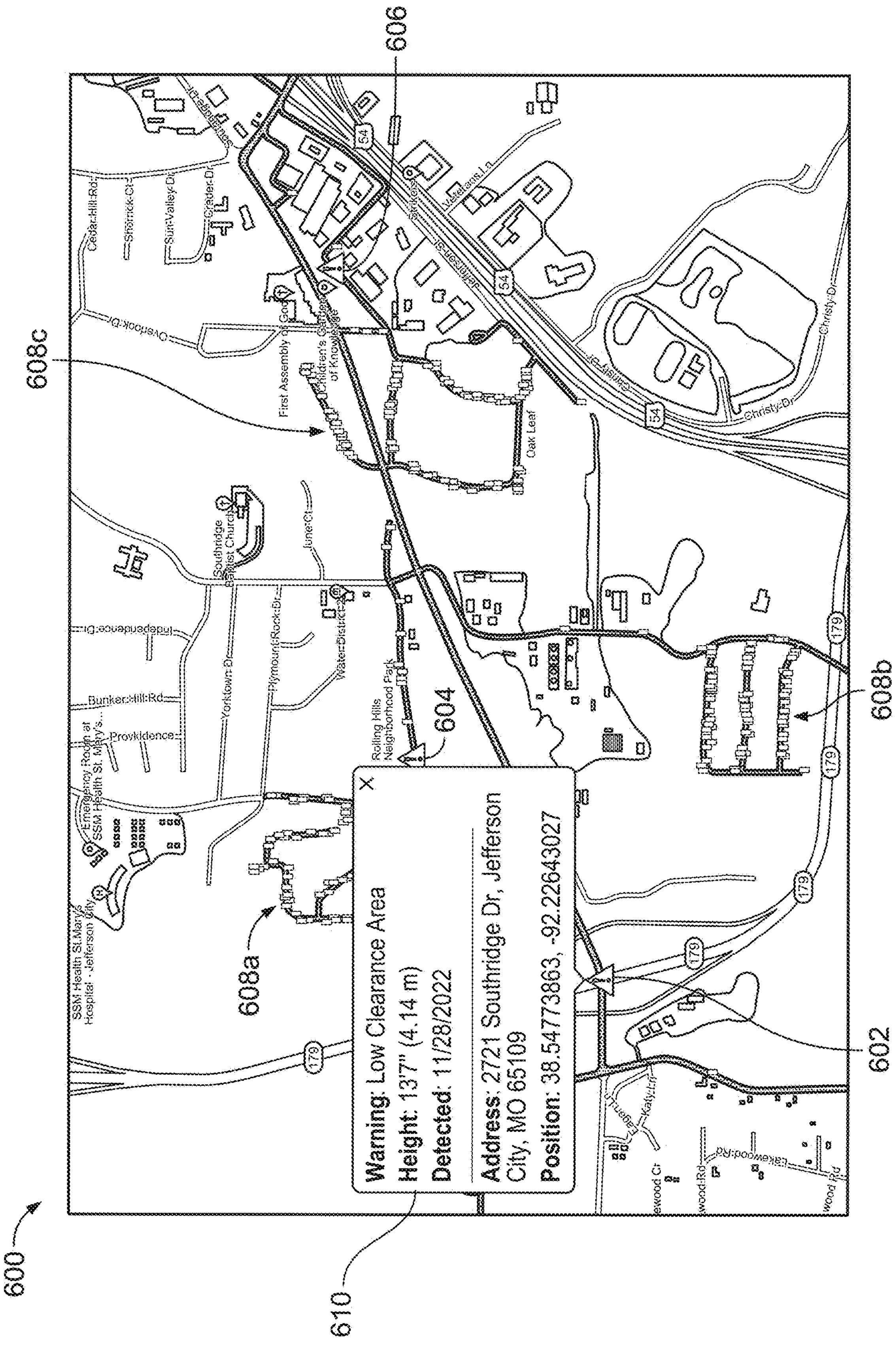

600
602
604
606
608a
608b
608c
610
Warning: Low Clearance Area
Height: 13'7" (4.14 m)
Detected: 11/28/2022
Address: 2721 Southridge Dr, Jefferson City, MO 65109
Position: 38.54773863, -92.22643027
Rolling Hills Neighborhood Park
Southridge Baptist Church
First Assembly of God
Oak Leaf
Yorktown Dr
Bunker Hill Rd
Independence Dr
Plymouth Rock Dr
June Ct
Cedar Hill Rd
Sun Valley Dr
Veterans Ln
Christy Dr
54
179

FIG. 6

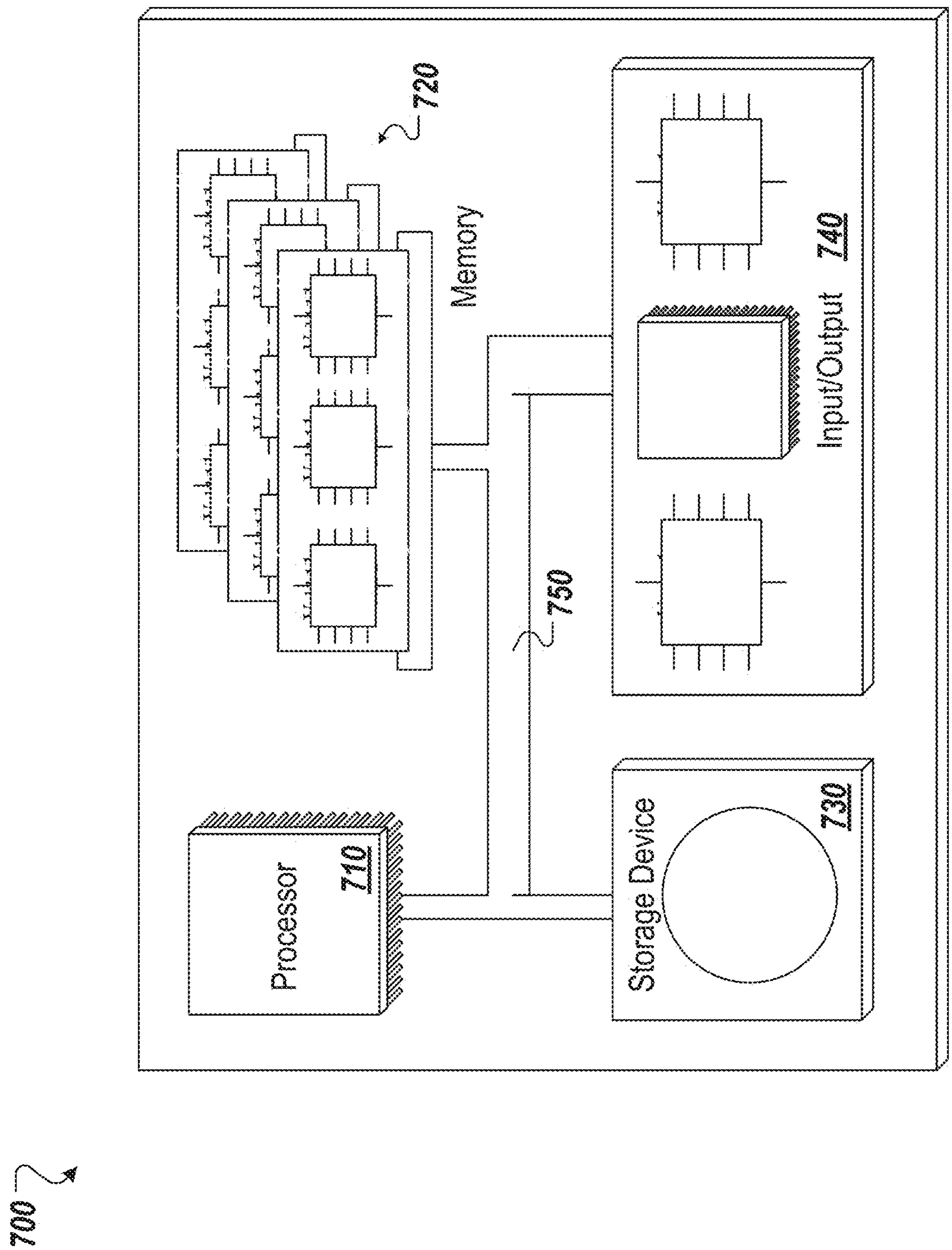

700
720
Memory
Processor
710
750
Storage Device
730
Input/Output
740

FIG. 7

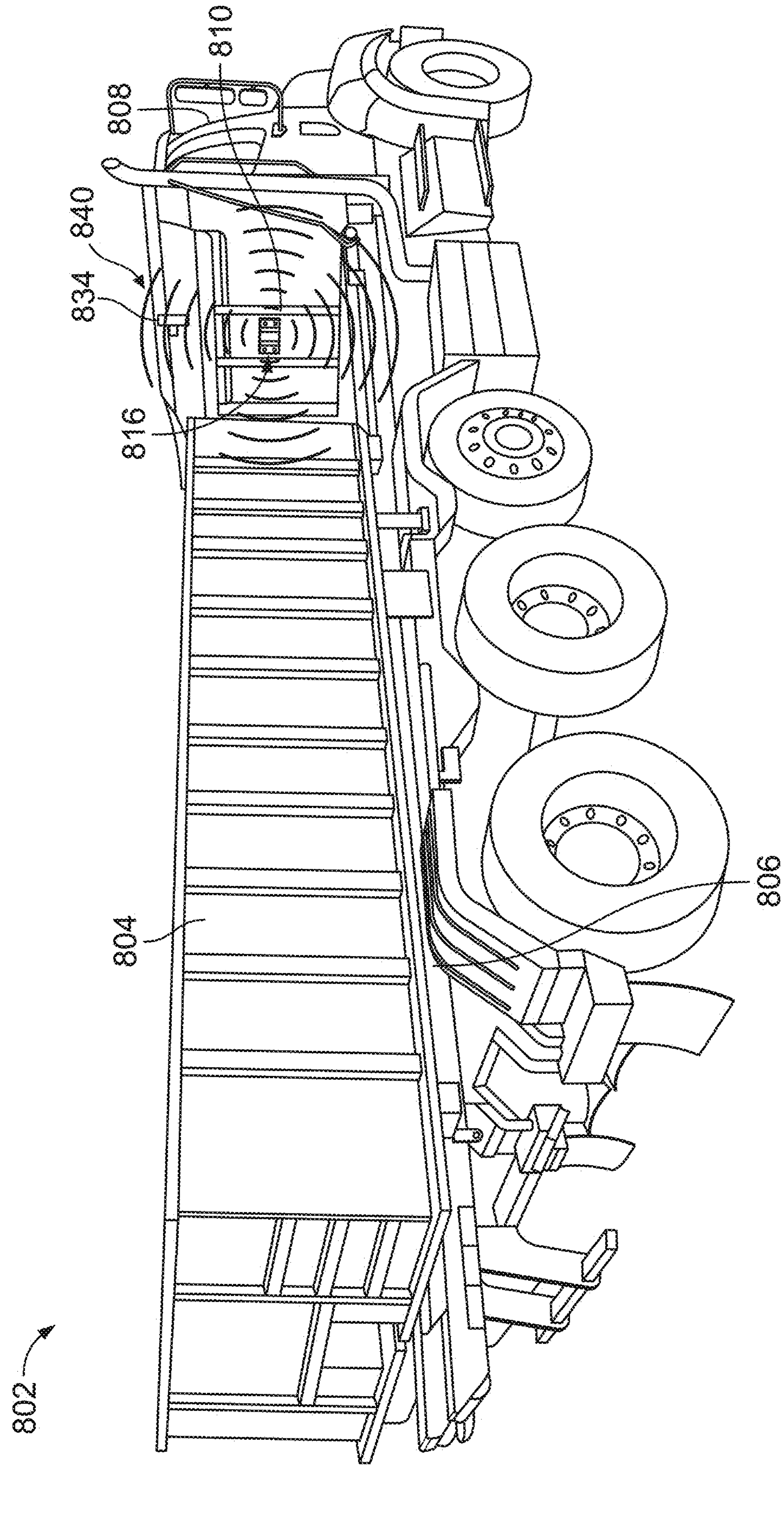


FIG. 8

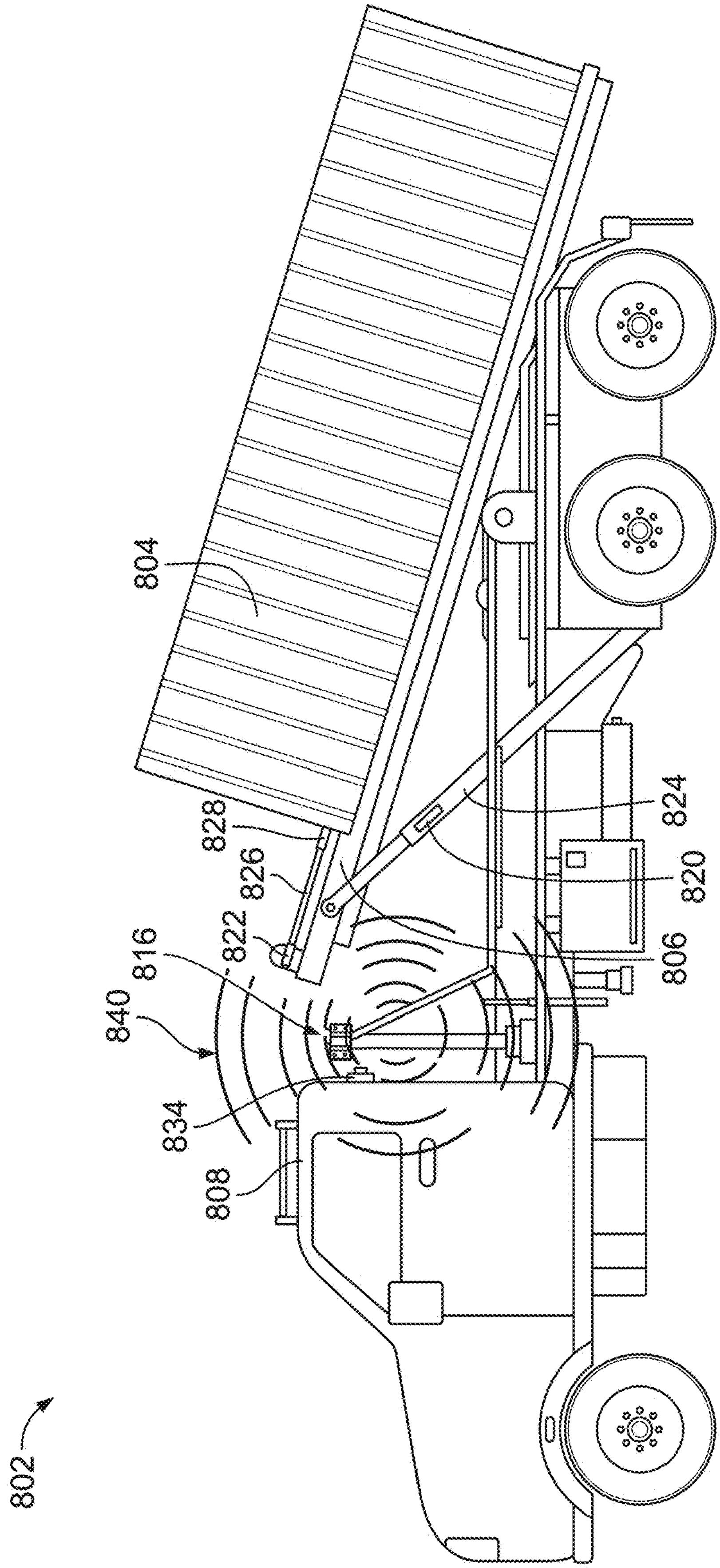


FIG. 9

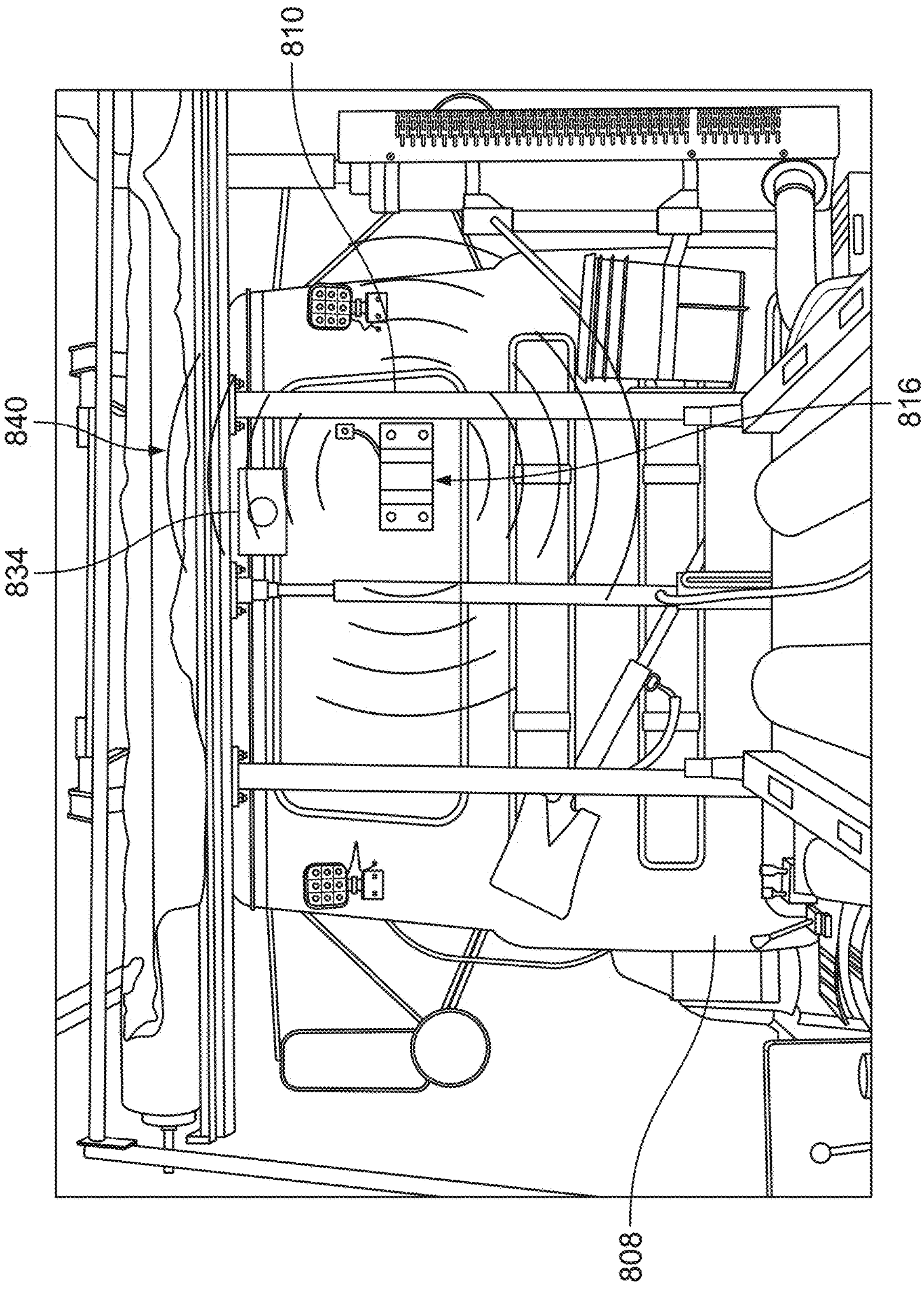


FIG. 10

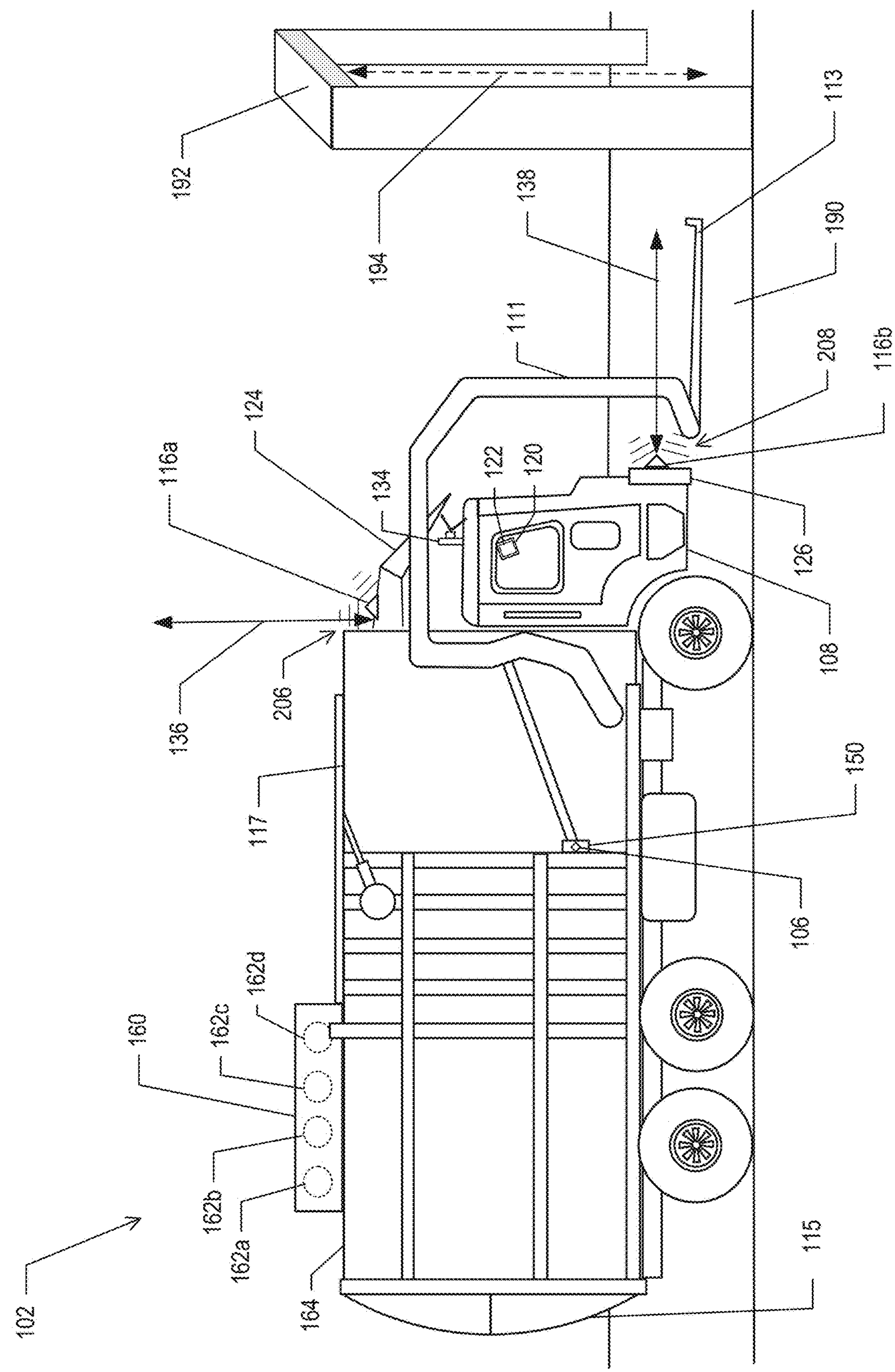

102
160
162a
162b
162c
162d
164
115
117
106
150
136
206
116a
124
134
122
120
108
126
116b
208
111
138
190
113
194
192

FIG. 11

RADAR-BASED ANALYTICS

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims the benefit under 35 U.S.C. § 119(e) of U.S. Patent Application No. 63/554,489, entitled "Radar-Based Analytics," filed Feb. 16, 2024, which is incorporated herein by reference in its entirety.

TECHNICAL FIELD

[0002] This disclosure relates to systems and methods for performing radar-based analytics based on a radar sensor on a refuse collection vehicle.

BACKGROUND

[0003] Refuse collection vehicles collect solid waste and transport the solid waste to landfills, recycling centers, or treatment facilities. The refuse collection routes driven by refuse collection vehicles can involve hazards that are difficult for the driver of the vehicle to detect, such as overhead objects, potholes in the road, and pedestrians near the vehicle.

SUMMARY

[0004] In an example implementation, a system includes a refuse collection vehicle and at least one radar sensor coupled to a portion of the refuse collection vehicle. The refuse collection vehicle includes a chassis and one or more body components. The at least one radar sensor is configured to detect one or more hazards positioned within a detection distance of the at least one radar sensor.

[0005] In an aspect combinable with the example implementation, the one or more hazards positioned within a detection distance of the at least one radar sensor includes one or more objects overlying the refuse collection vehicle.

[0006] In another aspect combinable with any of the previous aspects, the refuse collection vehicle includes a cab protector; and the at least one radar sensor is coupled to the cab protector.

[0007] In another aspect combinable with any of the previous aspects, the one or more objects overlying the refuse collection vehicle include at least one of a tree branch, a power line, or an overpass.

[0008] In another aspect combinable with any of the previous aspects, the detection distance is in a range of 1 foot to 10 feet.

[0009] In another aspect combinable with any of the previous aspects, the one or more hazards positioned within a detection distance of the at least one radar sensor include one or more hazards along a surface on which the refuse collection vehicle is positioned.

[0010] In another aspect combinable with any of the previous aspects, wherein the refuse collection vehicle includes a front bumper; and the at least one radar sensor is coupled to the front bumper.

[0011] In another aspect combinable with any of the previous aspects, the one or more hazards includes a pothole in a road surface.

[0012] In another aspect combinable with any of the previous aspects, the detection distance is in a range of 5 feet to 20 feet.

[0013] In another aspect combinable with any of the previous aspects, the one or more hazards positioned within a detection distance of the at least one radar sensor include an object in front of the refuse collection vehicle and that could result in a potential overhead collision with the refuse collection vehicle.

[0014] In another aspect combinable with any of the previous aspects, the at least one radar sensor includes at least one radar sensor coupled to a cab protector of the refuse collection vehicle.

[0015] In another aspect combinable with any of the previous aspects, data generated by the at least one radar sensor can be used to determine whether a clearance height the of object is less than an overall height of the refuse collection vehicle.

[0016] In another aspect combinable with any of the previous aspects, the refuse collection vehicle comprises one or more fuel tanks coupled to a roof of the refuse collection vehicle.

[0017] In another aspect combinable with any of the previous aspects, the at least one radar sensor is configured to generate a point cloud and process the point cloud to detect the one or more hazards.

[0018] In another aspect combinable with any of the previous aspects, the refuse collection vehicle further includes a camera configured to capture image data or video data of the one or more hazards.

[0019] In another aspect combinable with any of the previous aspects, the system further includes a computing device, and the at least one radar sensor is configured to transmit, to the computing device, a signal indicating the one or more hazards.

[0020] In another aspect combinable with any of the previous aspects, the computing device is an onboard computing device of the refuse collection vehicle.

[0021] In another aspect combinable with any of the previous aspects, the computing device is configured to generate a map comprising one or more elements indicating a location of each of the one or more hazards detected by the at least one radar sensor.

[0022] In another aspect combinable with any of the previous aspects, the refuse collection vehicle includes a display device within the chassis, and the computing device is configured to display the map on the display device.

[0023] In another aspect combinable with any of the previous aspects, the computing device is configured to transmit the map to one or more other computing devices for display.

[0024] In another aspect combinable with any of the previous aspects, the computing device is configured to control at least one of the one or more body components based on the location of each of the one or more hazards indicated in the map.

[0025] In another aspect combinable with any of the previous aspects, the computing device is configured to control at least one of the one or more body components based on receiving the signal indicating the one or more hazards.

[0026] In another aspect combinable with any of the previous aspects, in response to receiving the signal indicating the one or more hazards, the computing device is configured to prevent a lift arm of the refuse collection vehicle from being raised above a threshold height.

[0027] In another aspect combinable with any of the previous aspects, the computing device is configured to generate a visual alert or an audible alert based on receiving the signal indicating the one or more hazards.

[0028] In another example implementation, a method of operating a refuse collection vehicle includes: detecting, using at least one radar sensor coupled to the refuse collection vehicle, a hazard positioned within a detection distance of the at least one radar sensor; transmitting, from the at least one radar sensor to a computing device, a signal indicating the hazard detected by the at least one radar sensor; and in response to receiving the signal, controlling the refuse collection vehicle to prevent damage to the refuse collection vehicle resulting from contact between the hazard and the refuse collection vehicle.

[0029] In an aspect combinable with the example implementation, the hazard includes an object overlying the refuse collection vehicle.

[0030] In another aspect combinable with any of the previous aspects, controlling the refuse collection vehicle to prevent damage to the refuse collection vehicle resulting from contact between the hazard and the refuse collection vehicle includes preventing a lift arm of the refuse collection vehicle from being raised above a threshold height.

[0031] In another aspect combinable with any of the previous aspects, the hazard includes a hazard along a road surface on which the refuse collection vehicle is positioned.

[0032] In another aspect combinable with any of the previous aspects, controlling the refuse collection vehicle to prevent damage to the refuse collection vehicle resulting from contact between the hazard and the refuse collection vehicle includes causing the vehicle to change its position on the road surface to avoid contact with the hazard.

[0033] In another aspect combinable with any of the previous aspects, the hazard includes an object in front of the refuse collection vehicle and that could result in a potential overhead collision with the refuse collection vehicle.

[0034] In another aspect combinable with any of the previous aspects, detecting the hazard includes detecting, based on data generated by the at least one radar sensor, a clearance height of the object; and determining that the clearance height of the object is less than an overall height of the refuse collection vehicle.

[0035] In another aspect combinable with any of the previous aspects, determining the clearance height of the object includes determining, based on data received from the at least one radar sensor, a height of the object relative to a road surface beneath the object.

[0036] In another aspect combinable with any of the previous aspects, controlling the refuse collection vehicle to prevent damage to the refuse collection vehicle resulting from contact between the hazard and the refuse collection vehicle includes alerting a driver of the refuse collection vehicle that the clearance height of the object is less than an overall height of the refuse collection vehicle.

[0037] In another aspect combinable with any of the previous aspects, detecting, the hazard positioned within the detection distance of the at least one radar sensor includes: generating, by the radar sensor, a point cloud; and processing, by the radar sensor, the point cloud to detect the hazard.

[0038] Another aspect combinable with any of the previous aspects includes, in response to receiving the signal, causing a camera coupled to the refuse collection vehicle to capture image data or video data of the hazard.

[0039] In another aspect combinable with any of the previous aspects, the computing device is an onboard computing device of the refuse collection vehicle.

[0040] Another aspect combinable with any of the previous aspects includes generating a map comprising a map element indicating a location of the hazard detected by the radar sensor.

[0041] Another aspect combinable with any of the previous aspects includes displaying the map on a display device within a cab of the refuse collection vehicle.

[0042] Another aspect combinable with any of the previous aspects includes transmitting, by the computing device, the map to one or more other computing devices for display.

[0043] In another aspect combinable with any of the previous aspects, controlling the refuse collection vehicle to prevent damage to the refuse collection vehicle resulting from contact between the hazard and the refuse collection vehicle comprises controlling the refuse collection vehicle based at least partly on a location of each of one or more hazards indicated in the map.

[0044] Another aspect combinable with any of the previous aspects includes in response to receiving the signal, generating a visual alert or an audible alert.

[0045] In another example implementation, a system includes a refuse collection vehicle and at least one radar sensor coupled to a portion of the refuse collection vehicle. The refuse collection vehicle includes a chassis including a bed. The at least one radar sensor is configured to detect a roll-off container positioned on the bed of the refuse collection vehicle.

[0046] In another aspect combinable with the example implementation, the refuse collection vehicle includes a tarp bracket; and the at least one radar sensor is coupled to the tarp bracket.

[0047] In another aspect combinable with any of the previous aspects, the at least one radar sensor is configured to generate a point cloud and process the point cloud to detect whether a roll-off container is positioned on the bed of the refuse collection vehicle.

[0048] In another aspect combinable with any of the previous aspects, the refuse collection vehicle further includes a camera configured to capture image data or video data of the roll-off container.

[0049] In another aspect combinable with any of the previous aspects, the system further includes a computing device, and the at least one radar sensor is configured to transmit, to the computing device, a signal indicating a roll-off container service event performed by the refuse collection vehicle.

[0050] In another aspect combinable with any of the previous aspects, the computing device is configured to store the signal received from the at least one radar sensor together with data related to the roll-off container service event.

[0051] In another aspect combinable with any of the previous aspects, the data related to the roll-off container service event includes at least one of an indication of whether the roll-off container service event was a loading event or an unloading event, a weight of the roll-off container, an indication of whether the roll-off container was full or empty, GPS coordinates corresponding to a location of the roll-off container service event, image data of the roll-off container, video data of the roll-off container, or a timestamp corresponding to the time that signal was generated.

[0052] In another aspect combinable with any of the previous aspects, the computing device is an onboard computing device of the refuse collection vehicle.

[0053] In another aspect combinable with any of the previous aspects, the computing device is configured to generate, based at least partly on the signal, a map comprising one or more elements indicating one or more roll-off container service events performed by the refuse collection vehicle.

[0054] In another aspect combinable with any of the previous aspects, the computing device is configured to transmit the map to one or more other computing devices for display.

[0055] In another aspect combinable with any of the previous aspects, one or more signals generated by the at least one radar sensor are processed to determine whether the roll-off container positioned on the bed of the refuse collection vehicle is full or empty.

[0056] In another aspect combinable with any of the previous aspects, the refuse collection vehicle further includes a hoist configured to be coupled to a roll-off container; and a body sensor configured to detect extension and retraction of the hoist; and one or more signals generated by the body sensor and one or more signals generated by the at least one radar sensor can be used to detect the roll-off container being loaded onto the bed or the roll-off container being unloaded from the bed.

[0057] In another aspect combinable with any of the previous aspects, the one or more signals generated by the body sensor and the one or more signals generated by the radar sensor can be used to detect whether the roll-off container positioned on the bed of the refuse collection vehicle is full or empty.

[0058] In another aspect combinable with any of the previous aspects, the refuse collection vehicle further includes one or more hydraulic cylinders configured to raise and lower the bed; and a body sensor configured to detect extension and retraction of the one or more hydraulic cylinders; and one or more signals generated by the body sensor can be combined with one or more signals generated by the at least one radar sensor to detect the roll-off container being loaded onto the bed or the roll-off container being unloaded from the bed.

[0059] Particular implementations of the subject matter described in this specification can be implemented so as to realize one or more of the following advantages.

[0060] For example, the refuse collection vehicle of the present disclosure can reduce the risk of damage to the vehicle by detecting one or more hazards proximate the refuse collection vehicle using one or more radar sensors. In some implementations, the refuse collection vehicle of the present disclosure prevents injury to people proximate the refuse collection vehicle by detecting people proximate the refuse collection vehicle, such as people inside refuse containers to be serviced by the refuse collection vehicle. In some implementations, the refuse collection vehicle of the present disclosure can optimize refuse collection by detecting, monitoring, and tracking one or more operations performed by the vehicle using one or more radar sensors. In some implementations, the radar sensors coupled to the refuse collection vehicle of the present disclosure can improve accuracy of objection detection on or near the refuse collection vehicle compared to other sensors. For example, the one or more radar sensors of the present disclosure do not require line-of-sight visibility in order to detect objects proximate the sensor and, therefore, can still accurately perform object detection during vibrations caused by the vehicle and when exposed to dirty environments.

[0061] It is appreciated that methods in accordance with the present specification may include any combination of the aspects and features described herein. That is, methods in accordance with the present specification are not limited to the combinations of aspects and features specifically described herein, but also include any combination of the aspects and features provided.

[0062] The details of one or more implementations of the subject matter described in this disclosure are set forth in the accompanying drawings and the description below. Other features, objects, and advantages of the subject matter will be apparent from the description and drawings, and from the claims.

DESCRIPTION OF DRAWINGS

[0063] FIG. **1** depicts an example system for collecting refuse.

[0064] FIG. **2** is a side, schematic view of a front-loader refuse collection vehicle.

[0065] FIG. **3** is another side, schematic view of the refuse collection vehicle of FIG. **2**.

[0066] FIG. **4** is a perspective view of a radar sensor of the refuse collection vehicle of FIG. **2**.

[0067] FIG. **5** depicts one or more settings of the radar sensor of the refuse collection vehicle of FIG. **2**.

[0068] FIG. **6** is an example map generated based on data received from one or more radar sensors of the refuse collection vehicle of FIG. **2**.

[0069] FIG. **7** is a schematic illustration of an example control system or controller for a refuse collection vehicle.

[0070] FIG. **8** is a schematic view of a vehicle for servicing and transporting roll-off containers.

[0071] FIG. **9** is a side, schematic view of the vehicle of FIG. **8**.

[0072] FIG. **10** is schematic view of a radar sensor of the vehicle of FIG. **8**.

[0073] FIG. **11** is another side, schematic view of the refuse collection vehicle of FIG. **2**.

DETAILED DESCRIPTION

[0074] The refuse collection vehicle of the present disclosure includes one or more radar sensors. The radar sensor(s) of the refuse collection vehicle can be used to detect one or more hazards proximate the refuse collection vehicle.

[0075] FIG. **1** depicts an example system for collection of refuse. Vehicle **102** is a refuse collection vehicle that operates to collect and transport refuse (e.g., garbage). The refuse collection vehicle **102** can also be described as a garbage collection vehicle, or garbage truck. The vehicle **102** is configured to lift containers **130** that contain refuse, and empty the refuse in the containers into a hopper of the vehicle **102**, to enable transport of the refuse to a collection site, compacting of the refuse, and/or other refuse handling activities.

[0076] The body components **104** of the vehicle **102** can include various components that are appropriate for the particular type of vehicle **102**. For example, a refuse collection vehicle may be a truck with an automated side loader (ASL). Alternatively, the vehicle may be a front-loading truck, a rear loading truck, a roll-off truck, or some other type of garbage collection vehicle. A vehicle with an ASL may include body components **104** involved in the operation of the ASL, such as an arm and/or grabbers, as well as other body components such as a pump, a tailgate, a packer, and so forth. A front-loading vehicle, such as the example shown in FIG. **2**, may include body components **104** such as a pump, tailgate, packer, fork assembly, commercial grabbers, and so forth. A rear loading vehicle may include body components **104** such as a pump, blade, tipper, and so forth. A roll-off vehicle may include body components such as a pump, hoist, cable, and so forth. Body components **104** may also include other types of components that operate to bring garbage into a hopper of a truck, compress and/or arrange the garbage in the vehicle, and/or expel the garbage from the vehicle.

[0077] The vehicle **102** can include any number of body sensor devices **106** that sense body component(s) **104** and generate sensor data **110** describing the operation(s) and/or the operational state of various body components. The body sensor devices **106** are also referred to as sensor devices, or sensors. Sensors may be arranged in the body components, or in proximity to the body components, to monitor the operations of the body components. The body sensor devices **106** emit signals that include the body sensor data **110** describing the body component operations, and the signals may vary appropriately based on the particular body component being monitored. Body sensor devices **106** can be provided on the vehicle body to evaluate cycles and/or other parameters of various body components. For example, as described in further detail herein, the sensors **106** can detect and/or measure the particular position and/or operational state of body components such a lift arm, a fork assembly, and so forth.

[0078] Body sensor devices **106** can include, but are not limited to, an analog sensor, a digital sensor, a Controller Area Network (CAN) bus sensor, a magnetostrictive sensor, a radio detection and ranging (Radar) sensor, a light detection and ranging (LIDAR) sensor, a laser sensor, an ultrasonic sensor, an infrared (IR) sensor, a stereo camera sensor, a three-dimensional (3D) camera, in-cylinder sensors, or a combination thereof. In some implementations, the body sensor devices **106** may be incorporated into the various body components. Alternatively, the body sensor devices **106** may be separate from the body components.

[0079] The vehicle **102** can also include one or more a radio detection and ranging (radar) sensors **116** that can be used to detect one or more hazards proximate the vehicle **102**. For example, as will be described in further detail herein, the Radar sensor(s) **116** can be used to detect low-lying objects above the vehicle **102**, potholes or other damage or debris along a path travelled by the vehicle **102**, or people near the vehicle **102**. In some implementations, one or more body components **104** of the vehicle **102** can be controlled based on the output of the radar sensors **116**.

[0080] In some implementations, the radar sensors **116** are configured to generate radar sensor data, such as a point cloud, indicating the presence of one or more objects proximate the respective radar sensors **116**. The point cloud generated by the radar sensors **116** includes a discrete set of data points in a two-dimensional (2D) coordinate system. Each data point in the point clouds generated by the respective radar sensor **116** has a set of Cartesian coordinates (X, Y) and represents a single point on a surface of an object proximate the vehicle **102** detected by the respective radar sensor **116**. The Cartesian coordinates of the data points in the point cloud can be used to determine the angle and distance of the detected object relative to the radar sensor **116**. In particular, as will be described in further detail herein, the point clouds generated by the radar sensors **116** can be processed in order to detect, identify, and map one or more potentially hazardous objects proximate the vehicle **102**, such as low-lying branches, potholes, or humans near the vehicle **102**. In some implementations, point clouds are generated at a predefined time interval based on updated data received from the radar sensors **116** to create a set of point clouds, and the set of point clouds can be processed to detect objects proximate the vehicle **102**. For example, a new point cloud can be generated every 30-40 milliseconds based on updated data received from the radar sensors **116**, and two or more point clouds generated consecutively can be processed in combination to detect objects proximate the vehicle **102** as the vehicle **102** moves through an environment.

[0081] In some implementations, the radar sensors **116** are configured to output analog signals or digital signals indicating the presence of one or more objects proximate the respective radar sensors **116**. In some implementations, the radar sensors **116** are configured to output Controller Area Network (CAN) messages to indicating the presence of one or more objects proximate the respective radar sensors **116**.

[0082] In some implementations, the body sensor data **110** and radar sensor data **140** may be communicated from the body sensor devices **106** and the radar sensors **116**, respectively, to an onboard computing device **112** in the vehicle **102**. In some instances, the onboard computing device is an under-dash device (UDU), and may also be referred to as the Gateway. Alternatively, the device **112** may be placed in some other suitable location in or on the vehicle. The body sensor data **110** and radar sensor data **140** may be communicated from the body sensor devices **106** and the radar sensors **116**, respectively, to the onboard computing device **112** over a wired connection (e.g., an internal bus) and/or over a wireless connection. In some implementations, a Society of Automotive Engineers standard J1939 bus in conformance with International Organization of Standardization (ISO) standard 11898 connects the various sensors with the onboard computing device. In some implementations, a Controller Area Network (CAN) bus connects the various the body sensor devices **106** and the Radar sensors **116** with the onboard computing device **112**. For example, a CAN bus in conformance with ISO standard 11898 can connect the various sensors with the onboard computing device. In some implementations, body sensor data **110** and/or the radar sensor data **140** digitize the signals that communicate the sensor data **110**, **140** before sending the signals to the onboard computing device **112**, if the signals are not already in a digital format.

[0083] The analysis of the body sensor data **110** and the radar sensor data **140** can be performed at least partly by the onboard computing device **112**, e.g., by processes that execute on the processor(s) **114**. For example, the onboard computing device **112** can execute processes that perform an analysis of the body sensor data **110** to determine the current position of the body components **104**, such as the lift arm position or the fork assembly position. In some implementations, an onboard program logic controller or an onboard mobile controller perform analysis of the body sensor data

110 to determine the current position of the body components **104**. The onboard computing device **112** can execute processes that perform an analysis of the radar sensor data **140** to detect one or more hazards proximate the vehicle **102**, such as low-lying tree branches, low-lying overpasses, low-lying power lines, potholes in the road, or animals or humans proximate the vehicle **102** (e.g., inside a refuse container). In some implementations, an onboard program logic controller or an onboard mobile controller perform analysis of the Radar sensor data **140** to detect hazards proximate the vehicle **102**.

[0084] The onboard computing device **112** can include one or more processors **114** that provide computing capacity, data storage **166** of any suitable size and format, and network interface controller(s) **118** that facilitate communication of the onboard computing device **112** with other device(s) over one or more wired or wireless networks.

[0085] In some implementations, the vehicle **102** includes a body controller that manages and/or monitors various body components of the vehicle. The body controller of the vehicle **102** can be connected to multiple sensors in the body of the vehicle. The body controller can transmit one or more signals over the J1939 network, or other wiring on the vehicle, when the body controller senses a state change from any of the sensors. These signals from the body controller can be received by the onboard computing device **112** that is monitoring the J1939 network.

[0086] In some implementations, the onboard computing device **112** is a multi-purpose hardware platform. The device can include a under dash unit (UDU) and/or a window unit (WU) (e.g., camera) to record video and/or audio operational activities of the vehicle. The onboard computing device hardware subcomponents can include, but are not limited to, one or more of the following: a CPU, a memory or data storage unit, a CAN interface, a CAN chipset, NIC(s) such as an Ethernet port, USB port, serial port, I2c lines(s), and so forth, I/O ports, a wireless chipset, a global positioning system (GPS) chipset, a real-time clock, a micro SD card, an audio-video encoder and decoder chipset, and/or external wiring for CAN and for I/O. The device can also include temperature sensors, battery and ignition voltage sensors, motion sensors, CAN bus sensors, an accelerometer, a gyroscope, an altimeter, a GPS chipset with or without dead reckoning, and/or a digital can interface (DCI). The DCI cam hardware subcomponent can include the following: CPU, memory, can interface, can chipset, Ethernet port, USB port, serial port, I2c lines, I/O ports, a wireless chipset, a GPS chipset, a real-time clock, and external wiring for CAN and/or for I/O. In some implementations, the onboard computing device **112** is a smartphone, tablet computer, and/or other portable computing device that includes components for recording video and/or audio data, processing capacity, transceiver(s) for network communications, and/or sensors for collecting environmental data, telematics data, and so forth.

[0087] In some implementations, one or more cameras **134** can be mounted on the vehicle **102** or otherwise present on or in the vehicle **102**. The camera(s) **134** each generate image data **128** that includes one or more images of a scene external to and in proximity to the vehicle **102**. In some implementations, one or more cameras **134** are arranged to capture image(s) and/or video of a container **130** before, after, and/or during the operations of body components **104** to engage and empty a container **130**. For example, for a front-loading vehicle, the camera(s) **134** can be arranged to image objects in front of, above, and/or behind the vehicle **102**. As another example, for a side loading vehicle, the camera(s) **134** can be arranged to image objects to the side of the vehicle, such as a side that mounts the ASL to lift containers. In some implementations, the camera(s) **134** can capture video of a scene external to, internal to, and in proximity to the vehicle **102**. In some implementations, the camera(s) **134** are controlled to capture image data and/or video data of a hazard detected by the radar sensors **116** coupled to the refuse collection vehicle **102**.

[0088] In some implementations, the camera(s) **134** are communicably coupled to a graphical display **120** to communicate images and/or video captured by the camera(s) **134** to the graphical display **120**. In some implementations, the graphical display **120** is placed within the interior of the vehicle. For example, the graphical display **120** can be placed within the cab **108** of vehicle **102** such that the images and/or video can be viewed by an operator of the vehicle **102** on a screen **122** of the graphical display **120**. In some implementations, the graphical display **120** is a heads-up display that projects the images and/or video captured by the camera(s) **134** onto the windshield of the vehicle **102** for viewing by an operator of the vehicle **102**. In some implementations, the images and/or video captured by the camera (s) **134** can be communicated to a graphical display **120** of the onboard computing device **112** in the vehicle **102**. Images and/or video captured by the camera(s) **134** can be communicated from the sensors to the onboard computing device **112** over a wired connection (e.g., an internal bus) and/or over a wireless connection. In some implementations, a network bus (e.g., a J1939 network bus, a CAN network bus, etc.) connects the camera(s) with the onboard computing device **112**. In some implementations, the camera(s) are incorporated into the various body components **104**. Alternatively, the camera(s) may be separate from the body components **104**.

[0089] FIGS. **2** and **3** depict example schematics of a refuse collection vehicle. As shown in the example of FIGS. **2** and **3**, the vehicle **102** includes various body components **104** including, but not limited to: a lift arm **111**, a fork assembly **113** (also referred to herein as forks **113**), a back gate or tailgate **115**, and a hopper **117** to collect refuse for transportation.

[0090] Referring to FIG. **2**, in some implementations, the vehicle **102** includes one or more fuel tanks **162***a*, **162***b*, **162***c*, **162***d* (collectively referred to herein as "fuel tanks **162**") that contain a fuel source for powering the chassis and/or one or more body components **104** of the vehicle **102**. The fuel tanks **162** can be used to store various types of gaseous fuel including, but not limited to, compressed natural gas ("CNG") or hydrogen. As depicted in FIGS. **2** and **3**, the fuel tanks **162** can be stored in a in a pod **160** on a top surface **164** (e.g., roof) of the refuse collection vehicle **102**.

[0091] One or more body sensor devices **106** can be situated to determine the state and/or detect the operations of the body components **104**. In the example shown, the vehicle **102** includes a body sensor device **106** that is arranged to detect the position of the lift arm **111** and/or the forks **113**. For example, the body sensor device **106** can provide data about the current position of the lift arm **111** and the forks **113** throughout a cycle to dump refuse from the container **130** into the vehicle **102**. In some implementations, the body sensor device(s) **106** are located in one or more cylinders of the refuse collection vehicle **102**. In some examples, body sensor device **106** is located inside a cylinder **150** used for raising the lift arm **111** and a body sensor device **106** (not shown) is located inside a cylinder used for moving the fork assembly **113** (not shown). In some implementations, body sensor device **106** is located on the outside of a housings containing the cylinder **150** coupled to the lift arm **111**. In some examples, the body sensor device **106** is an in-cylinder, magnetostrictive sensor.

[0092] In some implementations, the vehicle **102** includes one or more cameras **134** oriented to capture images of the exterior of the vehicle **102**. For example, the camera **134** can be configured to capture image data or video data of a scene external to and in proximity to the vehicle **102**, such as in a direction of travel of the vehicle **102**, behind the vehicle **102**, or above the vehicle **102**. As will be described in further detail herein, the image data or video data captured by the camera(s) **134** can be combined with data captured by the radar sensors **116** to detect and track hazards proximate the vehicle **102**.

[0093] Referring to FIGS. **2-4**, the vehicle **102** can include one or more radar sensors **116*a*, 116*b*** (collectively referred to herein as radar sensors **116**). For example, the vehicle **102** includes a first radar sensor **116*a*** coupled to an upper surface of a cab protector **124** of the vehicle **102** and a second radar sensor **116*b*** coupled to a front bumper **126** of the vehicle **102**.

[0094] As can be seen in FIG. **4**, the radar sensor **116*a*** is attached to cab protector **124** proximate the opening of the hopper **117**. In some implementations, the radar sensor **116*a*** is attached to cab protector **124** by fixing the radar sensor **116*a*** to a plate **402** coupled to an upper surface **404** of the cab protector **124** using one or more mechanical fasteners **406**, **408** (e.g., bolts or screws). In some implementations, the plate **402** extends into and is coupled to the hopper **117** of the vehicle **102**. In some implementations, the radar sensor **116*a*** is directly attached to the upper surface **404** of the cab protector **124**, for example, using welding or mechanical attachment devices, such as screws or bolts. Similarly, the radar sensor **116*b*** can be coupled to the front bumper **126** of the vehicle **102** using a plate on the front bumper **126** or via direct attachment by welding or mechanical fasteners.

[0095] The radar sensor **116*a*** attached to the cab protector **124** of the vehicle **102** can be used to detect low-lying objects positioned above the vehicle **102** that may cause interference with one or more body components **104** (e.g., while driving along a collection route or while servicing a refuse container **130**). The radar sensor **116*b*** attached to a front bumper **126** of the vehicle **102** can be used to detect hazards along the path the vehicle **102** is travelling, such as potholes in a road on which the vehicle **102** is currently positioned. In some implementations, the data generated by the radar sensor **116*a*** attached to the cab protector **124** is combined with the data generated by the radar sensor **116*b*** attached to a front bumper **126** of the vehicle **102** to determine a height relative to the road surface **190** of low-lying objects proximate the vehicle **102**. The radar sensors **116** are configured to detect objects proximate the vehicle **102** under various conditions, including during refuse collection operations that cause increased levels of vibration or shock to the sensor **116** and dirty environments that would cause debris to cover the radar sensors **116**.

[0096] An antenna of each of the radar sensors **116*a*, 116*b*** emits radio waves **206**, **208** (e.g., electromagnetic radiation) outwards from the respective radar sensor **116*a*, 116*b***. In some implementations, the radar sensors **116*a*, 116*b*** are each configured to emit radio waves **206**, **208** at a predefined time interval. For example, the radar sensors **116*a*, 116*b*** can be configured to emit radio waves **206**, **208** every 30 milliseconds.

[0097] Referring to FIGS. **2** and **3**, the radio waves **206**, **208** emitted by the radar sensors **116*a*, 116*b*** contact and reflect off of objects that are positioned proximate the respective radar sensor **116*a*, 116*b***, and the reflected radio waves **206**, **208** are detected by a receiver of the respective radar sensor **116*a*, 116*b***. For example, radio waves **206** reflected off of objects above the upper surface **404** of the cab protector **124**, as well as objects in front of and above the vehicle **102** within a particular distance, are detected by a receiver of the radar sensor **116*a*** and radio waves **208** reflected off of objects on the road surface **190** in front of the vehicle **102** are detected by a receiver of the radar sensor **116*b***. The reflected radio waves detected by each of the radar sensors **116*a*, 116*b*** are used to form respective point clouds indicating the presence and position of one or more objects proximate the respective radar sensors **116*a*, 116*b***. The point clouds generated by the radar sensors **116*a*, 116*b*** each include a discrete set of data points in a three-dimensional (3D) coordinate system, with each data point corresponding to a point on the surface of an object proximate the vehicle **102** within the detection distance **136**, **138** of the respective radar sensor **116*a*, 116*b***. The coordinates corresponding to each data point in the point cloud generated by the radar sensor **116*a*, 116*b*** can be used to determine the distance and angle of the respective point on the surface of the detected object relative to the radar sensor **116*a*, 116*b***.

[0098] In some implementations, the point clouds generated by the radar sensors **116*a*, 116*b*** are processed by the respective radar sensor **116*a*, 116*b*** in real time to detect one or more hazards proximate the vehicle **102**. For example, the point cloud generated by the radar sensor **116*a*** is processed by radar sensor **116*a*** in real time to detect one or more hazards overlying the cab protector **124** of the vehicle **102** and objects in front of and above the vehicle **102**, and the point cloud generated by the radar sensor **116*b*** is processed by radar sensor **116*b*** in real time to detect one or more hazards on the surface **190** along which the vehicle **102** is travelling. In some implementations, an object proximate the vehicle **102** is detected based on the size of the point cloud and/or the intensity of the points in the point cloud. For example, the radar sensors **116*a*, 116*b*** can determine that there is an object within a threshold distance of the radar sensor **116*a*, 116*b*** based on detecting that the point cloud generated by the radar sensor **116*a*, 116*b*** is equal to or exceeds a threshold point cloud size and that point cloud includes one of more clusters of points indicating a detected object. In some implementations, clusters indicating the presence of a detected object are portions of the point cloud that have an average intensity of the points within the point cloud equal to or exceeding a threshold intensity.

[0099] In some implementations, the data generated by the radar sensors **116** is processed such that only hazards that are positioned within a particular detection distance **136**, **138** relative to the respective radar sensor **116*a*, 116*b*** are detected. For example, the distance between a particular object or other hazard (such as a pothole) and a radar sensor

116*a*, **116***b* can be determined based on an amount of time that has elapsed between the time that a radio wave **206**, **208** was transmitted by the radar sensor **116***a*, **116***b* and the time that the reflected radio wave was received by the respective radar sensor **116***a*, **116***b*. Reflected radio waves that are received by the radar sensor **116***a*, **116***b* after a particular elapsed time that corresponds to distances greater than the respective detection distance **136**, **138** can be discarded and are not included in the point cloud. As a result, the point cloud only represents objects or other hazards that are positioned within the detection distance **136**, **138** relative to the respective radar sensor **116***a*, **116***b*. In some implementations, the detection distance **136** relative to the radar sensor **116***a* coupled to the cab protector **124** is in a range of 1 foot to 10 feet. In some implementations, the detection distance **138** relative to the radar sensor **116***b* coupled to the front bumper **126** is in a range of 5 feet to 20 feet. In some implementations, the detection distance **136** relative to the radar sensor **116***a* coupled to the cab protector **124** and the detection distance **138** relative to the radar sensor **116***b* coupled to the front bumper **126** are configured to enable detection of objects that are within a particular distance in front of the vehicle **102** and could result in a potential overhead collision with the vehicle **102**. In some implementations, the detection distances **136**, **138** relative to the respective radar sensors **116***a*, **116***b* are configured to detect potential overhead hazards that are in a range of 10 feet to 200 feet in front of the vehicle **102**.

[0100] In some implementations, the detection distances **136**, **138** of the radar sensors **116** are adjusted based on a current speed of travel of the vehicle **102**. For example, as the speed of travel of the vehicle **102** increases, the detection distances **136**, **138** of the radar sensors **116** can increase proportionally to ensure that upcoming objects that may contact the vehicle **102** are detected far enough in advance of the vehicle **102** to provide the operator of the vehicle **102** with sufficient time to avoid contact with the detected object (e.g., by stopping or re-routing the vehicle **102**).

[0101] In some implementations, each radar sensor **116***a*, **116***b* can have multiple levels of detection distances indicating a different respective levels of potential risk a particular hazard presents to the vehicle **102**. FIG. **5** depicts one or more settings of the radar sensors **116** of the refuse collection vehicle of FIG. **2**. For example, the radar sensors **116** can each have an outer ("Level 3") detection distance **502** beyond which hazards are not detected (e.g., detection distances **136**, **138**), and one or more shorter detection distances that are closer to the respective radar sensor **116**, such as an intermediate ("Level 2") detection distance **504** and an inner ("Level 1") detection distance **506**. Objects and other hazards that are detected within the intermediate detection distance **504** or the inner detection distance **506** can be prioritized as being a higher risk than hazards detected only within the outer detection distance **502** due to the closer proximity between the detected hazard and the vehicle **102** for hazards positioned within the intermediate or inner detection distances **504**, **506** compared to detected objects positioned outside the intermediate or inner detection distances **504**, **506**.

[0102] In addition, radar sensors **116** can be configured to limit the distance to the sides (i.e., left or right) of the radar sensor **116** within which hazards can be detected. For example, as depicted in FIG. **5**, a radar sensor **116** can be configured to only detect objects that are within a predefined left detection distance **514** (e.g., 2.3 meters) to the left of the radar sensor **116** and only detect objects that are within a predefined right detection distance **516** (e.g., 2.3 meters) to the right of the radar sensor **116**. In some implementations, the left detection distance **514** and the right detection distance **516** for a radar sensor **116** that is configured to detect hazards behind the vehicle **102** are defined in order to prevent the detection of objects that are positioned to the side of the vehicle **102**, rather than directly behind the vehicle **102**, such as the sides of buildings positioned to the side of the vehicle **102**. As a result, by limiting the left and right detection distances **514**, **516**, a radar sensor coupled to a rear of the vehicle **102** can be used to reliably identify whether an object is positioned within a potential path of travel of the vehicle **102** when the vehicle **102** is backing.

[0103] The detection distances for the radar sensors **116** can also define an excluded distance **518** within which detected objects are not identified as hazards. The excluded distance **518** for a radar sensor **116** can be defined in order to prevent falsely detecting portions of vehicle **102** proximate the radar sensor **116** as hazards. For example, in FIG. **5**, an excluded distance **518** of 0.3 meters is defined for the radar sensor **116** and, as a result, portions of the vehicle or other objects positioned within 0.3 meters of radar sensor **116** in any direction are not identified as hazards when processing the signals generated by the radar sensor **116**.

[0104] In addition, an installation height **520** can be identified for each of the radar sensors **116**, and the installation height **520** of the radar sensor **116** can be used in determining the position of one or more potential hazards in the road proximate the vehicle **102**. For example, an installation height **520** can be set for a radar sensor **116** that is coupled to a bumper of the vehicle **102** (e.g., radar sensor **116***b*) and the installation height **520** for the radar sensor **116** can be used to determine, based on the radar sensor signals, one or more changes in the elevation of the road surface proximate the vehicle that indicate a hazard in the road, such as a pothole proximate the vehicle **102**.

[0105] Referring to FIGS. **5** and **11**, the installation height **520** of each of the radar sensors **116***a*, **116***b* can be used to determine the height of an object being approached by the vehicle **102** relative to the road surface **190** the vehicle **102** is travelling on. For example, data generated by the radar sensor **116***b* coupled to bumper **126** can be processed in view of the installation height of the radar sensor **116***b* in order to determine the vertical location of the road surface **190** relative to the location of the radar sensor **116***b* at a particular distance in front of the vehicle **102**. Data generated by the radar sensor **116***a* coupled to cab protector **124** can be used to detect objects that are located at the same particular distance in front of the vehicle **102** and that are above the level of the cab protector **124** (e.g., overpass **192**).

[0106] Based on the height of the object detected by the radar sensor **116***a* relative to the radar sensor **116***a* and the vertical location of the road surface **190** beneath the detected object **192** relative to the location of the radar sensor **116***b*, the vertical distance **194** between the road surface **190** and the detected object **192** (also referred to herein as "clearance height **194**") can be determined. For example, based on an amount of time that has elapsed between the time that a radio wave **206** was transmitted by the radar sensor **116***a* and the time that the reflected radio wave was received by the radar sensor **116***a*, the vertical distance between the object **192** and the radar sensor **116***a* can be determined. Similarly, based on an amount of time that has elapsed between the time that a radio wave **208** was transmitted by the radar sensor **116***b* and the time that the reflected radio wave was received by the radar sensor **116***b*, the vertical distance between the road surface **190** beneath the object **192** and the radar sensor **116***b* can be determined. Because the installation height of each of the radar sensors **116***a*, **116***b* is known, the vertical difference between the radar sensor **116***a* and radar sensor **116***b* is also known. The clearance height **194** of the detected object **192** can therefore be calculated based on adding the detected vertical distance between the object **192** and the radar sensor **116***a*, the detected vertical distance between the road surface **190** beneath the object **192** and the radar sensor **116***b*, and the vertical distance between the two radar sensors **116***a*, **116***b*.

[0107] The radar sensors **116** can also each have a predefined sensitivity **522**. In some implementations, each of the radar sensors **116** coupled to the vehicle **102** have the same sensitivity **522**. In some implementations, one or more of the radar sensors **116** coupled to the vehicle **102** have a different sensitivity **522**. In some implementations, the sensitivity **522** of the radar sensors **116** is in a range between 1 and 200.

[0108] In some implementations, based on processing the point cloud generated by the radar sensors **116***a*, **116***b* and detecting one or more hazards proximate the vehicle **102**, the radar sensors **116***a*, **116***b* can transmit a CAN message to the onboard computing device **112** of the vehicle **102** indicating the presence of the detected hazards. For example, the radar sensor **116***a* can transmit a CAN message to the onboard computing device **112** of the vehicle **102** indicating detected hazards overlying the vehicle **102** within the detection distance **136** of the radar sensor **116***a*. Similarly, the radar sensor **116***b* can transmit a CAN message to the onboard computing device **112** of the vehicle **102** indicating detected hazards in front of the vehicle **102** within the detection distance **138** of the radar sensor **116***b*. In some implementations, the radar sensors **116***a*, **116***b* transmit a CAN message to the onboard computing device **112** of the vehicle **102** indicating an angular location relative to the respective radar sensor **116***a*, **116***b* for each of the detected hazards. In some implementations, the angular location of the detected hazards relative to the respective radar sensor **116***a*, **116***b* is provided as (X, Y) Cartesian coordinates. In some implementations, in response to detecting a hazard proximate the vehicle, the radar sensors **116***a*, **116***b* can transmit a CAN message to the onboard computing device **112** as a digital (e.g., discrete) output, for example, a positive indication that a hazard located is within the respective detection distance **136**, **138** of the vehicle **102**.

[0109] In response to receiving a signal from one or more of the radar sensors **116***a*, **116***b* indicating that the vehicle **102** is proximate a hazard, the onboard computing device **112** can perform one or more actions to record and/or to respond to the detected hazard. In some implementations, the onboard computing device controls one or more body components **104** of the vehicle **102** in order to prevent or mitigate contact between the vehicle and the detected hazard.

[0110] For example, in response to receiving a signal from the radar sensor **116***a* coupled to the cab protector **124** indicating that an object (e.g., a tree branch, an overpass, or a power line) is positioned above the vehicle **102** within the detection distance **136**, the onboard computing device **112** can control the lift arm **111** of the vehicle to prevent the lift arm from being lifted above a height that would result in contact between the forks **113** or lift arm **111** and the object detected by the radar sensor **116***a*. In some implementations, the onboard computing device **112** receives signals from one or more body sensor devices **106** indicating the current position of the lift arm **111** and the forks **113**, and prevents the lift arm **111** from being raised when the height of the lift arm **111** or the forks **113** indicated by the signals from the body sensor device(s) **106** is within a threshold distance of the object detected by the radar sensor **116***a* in order to prevent collision between the lift arm **111** and/or forks **113** with the detected hazard.

[0111] In some implementations, in response to receiving a signal from the radar sensor **116***b* coupled to the front bumper **126** indicating that a hazard is present in front of the vehicle **102** within the detection distance **138**, such as a pothole in the road surface **190** or debris on the road surface **190**, the onboard computing device **112** can control the vehicle **102** to change its position on the road surface **190** to avoid contact between the vehicle **102** and the detected hazard. In some implementations, in response to receiving a signal from the radar sensor **116***b* coupled to the front bumper **126** indicating that a pothole is within the detection distance **138** of the vehicle **102**, the onboard computing device **112** can control the vehicle **102** to reduce its speed of travel below a threshold speed in order to mitigate damage caused by the vehicle **102** driving through the detected pothole.

[0112] In some implementations, the data generated by one or more of the radar sensors **116***a*, **116***b* can be used to determine whether the fuel pod **160** is likely to contact a low-lying object (e.g., overpass, tree branch, power line, etc.) that the vehicle **102** is approaching. The radar sensors **116***a*, **116***b* can improve the safety of the vehicle by detecting objects the vehicle **102** is approaching that are at risk of contacting the fuel pod **160**.

[0113] In response to determining that an upcoming overhead object (e.g., low-lying tree branch, a low-lying power line, or a low-lying overpass) detected by the radar sensor **116***a* is likely to contact the fuel pod **160** and/or the roof **164** of the vehicle **102**, the onboard computing device **112** can cause a visual alert and/or an audible alert to be generated to alert the driver of the vehicle **102** that an upcoming overhead object is likely to contact the fuel pod **160** and/or the roof **164** of the vehicle **102** if the vehicle passes underneath the detected object. In some implementations, in response to determining that an upcoming overhead object detected by the radar sensor **116***a* is likely to contact the fuel pod **160** and/or the roof **164** of the vehicle **102**, the onboard computing device **112** can control the vehicle **102** to reduce its speed of travel below a threshold speed in order to provide the driver with sufficient time to re-route the vehicle to avoid collision with the overhead object. In some implementations, in response to determining that an upcoming overhead object detected by the radar sensor **116***a* is likely to contact the fuel pod **160** and/or the roof **164** of the vehicle **102**, the onboard computing device **112** can control the vehicle **102** to automatically re-route the vehicle to avoid collision with the object.

[0114] In some implementations, the objection detections are tracked over time using signals received from the radar sensors **116**, and one or more components of the vehicle are controlled based on the object tracking. For example, in some implementations, the onboard computing device **112** locks the position of the lift arm **111** and the forks **113** in response to detecting an overhead object a threshold number of times (e.g., 2 detections, 3 detections, etc.) within a particular time interval (e.g., within 10 milliseconds, 100 milliseconds, 1 second, etc.). The overhead object can be continued to be tracked based on the radar sensor signals and the position of the lift arm **111** and the forks **113** remains locked until the number of detections of an overhead object within the particular time interval is below the threshold. In some implementations, the onboard computing device **112** controls the vehicle **102** to reduce its speed of travel below a threshold speed in response to detecting a pothole a threshold number of times (e.g., 2 detections, 3 detections, etc.) within a particular time interval (e.g., within 10 milliseconds, 100 milliseconds, 1 second, etc.). The pothole can be continued to be tracked based on the radar sensor signals and the speed of the vehicle **102** can continue to be restricted to a threshold speed until the number of detections of a pothole within the particular time interval is below the threshold.

[0115] In some implementations, in response to receiving a signal from one or more of the radar sensors **116***a*, **116***b* indicating that the vehicle **102** is proximate a hazard, the onboard computing device **112** can cause a visual alert and/or an audible alert to be generated that alerts an operator of the vehicle **102** to the presence of the detected hazard. In some implementations, a visual alert is displayed on the screen **122** of display device **120** inside the cab **108** of the vehicle **102** in response to receiving a signal from a radar sensor **116***a*, **116***b* indicating the presence of a hazard proximate the vehicle. In some implementations, the onboard computing device **112** controls one or more body components **104** of the vehicle **102** based on an operator of the vehicle **102** acknowledging, or failing to acknowledge, an alert generated in response to detecting a hazard proximate the vehicle. For example, in response to receiving a signal from one or more of the radar sensors **116***a*, **116***b* indicating that the vehicle **102** is proximate a hazard, the onboard computing device **112** can cause a visual alert to be displayed within the cab **108** of the vehicle **102** (e.g., on the screen **122** of display device **120**), and the onboard computing device can prevent the position of one or more body components **104** of the vehicle (e.g., the lift arm **111**) from being adjusted until the operator of the vehicle has provided an input to acknowledging the displayed alert. In some implementations, in response to determining that an upcoming overhead object (e.g., low-lying tree branch, a low-lying power line, or a low-lying overpass) is likely to contact the fuel pod **160** and/or the roof **164** of the vehicle **102**, the onboard computing device **112** can cause a visual alert and/or an audible alert to be generated to alert the driver of the vehicle **102** that an upcoming overhead object is likely to contact the fuel pod **160** and/or the roof **164** of the vehicle **102** if the vehicle passes underneath the detected object.

[0116] In some implementations, in response to receiving a signal from one or more of the radar sensors **116***a*, **116***b* indicating that the vehicle **102** is proximate a hazard, the onboard computing device **112** can store information related to the detected hazard, including, but not limited to, a size of the detected hazard, a type of object corresponding to the detected hazard (e.g., a low-lying tree branch, a low-lying power line, a low-lying overpass, or a pothole), GPS coordinates corresponding to the location of the detected hazard, image data and/or video data of the detected hazard, the detected clearance height **194** of an overhead object, and a timestamp corresponding to the time that the hazard was detected by the radar sensor **116**. The data related to the detected hazard can be stored (e.g., in a database) by the onboard computing device **112** or by a remote computing device (i.e., a computing device located remotely from the vehicle **102**).

[0117] In some implementations, in response to receiving a signal from one or more of the radar sensors **116***a*, **116***b* indicating that the vehicle **102** is proximate a hazard, the onboard computing device **112** causes one or more cameras **134** coupled to the vehicle **102** to capture image and/or video data of the hazard detected by the radar sensor **116***a*, **116***b*. The image data and/or video data captured by the one or more cameras **134** can include a timestamp, and the data captured by the camera(s) **134** can be identified as corresponding to a detected hazard based on a signal received from a radar sensor **116***a*, **116***b*. The onboard computing device **112** or a remote computing device can process the data captured by the camera(s) **134** and the signals received from the radar sensors **116***a*, **116***b* to determine image and/or video data corresponding to a detected hazard, and store the corresponding image and/or video data together with other data related to the detected hazard.

[0118] In some implementations, the GPS coordinates of a hazard detected by a radar sensor **116***a*, **116***b* can be determined and stored together with other data related to the hazard detected by the radar sensor **116***a*, **116***b*. In some implementations, the GPS coordinates of the detected hazard are determined based on the GPS coordinates of the vehicle **102** at the time the signal corresponding to the respective hazard is generated by the radar sensor **116***a*, **116***b*. In some implementations, the GPS coordinates of the detected hazard are determined based on the GPS coordinates of the vehicle **102** at the time the signal corresponding to the respective hazard is received by the onboard computing device **112** from the respective radar sensor **116***a*, **116***b*. The onboard computing device **112** or a remote computing device can determine the GPS location of the detected hazard and store the GPS location with other data related to the detected hazard.

[0119] In some implementations, the size of the hazard and the type of hazard detected by a radar sensor **116***a*, **116***b* is determined based on processing the point cloud generated by the radar sensor **116***a*, **116***b* to detect one or more characteristics of the point cloud corresponding to a particular object hazard type. For example, the point cloud generated by a radar sensor **116***a*, **116***b* can be processed (e.g., by the radar sensor **116***a*, **116***b*, by the onboard computing device **112**, or by a remote computing device) using machine learning based processing techniques to determine the type of object (e.g., a low-lying tree branch, a low-lying power line, a low-lying overpass, a pothole, etc.) corresponding to the respective hazard detected by the radar sensor **116***a*, **116***b*. In some implementations, image data and/or video data captured by the camera(s) **134** of the vehicle **102** can be used to determine the size of the hazard and the type of object corresponding to the hazard detected by a radar sensor **116***a*, **116***b*. For example, image data and/or video data captured by the camera(s) **134** of the vehicle **102** can be processed (e.g., by the onboard computing device **112** or by a remote computing device) using machine learning based image processing techniques to determine the size of the hazard and the type of object (e.g., a low-lying tree branch, a low-lying power line, a low-lying overpass, a pothole, etc.) corresponding to the respective hazard.

[0120] In some implementations, the hazards detected by the radar sensors **116***a*, **116***b* can be recorded in a hazards map **600**. For example, based on the signals received from the radar sensors **116***a*, **116***b*, a processor (e.g., onboard computing device **112** or a remote computing device) can generate a map **600** that includes hazard warning map elements **602**, **604**, **606** that each indicate the location of a respective hazard detected by a radar sensor (e.g., radar sensors **116***a*, **116***b*) of a refuse collection vehicle (e.g., vehicle **102**). As can be seen in FIG. **6**, the hazard warning map elements **602**, **604**, **606** are overlaid on a topographical map at a GPS location of the corresponding hazard detected by a radar sensor on a refuse collection vehicle. The hazard map **600** can also include map elements **608***a*, **608***b*, **608***c* indicating service events performed by a refuse collection vehicle, such as collection of refuse from refuse containers. In some implementations, the hazard map **600** is generated based on signals received from radar sensors positioned on multiple refuse collection vehicles.

[0121] The hazard map **600** can be displayed to a user (e.g., an operator of the vehicle **102**) on a display device, such as the screen **122** of the graphical display **120** positioned within the cab **108** of the vehicle **102**. An operator of the vehicle **102** can review the hazard map **600** to determine, and potentially avoid, one or more previously detected hazards in advance of or while travelling along a refuse collection route. In some implementations, the hazard map **600** is transmitted (e.g., by the onboard computing device **112** or by a remote computing device) to one or more entities associated with the location of a detected hazards included in the hazard map **600**. For example, in response to detecting a low-lying tree branch hazard located at a particular property, a hazard map with a hazard warning indicator corresponding to the detected tree branch hazard can be transmitted to a computing device of an entity associated with the property (e.g., the owner of the respective property).

[0122] As depicted in FIG. **6**, in response to a user selecting a particular hazard warning map element **602**, an informational map element **610** is displayed on the map **600** proximate the selected hazard warning map element **602**. The informational map element **610** displays one or more data items related to the hazard represented by the respective hazard warning map element **602**. For example, as depicted in FIG. **6**, the informational map element **610** for the selected hazard warning map element **602** displays the type of hazard detected at the respective location (e.g., a "Low Clearance" hazard), the clearance height of the hazard, relevant location information for the detected hazard (e.g., an address corresponding to the hazard and GPS coordinates corresponding to the hazard), and the date the hazard was detected by a radar sensor. In some implementations, the informational map element **610** for a respective hazard warning map element **602** can display one or more other items of data related to the hazard including, but not limited to, image data related to the detected hazard, video data related to the detected hazard, a size of the detected hazard, and a time that the hazard was detected by a radar sensor.

[0123] In some implementations, a refuse collection vehicle (e.g., vehicle **102**) can be controlled based on one or more hazards that are identified in a previously-generated hazard map **600**. For example, the speed of the vehicle **102** can automatically be limited to a threshold speed when the vehicle **102** is travelling in an area that the hazard map **600** indicates as having road hazards. In addition, the position of the lift arm **111** and the forks **113** can be automatically locked when the vehicle **102** is travelling in an area that the hazard map **600** indicates as having overhead hazards. The vehicle **102** can be re-routed to avoid an area that the hazard map **600** indicates as having overhead hazards with a clearance height that is less than or equal to the height of the vehicle **102**.

[0124] An example process for detecting a hazard overlying the vehicle **102**, such as a low lying tree branch, overpass, or power line, will now be described with reference to FIGS. **1**, **2**, and **6**. As depicted in FIG. **2**, a refuse container **130** to be serviced by the vehicle **102** is positioned underneath a tree **202** with a low-lying tree branch **204** that would contact the lift arm **111** and the forks **113** of the vehicle **102** when the lift arm **111** is raised to dump the contents of the refuse container **130** into the hopper **117**. As the vehicle **102** approaches the refuse container **130**, the radar sensor **116***a* coupled to the cab protector **124** emits radio waves **206** outwards a detection distance **136** away from the radar sensor **116***a*, and the radio waves **206** contact and are reflected off of objects within a volume around the radar sensor **116***a* defined by the detection distance **136**, including the tree branch **204**. Radio waves **206** emitted by the radar sensor **116***a* that are reflected off of the tree branch **204** are detected by a receiver of the radar sensor **116***a*, and the radar sensor **116***a* generates a point cloud based on the reflected radio waves **206** detected by a receiver of the radar sensor **116***a*. As previously described, the radar sensor **116***a* can process the point cloud to detect that a hazard **204** is overlying the vehicle **102** at the current location of the vehicle **102**. In some implementations, the point cloud can be processed to determine that the hazard **204** overlying the vehicle is a tree branch. As previously discussed, in addition to detecting low-lying tree branches, the radar sensor **116***a* can be used to detect other types of overlying hazards, such as low-lying power lines or overpasses.

[0125] In response to detecting the tree branch **204**, the radar sensor **116***a* transmits a CAN message to the onboard computing device **112** of the vehicle **102** indicating the presence of the tree branch hazard **204** detected by the radar sensor **116***a*. In some implementations, the CAN message transmitted by the radar sensor **116***a* includes an angular location of the tree branch hazard **204** relative to the radar sensor **116***a*. In some implementations, the CAN message transmitted by the radar sensor **116***a* includes a digital (e.g., discrete) output that indicates that an object is overlying the vehicle **102** within the detection distance **136** of the radar sensor **116***a*.

[0126] In response to receiving a signal from the radar sensor **116***a* that a tree branch **204** is positioned above the vehicle **102** within the detection distance **136** of the radar sensor **116***a*, the onboard computing device **112** can prevent the lift arm **111** of the vehicle from being lifted above a threshold height that would result in contact between forks **113** or lift arms **111** and the tree branch **204** detected by the radar sensor **116***a*. For example, based on the signal received from the radar sensor **116***a*, the onboard computing device **112** can determine a height of the tree branch **204** and can prevent the lift arm **111** and forks **113** from being raised above the detected height of the tree branch **204**. In some implementations, the onboard computing device **112** receives signals from one or more body sensor devices **106** indicating the current position of the lift arm **111** and the forks **113**, and prevents the lift arm **111** from being raised when the height of the lift arm **111** or the forks **113** indicated by the signals received from the body sensor device(s) **106** is within a threshold distance of the height of the tree branch **204** detected by the radar sensor **116***a*. In some implementations, in response to receiving a signal from the radar sensor **116***a* indicating the tree branch hazard **204**, the onboard computing device **112** can cause a visual alert and/or an audible alert to be generated indicating the presence of the tree branch **204** detected by the radar sensor **116***a*. For example, in response to receiving a signal from the radar sensor **116***a* indicating that a tree branch **204** is positioned above the vehicle **102**, the onboard computing device **112** can cause a visual alert to be displayed within the cab **108** of the vehicle **102** (e.g., on the screen **122** of display device **120**), and can prevent the lift arm **111** from being raised above a threshold height until the operator of the vehicle has provided an input acknowledging the displayed alert.

[0127] In response to the radar sensor **116***a* detecting the tree branch hazard **204**, data related to the detected tree branch hazard **204** can be captured and recorded by the onboard computing device **112**. For example, in response to receiving the signal from the radar sensor **116***a* indicating the tree branch hazard **204**, the onboard computing device **112** can control a camera **134** coupled to the vehicle **102** to capture image data and/or video data of the tree branch **204**, and the data captured by the camera **134** can be stored together with other data related to the detected tree branch hazard **204**. In addition, the location of the detected tree branch hazard **204** can be recorded in a hazard map (e.g., hazard map **600** of FIG. **6**) by displaying a hazard warning map element (e.g., map element **602** of FIG. **6**) at a location corresponding to the GPS location of the vehicle **102** at the time the radar sensor signal corresponding to the tree branch **204** was generated by the radar sensor **116***a* or was received by the vehicle **102**. As previously discussed, the hazard map can also be used to display additional data related to the detected tree branch hazard **204**, including, but not limited to, the size of the tree branch **204**, the type of object corresponding to the hazard **204** (i.e., tree branch), GPS coordinates corresponding to the location of the tree branch hazard **204**, image data and/or video data of the tree branch hazard **204**, and a timestamp corresponding to the time that the tree branch hazard **204** that was detected by the radar sensor **116***a*.

[0128] An example process for detecting a potential collision between the fuel pod **160** of the vehicle **102** and an overhead hazard that the vehicle **102** is approaching, such as a low lying tree branch, overpass, or power line, will now be described with reference to FIGS. **1**, **6**, and **11**. As depicted in FIG. **11**, a vehicle **102** is travelling along a road surface **190** and approaching an overpass **192** extending over the road surface **190**. As the vehicle **102** approaches the overpass **192**, the radar sensor **116***a* coupled to the cab protector **124** emits radio waves **206** away from the radar sensor **116***a* and the radio waves **206** contact and are reflected off of objects within a volume around the radar sensor **116***a* defined by the detection distance **136**, including the overpass **192**. Radio waves **206** emitted by the radar sensor **116***a* that are reflected off of the overpass **192** are detected by a receiver of the radar sensor **116***a*, and the radar sensor **116***a* generates a point cloud based on the reflected radio waves **206** detected by a receiver of the radar sensor **116***a*. As previously described, the radar sensor **116***a* can process the point cloud to detect that the vehicle **102** is approaching a potential overhead hazard **192**. In some implementations, the point cloud can be processed to determine that the hazard **192** is an overpass.

[0129] As previously discussed, the data generated by the radar sensors **116***a*, **116***b* can also be used to determine a height of the approaching overhead hazard **192**. For example, data generated by the radar sensors **116***a*, **116***b* can be processed to determine a height of the overpass **192** relative to the road surface **190**, and the detected height of the overpass **192** can be used to determine whether any portion of the vehicle **102**, such as the fuel pod **160** and/or the roof **164** of the vehicle **102**, is at risk of contacting the overpass **192**. For example, the onboard computing device **112** can compare the detected height of the overpass **192** with the overall height of the vehicle, including the fuel pod **160**, to determine whether the height of the overpass **192** is less than or substantially equal to the overall height of the vehicle **102** or that the height of the overpass is greater than the overall height of the vehicle **102** by less than a threshold amount. In response to determining that the height of the overpass **192** is less than or substantially equal to the overall height of the vehicle **102** or that the height of the overpass is greater than the overall height of the vehicle **102** by less than a threshold amount, the onboard computing device **112** determines that the fuel pod **160** and/or roof **164** of the vehicle **102** is at risk of contacting the upcoming overpass if the vehicle **102** travels underneath the overpass **192**.

[0130] In response to determining that the fuel pod **160** and/or roof **164** of the vehicle **102** is at risk of contacting the approaching overpass if the vehicle **102** travels underneath the overpass **129**, the onboard computing device **112** can cause a visual alert and/or an audible alert to be generated indicating that the vehicle **102** is at risk of coming into contact with an upcoming overhead object. For example, in response to determining, based on a signal from the radar sensor **116***a*, the height of an upcoming overpass **192** and determining that the vehicle **102** is at risk of contacting the upcoming overpass **192** if the vehicle **102** travels underneath the overpass **192**, the onboard computing device **112** can cause a visual alert to be displayed within the cab **108** of the vehicle **102** (e.g., on the screen **122** of display device **120**) alerting the driver of the vehicle **102** of the potential collision and suggesting that the driver of the vehicle **102** change the route to avoid collision with the detected overhead hazard **192**. In some implementations, in response determining that the vehicle **102** is at risk of contacting the upcoming overpass **192** if the vehicle **102** travels underneath the overpass **192**, the onboard computing device **112** can generate a visual and/or audible alert to notify the driver of the detected height of the overpass **192** relative to the road surface **190** (the clearance height **194** of the overpass **192**).

[0131] In some implementations, determining that the vehicle **102** is at risk of contacting the upcoming overpass **192** if the vehicle **102** travels underneath the overpass **192**, the onboard computing device **112** can cause the vehicle **102** to automatically reduce its speed of travel below a threshold speed in order to provide the driver with sufficient time to avoid collision between the vehicle **102** and the overpass **192**. In some implementations, for example, if the vehicle

102 is being driven autonomously or semi-autonomously, the onboard computing device **112** can automatically reroute the vehicle **102** to prevent the vehicle **102** from passing underneath the overpass **192** in response to detecting that the vehicle **102** is at risk of contacting the upcoming overpass **192** if the vehicle **102** travels underneath the overpass **192**.

[0132] In response to the radar sensor **116***a* detecting the overpass hazard **192**, data related to the detected overpass hazard **192** can be captured and recorded by the onboard computing device **112**. For example, in response to receiving the signal from the radar sensor **116***a* indicating the overhead hazard **192**, the onboard computing device **112** can control a camera **134** coupled to the vehicle **102** to capture image data and/or video data of the overpass **192**, and the data captured by the camera **134** can be stored together with other data related to the detected overhead hazard **192**, such as the detected height of the overhead hazard **192** relative to the road surface **190** (the clearance height **194** of the overhead hazard **192**). In addition, the location of the detected overhead hazard **192** can be recorded in a hazard map (e.g., hazard map **600** of FIG. **6**) by displaying a hazard warning map element (e.g., map element **602** of FIG. **6**) at a location corresponding to the GPS location of the vehicle **102** at the time the radar sensor signal corresponding to the overhead hazard **192** was generated by the radar sensor **116***a* or was received by the vehicle **102**. As previously discussed, the hazard map can also be used to display additional data related to the detected overhead hazard **192**, including, but not limited to, the height **194** of the hazard **192** relative to the road surface **190**, the type of object corresponding to the hazard **192** (i.e., overpass), GPS coordinates corresponding to the location of the hazard **192**, image data and/or video data of the hazard **192**, and a timestamp corresponding to the time that the hazard **192** that was detected by the radar sensor **116***a*.

[0133] An example process for detecting a hazard along a road surface **190** in front of the vehicle **102**, such as debris on the road surface **190** or a pothole in the road surface **190**, will now be described with reference to FIGS. **1**, **3**, and **6**. As depicted in FIG. **3**, while driving along a refuse collection route, a vehicle **102** may approach a pothole **304** or other surface defect in the road **190** that would potentially cause damage to vehicle **102**. As the vehicle **102** travels along the road surface **190**, the radar sensor **116***b* coupled to the front bumper **126** emits radio waves **208** outwards a detection distance **138** away from the radar sensor **116***b*. The radio waves **208** emitted by the radar sensor **116***b* contact and are reflected off of objects within a volume around the radar sensor **116***b* defined by the detection distance **138**, including the pothole **304**. Radio waves **208** emitted by the radar sensor **116***a* that are reflected off the pothole **304** in the road surface **190** ahead of the vehicle are detected by a receiver of the radar sensor **116***b*, and the radar sensor **116***b* generates a point cloud based on the reflected radio waves **208** detected by the radar sensor **116***b*. As previously described, the radar sensor **116***b* can process the point cloud to detect that a hazard **304** is positioned in front of the vehicle **102**. In some implementations, the point cloud can be processed to determine that the hazard **304** is a pothole **304** in the road surface **190** in front of the vehicle **102**. For example, a pothole **304** proximate the vehicle **102** can be detected based on receiving signals from the radar sensor **116***b* indicating that the distance between the radar sensor **116***b* and a particular area of the road surface corresponding to the pothole **304** is larger than the detected distance between the radar sensor **116***b* and the road surface surrounding the pothole **304** or an expected distance between the radar sensor **116***b* and the road surface (e.g., based on the installation height of the radar sensor **116**).

[0134] In response to detecting the pothole **304** in front of the vehicle **102**, the radar sensor **116***b* transmits a CAN message to the onboard computing device **112** of the vehicle **102** indicating the presence of the pothole hazard **304** detected within the detection distance **138** of the radar sensor **116***b*. In some implementations, the CAN message transmitted by the radar sensor **116***b* includes an angular location of the pothole **304** relative to the radar sensor **116***b*. In some implementations, the CAN message transmitted by the radar sensor **116***b* includes a digital (e.g., discrete) output that indicates that a hazard is located within the detection distance **138** of the radar sensor **116***b*.

[0135] In response to receiving a signal from the radar sensor **116***b* coupled indicating that a pothole **304** is present within the detection distance **138** in front of the vehicle **102**, the onboard computing device **112** can control one or more actions of the vehicle **102** to avoid the detected pothole. For example, in response to receiving a signal from the radar sensor **116***b* indicating that a pothole **304** is within the detection distance **138** of the vehicle **102**, the onboard computing device **112** can cause the vehicle **102** to reduce its speed of travel below a threshold speed in order to mitigate damage caused by the vehicle **102** driving over the pothole **304**. In some implementations, in response to receiving a signal from the radar sensor **116***b* indicating that a pothole **304** is within the detection distance **138** of the vehicle **102**, the onboard computing device **112** can control the vehicle **102** to change its position on the road surface **190** in order to avoid contact between the vehicle **102** and the detected hazard.

[0136] In some implementations, in response to receiving a signal from the radar sensor **116***b* indicating the pothole hazard **304**, the onboard computing device **112** can cause a visual alert and/or an audible alert to be generated indicating the presence of the detected pothole **304**. For example, in response to receiving a signal from the radar sensor **116***b* indicating the pothole hazard **304**, the onboard computing device **112** can cause a visual alert to be displayed within the cab **108** of the vehicle **102** (e.g., on the screen **122** of display device **120**) to warn the driver of the vehicle of the detected pothole **304** and suggest that the driver of the vehicle reduce the speed at which the vehicle **102** is travelling and/or change the position of the vehicle on the road **190** to avoid contact with the pothole **304**.

[0137] In some implementations, in response to the radar sensor **116***b* detecting the pothole hazard **304**, data related to the detected pothole hazard **304** can be captured and recorded. For example, in response to receiving the signal from the radar sensor **116***b* indicating a pothole hazard **304**, the onboard computing device **112** can control the camera **134** coupled to the vehicle **102** to capture image data and/or video data of the pothole **304**, and the data captured by the camera **134** can be stored together with other data related to the detected pothole **304**. In addition, the location of the detected pothole **304** can be recorded in a hazard map (e.g., hazard map **600** of FIG. **6**) by displaying a hazard warning map element (e.g., map element **604** of FIG. **6**) at a location corresponding to the GPS location of the vehicle **102** at the time the radar sensor signal corresponding to the pothole

304 was generated by the radar sensor **116***b* or was received by the vehicle **102**. As previously discussed, the hazard map can also be used to display additional data related to the detected hazard, including, but not limited to, the size of the pothole **304**, the type of object corresponding to the detected hazard **304** (i.e., pothole), GPS coordinates corresponding to the location of the pothole **304**, image data and/or video data of the pothole **304**, and a timestamp corresponding to the time that the pothole **304** was detected by the radar sensor **116***b*.

[0138] In addition to detecting hazards proximate to the vehicle **102** that could result in damage to the vehicle **102**, the radar sensor **116***b* can be used to detect humans and animals that are proximate the vehicle **102**, but that are difficult for the driver of the vehicle **102** to visualize while operating the vehicle **102**. For example, a person or animal walking behind the vehicle **102** could be detected using a radar sensor **116** coupled to a rear portion of the vehicle **102**, such as the tailgate **115** or the rear bumper of the vehicle **102**. Similarly, a person or animal positioned in front of the vehicle coupled be detected by a radar sensor coupled to the cab **108** of the vehicle **102**, such as radar sensor **116***b*. In some implementations, in response to receiving a signal from a radar sensor **116***b* that a person or animal is present within the detection distance of the radar sensor **116***b* in front of the vehicle **102**, the onboard computing device **112** can cause a visual alert and/or an audible alert to be generated indicating the presence of a person within the detection distance of the radar sensor **116***b*. For example, in response to receiving a signal from the radar sensor **116***b* that a person is present within the detection distance of the radar sensor **116***b* coupled to the front bumper **126** of the vehicle **102**, the onboard computing device **112** can cause a visual alert to be displayed within the cab **108** of the vehicle **102** (e.g., on the screen **122** of display device **120**), and onboard computing device **112** can prevent the lift arm **111** from being raised until the operator of the vehicle has provided an input to acknowledging the displayed alert. In some implementations, in response to receiving a signal from a radar sensor coupled to a rear portion of the vehicle **102** (such as the tailgate **115** or a rear bumper) indicating that a person is present within the detection distance of the radar sensor, the onboard computing device **112** can cause a visual alert to be displayed within the cab **108** of the vehicle **102** (e.g., on the screen **122** of display device **120**), and onboard computing device **112** can prevent the vehicle from being operated in reverse and/or prevent movement of the tailgate **115**.

[0139] While certain embodiments have been described, other embodiments are possible.

[0140] For example, while the vehicle **102** has been described as including two radar sensors **116**, other numbers of radar sensors are possible (e.g., 1, 3, 4, 5, etc.). In addition, while the radar sensors **116***a*, **116***b* have been described as being coupled to a cab protector **124** of the vehicle **102** and a front bumper **126** of the vehicle, respectively, radar sensors can be attached to other portions of the vehicle **102**, including, but not limited to, a surface of the cab **108** of the vehicle **102** (e.g., the roof of the cab **108**), the lift arm **111** of the vehicle **102**, a tailgate **115** of the vehicle **102**, a rear bumper of the vehicle **102**, to the sides of the storage body **119** of the vehicle **102**, on the roof of the storage body **119** of the vehicle **102**, or to the sides of the cab **108** of the vehicle **102**. For example, in some implementations, the radar sensor **116***a* is coupled to a roof of the storage body of the vehicle **102** (e.g., on the roof proximate the hopper **117**). In some implementations, the vehicle includes a radar sensor coupled to a rear bumper of the vehicle **102** or the tailgate **115** of the vehicle in order to detect hazards that are located behind the refuse collection vehicle **102**, and the onboard computing device **112** provides an operator of the vehicle an indication of the detected hazard behind the vehicle and/or prevents the vehicle from being driven in reverse in response to receiving a signal from the radar sensor coupled to the tailgate **115** or rear bumper indicating that a hazard is behind the vehicle **102**. In some implementations, the vehicle **102** includes one or more radar sensors that are mounted to the frame of the vehicle **102** and are pointed downwards in order to detect pothole or other road hazards. In some implementations, one or more radar sensors are coupled to one or more sides of the storage body **119** and/or the cab **108** of the vehicle **102** in order to detect objects positioned to the side of the vehicle **102**.

[0141] In addition, while the point cloud used to detect objects proximate the vehicle **102** has been described as being generated based data received from one or more radar sensors **116**, in some implementations, other types of sensors can be used to generate the point cloud. For example, one or more LiDAR sensors can be used to generate a point cloud to detect one or more objects proximate the vehicle **102**.

[0142] While the point cloud has been described as being processed by the respective radar sensor **116***a*, **116***b* that generated the point cloud, in some implementations, the point cloud is processed by another processor. For example, in some implementations, the point clouds generated by the radar sensors **116***a*, **116***b* are processed by the onboard computing device **112** or by a computing device that is remote from the vehicle **102**.

[0143] Further, while the point cloud generated by the radar sensors **116** has been described including a discrete set of data points in a two-dimensional (2D) coordinate system, in some implementations, the point cloud generated by the radar sensor includes data points in a three-dimensional (3D) coordinate system, and each data point in the point cloud generated by the radar sensors **116** has a set of Cartesian coordinates (X, Y, Z) that represent a single point on a surface of an object proximate the vehicle **102** detected by the respective radar sensor **116**.

[0144] Further, while the radar sensors **116** have been described as being used to detect hazards proximate a refuse collection vehicle **102**, in some implementation, radar sensors **116** can be used to detect the presence of roll-off container on a roll-off truck (also referred to herein as roll-off vehicle). FIGS. **8-10** depict a roll-off vehicle **802** with a radar sensor **816** for detecting a roll-off container **804** positioned on the bed **806** of the roll-off vehicle **802**. The radar sensor **816** is coupled to a portion of the roll-off vehicle **802** proximate the cab **808** of the vehicle **802** and is oriented towards the bed **806** of the vehicle **802**. For example, as depicted in FIG. **10**, the radar sensor **816** can be coupled to a tarp bracket **810** of the roll-off vehicle **802**.

[0145] The structure and function of the radar sensor **816** is substantially similar to that of the radar sensors **116** depicted in FIGS. **1-5**. For example, similar to radar sensors **116** of FIGS. **1-5**, the radar sensor **816** on the roll-off vehicle **802** is configured to generate radar sensor data, such as a point cloud, indicating the presence of one or more objects proximate the radar sensor **816**, such as a roll-off container positioned on the bed **806** of the vehicle **802**. In some implementations, the radar sensor **816** is configured to output analog signals or digital signals indicating the presence of one or more objects proximate the radar sensor **816**. In some implementations, the radar sensor **816** is configured to output Controller Area Network (CAN) messages to indicating the presence of one or more objects proximate the respective radar sensors **116**.

[0146] Based on the radar signals **840** generated by the radar sensor **816**, a determination can be made regarding whether a roll-off container **804** is present on the bed **806** of the vehicle **802**. For example, the presence a roll-off container **804** positioned on the bed **806** of the vehicle **802** can be detected based on determining that the point cloud generated by the radar sensor **816** is equal to or exceeds a threshold point cloud size and that point cloud includes one of more clusters of points corresponding to a roll-off container. In some implementations, clusters indicating the presence of a roll-off container are portions of the point cloud that have an average intensity of the points within the point cloud equal to or exceeding a threshold intensity

[0147] In some implementations, in order to detect the presence of a roll-off container **804** on the bed **806**, the radar signals **840** generated by the radar sensor **816** are processed to determine whether an object is detected within a particular detection distance from the radar sensor **816**. In some implementations, the detection distance for the radar sensor **816** is between 0.1 meters and 3 meters from the radar sensor **816**. In some implementations, the detection distance for the radar sensor **816** is configured to enable the radar sensor **816** to sense various sizes of roll-off containers loaded on the bed **806** of the vehicle **802**. In some implementations, the detection distance for the radar sensor **816** is 3 meters from the radar sensor **816**. By limiting the detection distance of the radar sensor **816**, the radar sensor **816** can be used to reliably detect the presence of a roll-off container **804** positioned on the bed **806** of the vehicle **802** while minimizing false detections based on other objects positioned proximate the vehicle **802**.

[0148] In some implementations, point clouds are generated at a predefined time interval based on updated data received from the radar sensors **816** to create a set of point clouds, and the set of point clouds can be processed to detect objects proximate the vehicle **802**. Referring to FIG. **9**, in some implementations, one or more point clouds are generated based on data received from the radar sensor **816** at a time corresponding to a roll-off container service event, as detected by one or more body sensors **820**, **822** on the vehicle **802**. For example, the vehicle **802** can include one or more body sensors **820** coupled to one or more of the hydraulic cylinders **824** used to raise and lower the bed **806**, and the one or more body sensors **820** are configured to detect extension and retraction of the hydraulic cylinders **824** during unloading or loading of a roll-off container **804**. In some implementations, the vehicle **802** can include a body sensor **822** coupled to a hoist **826** of the vehicle **802** in order to detect extension or retraction of the hoist **826** during unloading or loading of a roll-off container **804**. Based on receiving a signal from one or more body sensors **820**, **822**, the radar signals **840** generated by the radar sensor **816** can be processed to determine whether a roll-off container **804** has been loaded onto the vehicle **802** or unloaded from the vehicle **802**, for example, based on whether a container **804** is presently detected on the bed **806** of the vehicle **802** by the radar sensor **816**.

[0149] In some implementations, the signals generated by the radar sensor **816** can be used to determine whether a roll-off container loaded on the vehicle **802** is full or empty. For example, in response to detecting the presence of a roll-off container **804** on the bed **806**, the radar signals **840** can be further processed to determine a distance between the bed **806** and the surface that the vehicle **802** is positioned on (e.g., the road surface). Based on the detected distance between the bed **806** and the road surface, the amount of refuse contained within the roll-off container **804** can be determined. In some implementations, if the distance between the bed **806** and the road surface determined based on the radar signals **840** is less than a threshold distance, the roll-off container **804** can be identified as being full. In some implementations, if the distance between the bed **806** and the road surface determined based on the radar signals **840** is above a threshold distance, the roll-off container **804** can be identified as being empty.

[0150] The distance between the bed **806** and the surface that the vehicle **802** is positioned on determined based on the radar signal **840** can also be used to determine whether a roll-off container **804** is loaded on the vehicle **802**. For example, if the distance between the bed **806** and the road surface, as determined based on the radar signals **840**, is reduced (e.g., by 1 inch to 3 inches) compared to a baseline distance corresponding to a vehicle **802** without a roll-off container positioned on the bed **806**, a roll-off container **804** can be detected as being loaded on the bed **806** of the vehicle **802**.

[0151] In some implementations, the hoist **826** of the vehicle **802** is coupled to a load cell **828**, and the data generated by the load cell **828** can be combined with the radar signals **840** to determine the amount of refuse contained within a roll-off container **804** positioned on the bed **806** of the vehicle **802**. In some implementation, if the force detected by the load cell **828** is above a threshold force, the roll-off container **804** can be determined as being full. In some implementation, if the force detected by the load cell **828** is below a threshold force, the roll-off container **804** can be determined as being empty. In some implementations, a scale can be coupled to or incorporated into the bed **806** of the vehicle **802**, and the amount of refuse contained within a roll-off container **804** positioned on the bed **806** can be determined based on signals received from the scale coupled to or incorporated into the bed **806**.

[0152] In some implementations, in response to receiving a signal from the radar sensor **816** indicating that a roll-off container **804** has been loaded onto or unloaded from the roll-off vehicle **802**, an onboard computing device of the vehicle **802** (e.g., similar to onboard computing device **112** of FIG. **1**) causes one or more cameras **834** coupled to the vehicle **802** to capture image and/or video data of the roll-off container **804**. For example, in response to detecting that a roll-off container **804** has been loaded onto the bed **806** of the vehicle **802** based on the radar sensor signals **840**, a rear-facing camera **834** coupled to the vehicle **802** can be controlled to capture an image of the roll-off container **804** positioned on the vehicle **802**. Similarly, in response to detecting that a roll-off container **804** has been unloaded from the vehicle **802** based on the radar sensor signals **840**, a rear-facing camera **834** or a side-facing camera coupled to the vehicle **802** can be controlled to capture an image of the roll-off container **804** at the location that the roll-off container has been unloaded from the vehicle **802**. The image data and/or video data captured by the one or more cameras **834** can include a timestamp, and the data captured by the camera(s) **834** can be identified as corresponding to a corresponding roll-off container service event that is detected based on signals received from the radar sensor **816**. In some implementations, an onboard computing device or a remote computing device can process the data captured by the camera(s) **834** and the signals received from the radar sensor **816** to determine image and/or video data corresponding to a roll-off container service event, and store the corresponding image and/or video data together with other data related to the service event.

[0153] In some implementations, the GPS coordinates of a roll-off container service event performed by the vehicle **802** can be determined and stored together with other data related to the roll-off container service event detected by the radar sensor **816**. In some implementations, the GPS coordinates of the detected roll-off container service event are determined based on the GPS coordinates of the vehicle **802** at the time that a signal corresponding to the respective service event is generated by the radar sensor **816**. In some implementations, the GPS coordinates of the detected service event are determined based on the GPS coordinates of the vehicle **802** at the time a signal corresponding to radar signal **840** corresponding the respective service event is received by an onboard computing device of the vehicle **802** from the radar sensor **816**. An onboard computing device of the vehicle **802** or a remote computing device can determine the GPS location of the detected roll-off container service event and store the GPS location with other data related to the detected service event.

[0154] In addition, the location of the detected roll-off container service event can be recorded in a map by displaying a service event map element (e.g., service event elements **608***a*, **608***b*, **608***c* in hazard map **600** of FIG. **6**) at a location corresponding to the GPS location of the vehicle **802** at the time the radar sensor signal corresponding to the roll-off container service event was generated by the radar sensor **816** or was received by a computing device, such as an onboard computing device of the vehicle **802**. The map can also be used to display additional data related to the detected roll-off container service event, including, but not limited to, whether the service event was a loading versus an unloading event, the weight of the roll-off container, whether the roll-off container was full or empty, GPS coordinates corresponding to the location of the service event, image data and/or video data of the roll-off container, and a timestamp corresponding to the time that service event was detected by the radar sensor **816**.

[0155] In some implementations, data related to the detected roll-off container service event can be stored (e.g., in a database) by an onboard computing device (e.g., similar to onboard computing device **112** of FIG. **1**) or by a remote computing device (i.e., a computing device located remotely from the vehicle **802**). The data related to a detected roll-off container service event can include, but is not limited to, whether the service event was a loading versus an unloading event, a detected weight of the roll-off container (e.g., as received from one or more of the body sensor **820**, **822** or a scale on the bed **806** of the vehicle **802**), whether the roll-off container was full or empty, GPS coordinates corresponding to the location of the service event, image data and/or video data of the roll-off container, and a timestamp corresponding to the time that service event was detected by the radar sensor **816**. As previously discussed, the data related to roll-off container service events detected based on the radar signals **840** can be used to generate a map indicating the location of each of the detected service events. The stored roll-off container service event data can be used to modify routes of travel performed by roll-off vehicles in order to optimize efficiency of the roll-off container service events performed by the roll-off container vehicle. For example, the stored roll-off container service event data can be used to determine the amount of time spent performing each detected roll-off container service event, and the route performed by the roll-off container vehicle can be modified to reduce the amount of time between roll-off container service events. In addition, the data related to the detected roll-off container service events can be used for service verification and billing purposes. For example, a customer related to a particular roll-off container service event detected by the radar sensor **816** could be automatically charged for the detected service event. In some implementations, a customer can access the stored roll-off container service event data in order to track the service events that have been performed for one or more roll-off containers **804** associated with the customer.

[0156] FIG. **7** depicts an example computing system, according to implementations of the present disclosure. The system **700** may be used for any of the operations described with respect to the various implementations discussed herein. For example, the system **700** may be included, at least in part, in one or more of the onboard computing device **112**, and/or other computing device(s) or system(s) described herein. The system **700** is intended to include various forms of digital computers, such as printed circuit boards (PCB), processors, digital circuitry, or otherwise. Additionally, the system can include portable storage media, such as, Universal Serial Bus (USB) flash drives. For example, the USB flash drives may store operating systems and other applications. The USB flash drives can include input/output components, such as a wireless transmitter or USB connector that may be inserted into a USB port of another computing device.

[0157] The system **700** includes a processor **710**, a memory **720**, a storage device **730**, and an input/output device **740**. Each of the components **710**, **720**, **730**, and **740** are interconnected using a system bus **540**. The processor **710** is capable of processing instructions for execution within the system **700**. The processor may be designed using any of a number of architectures. For example, the processor **710** may be a CISC (Complex Instruction Set Computers) processor, a RISC (Reduced Instruction Set Computer) processor, or a MISC (Minimal Instruction Set Computer) processor.

[0158] In one implementation, the processor **710** is a single-threaded processor. In another implementation, the processor **710** is a multi-threaded processor. The processor **710** is capable of processing instructions stored in the memory **720** or on the storage device **730** to display graphical information for a user interface on the input/output device **740**.

[0159] The memory **720** stores information within the system **700**. In one implementation, the memory **720** is a computer-readable medium. In one implementation, the memory **720** is a volatile memory unit. In another implementation, the memory **720** is a non-volatile memory unit.

[0160] The storage device **730** is capable of providing mass storage for the system **700**. In one implementation, the storage device **730** is a computer-readable medium. In various different implementations, the storage device **730** may be a floppy disk device, a hard disk device, an optical disk device, or a tape device.

[0161] The input/output device **740** provides input/output operations for the system **700**. In one implementation, the input/output device **740** includes a joystick. In some implementations, the input/output device **740** includes a display unit for displaying graphical user interfaces. For example in some implementations, the input/output device **740** is a display device that includes one or more buttons and/or a touchscreen for receiving input from a user. In some implementations, the input/output device **740** includes a keyboard and/or a pointing device. In some implementations, the input/output device **740** is located within a cab of a refuse collection vehicle (e.g., within cab **108** of vehicle **102**). For example, the input/output device **740** can be attached to or incorporated within a dashboard inside the cab of a refuse collection vehicle.

[0162] Although the following detailed description contains many specific details for purposes of illustration, it is understood that one of ordinary skill in the art will appreciate that many examples, variations and alterations to the following details are within the scope and spirit of the disclosure. Accordingly, the exemplary implementations described in the present disclosure and provided in the appended figures are set forth without any loss of generality, and without imposing limitations on the claimed implementations.

[0163] Although the present implementations have been described in detail, it should be understood that various changes, substitutions, and alterations can be made hereupon without departing from the principle and scope of the disclosure. Accordingly, the scope of the present disclosure should be determined by the following claims and their appropriate legal equivalents.

[0164] The singular forms "a", "an" and "the" include plural referents, unless the context clearly dictates otherwise.

[0165] As used in the present disclosure and in the appended claims, the words "comprise," "has," and "include" and all grammatical variations thereof are each intended to have an open, non-limiting meaning that does not exclude additional elements or steps.

[0166] As used in the present disclosure, terms such as "first" and "second" are arbitrarily assigned and are merely intended to differentiate between two or more components of an apparatus. It is to be understood that the words "first" and "second" serve no other purpose and are not part of the name or description of the component, nor do they necessarily define a relative location or position of the component. Furthermore, it is to be understood that that the mere use of the term "first" and "second" does not require that there be any "third" component, although that possibility is contemplated under the scope of the present disclosure.

What is claimed is:

1. A system comprising:

a refuse collection vehicle, comprising:

a chassis; and

one or more body components; and

at least one radar sensor coupled to a portion of the refuse collection vehicle, the at least one radar sensor configured to detect one or more hazards positioned within a detection distance of the at least one radar sensor.

2. The system of claim **1**, wherein the one or more hazards positioned within a detection distance of the at least one radar sensor comprise one or more objects overlying the refuse collection vehicle.

3. The system of claim **2**, wherein:

the refuse collection vehicle includes a cab protector; and

the at least one radar sensor is coupled to the cab protector.

4. The system of claim **1**, wherein the one or more hazards positioned within a detection distance of the at least one radar sensor comprise one or more hazards along a surface on which the refuse collection vehicle is positioned.

5. The system of claim **4**, wherein the refuse collection vehicle includes a front bumper; and the at least one radar sensor is coupled to the front bumper.

6. The system of claim **1**, wherein the one or more hazards positioned within a detection distance of the at least one radar sensor comprise an object in front of the refuse collection vehicle and that could result in a potential overhead collision with the refuse collection vehicle.

7. The system of claim **6**, wherein the refuse collection vehicle comprises one or more fuel tanks coupled to a roof of the refuse collection vehicle.

8. The system of claim **1**, wherein the refuse collection vehicle further comprises a camera configured to capture image data or video data of the one or more hazards.

9. The system of claim **1**, wherein the system further comprises a computing device, and the at least one radar sensor is configured to transmit, to the computing device, a signal indicating the one or more hazards.

10. A method of operating a refuse collection vehicle, the method comprising:

detecting, using at least one radar sensor coupled to the refuse collection vehicle, a hazard positioned within a detection distance of the at least one radar sensor;

transmitting, from the at least one radar sensor to a computing device, a signal indicating the hazard detected by the at least one radar sensor; and

in response to receiving the signal, controlling the refuse collection vehicle to prevent damage to the refuse collection vehicle resulting from contact between the hazard and the refuse collection vehicle.

11. The method of claim **10**, wherein the hazard comprises an object overlying the refuse collection vehicle.

12. The method of claim **11**, wherein controlling the refuse collection vehicle to prevent damage to the refuse collection vehicle resulting from contact between the hazard and the refuse collection vehicle comprises preventing a lift arm of the refuse collection vehicle from being raised above a threshold height.

13. The method of claim **10**, wherein the hazard comprises a hazard along a road surface on which the refuse collection vehicle is positioned.

14. The method of claim **10**, wherein the hazard comprises an object in front of the refuse collection vehicle and that could result in a potential overhead collision with the refuse collection vehicle.

15. The method of claim **14**, wherein detecting the hazard comprises:

detecting, based on data generated by the at least one radar sensor, a clearance height of the object; and

determining that the clearance height of the object is less than an overall height of the refuse collection vehicle.

16. The method of claim **10**, wherein detecting, the hazard positioned within the detection distance of the at least one radar sensor comprises:

generating, by the radar sensor, a point cloud; and

processing, by the radar sensor, the point cloud to detect the hazard.

17. The method of claim **10**, further comprising in response to receiving the signal, causing a camera coupled to the refuse collection vehicle to capture image data or video data of the hazard.

18. The method of claim **10**, further comprising generating a map comprising a map element indicating a location of the hazard detected by the radar sensor.

19. The method of claim **10**, further comprising in response to receiving the signal, generating a visual alert or an audible alert.

20. A system comprising:

refuse collection vehicle, comprising:

a chassis comprising a bed; and

at least one radar sensor coupled to a portion of the refuse collection vehicle, the at least one radar sensor configured to detect a roll-off container positioned on the bed of the refuse collection vehicle.

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