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(54) **PREVENTING DAMAGE TO AN INTERMEDIATE CONTAINER COUPLED WITH A REFUSE COLLECTION VEHICLE**

(71) Applicant: **The Heil Co.**, Chattanooga, TN (US)

(72) Inventors: **Albert Xiaoxia Jiang**, Chattanooga, TN (US); **Bryan Kelly Stewart**, Chattanooga, TN (US)

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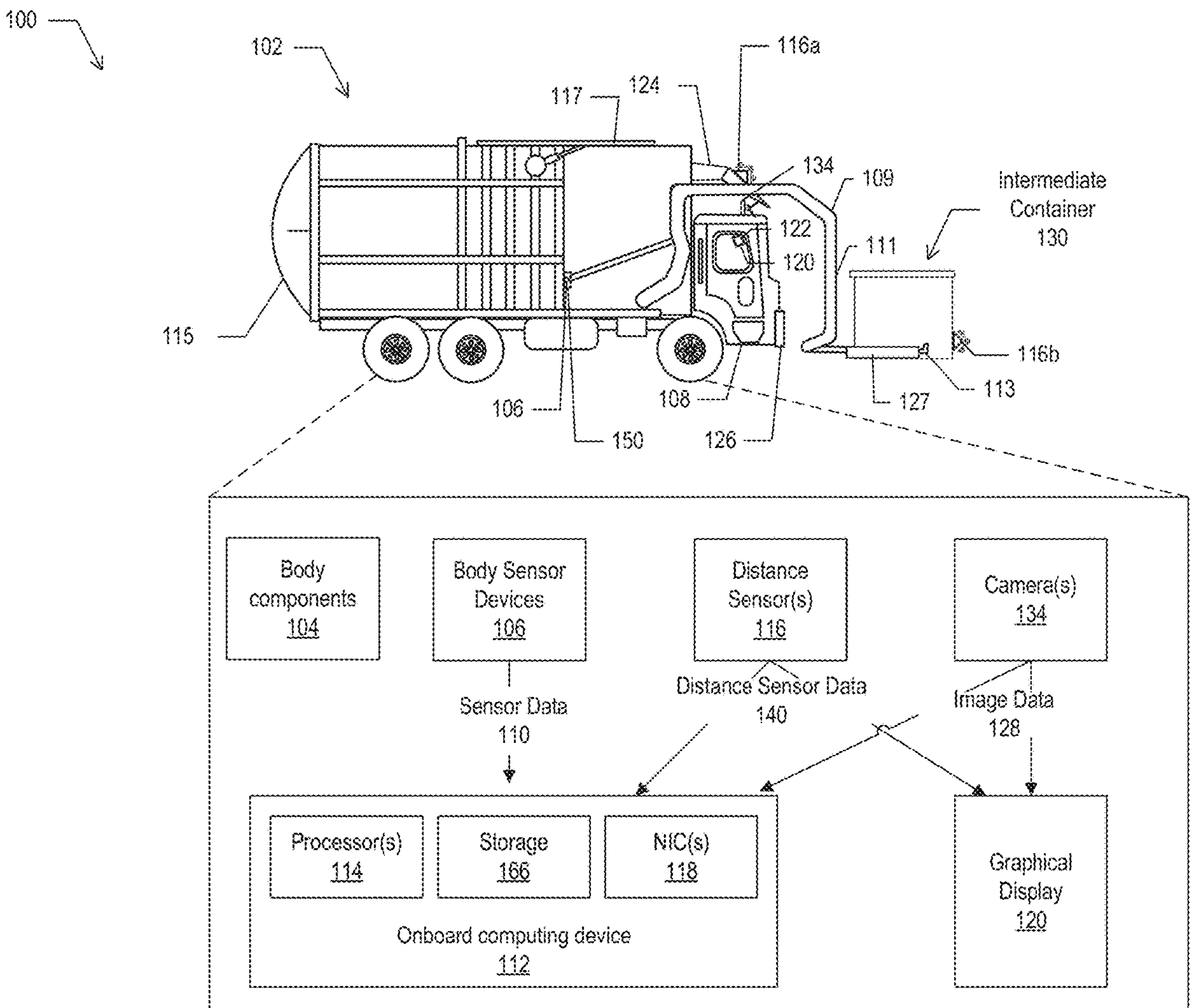
(57) **ABSTRACT**

Systems and methods include a refuse collection vehicle including a chassis; a refuse collecting body supported by the chassis; and a front loading arm assembly coupled to the refuse collecting body. An intermediate container for receiving refuse is positioned in front of the refuse collection vehicle and coupled to the front loading arm assembly. At least one sensor is coupled to a portion of the refuse collection vehicle or to a portion of the intermediate container. The at least one sensor is oriented toward a road surface in front of the refuse collection vehicle. At least one processor communicably coupled to the at least one sensor, the at least one processor configured to perform operations including receiving a signal from the at least one sensor; and in response to receiving the signal, determining an elevation change of the road surface in front of the refuse collection vehicle.



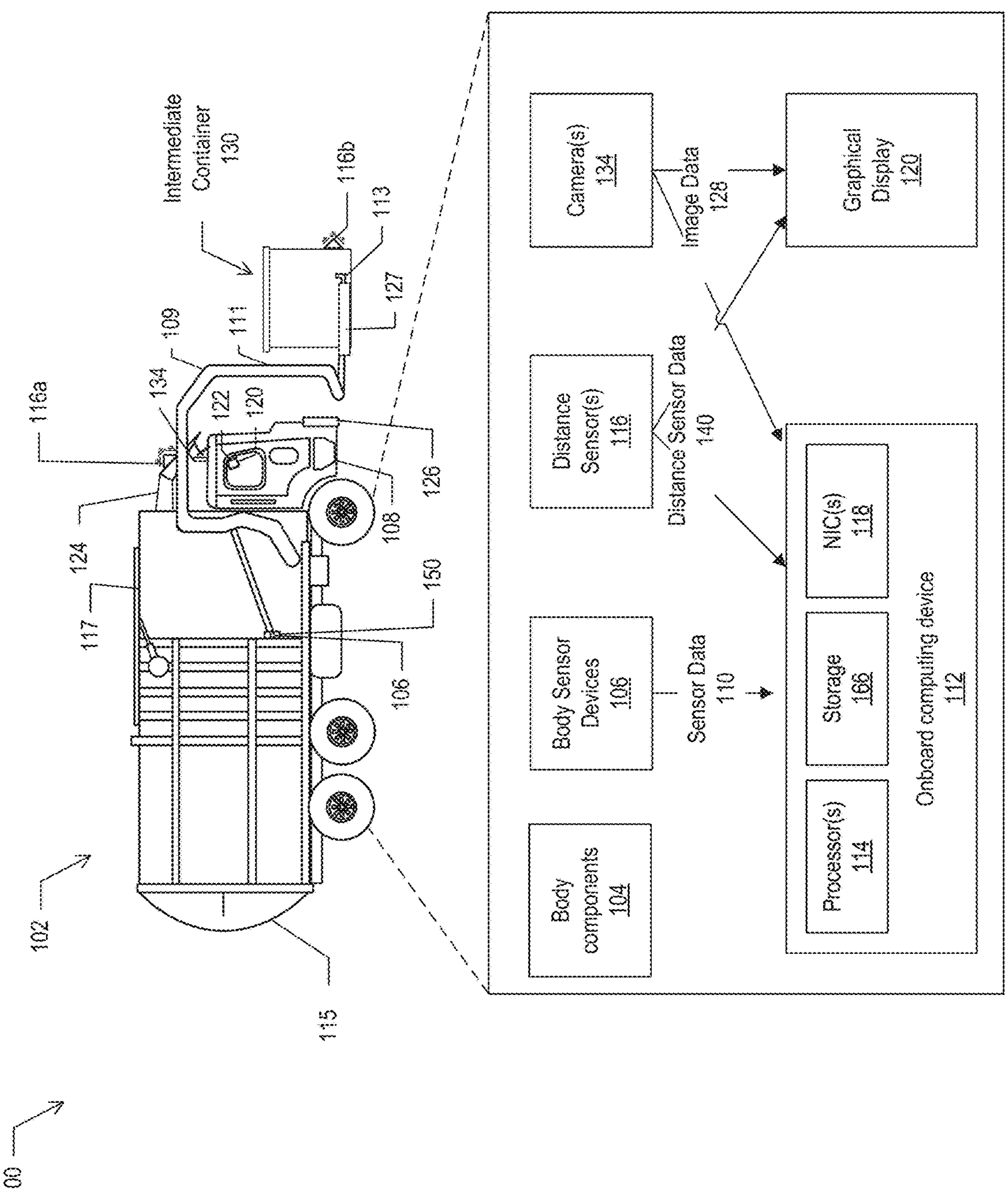

100
102
115
117
124
116a
134
122
120
109
111
Intermediate Container 130
116b
113
127
126
108
150
106
Body components 104
Body Sensor Devices 106
Sensor Data 110
Distance Sensor(s) 116
Distance Sensor Data 140
Camera(s) 134
Image Data 128
Graphical Display 120
Processor(s) 114
Storage 166
NIC(s) 118
Onboard computing device 112

FIG. 1

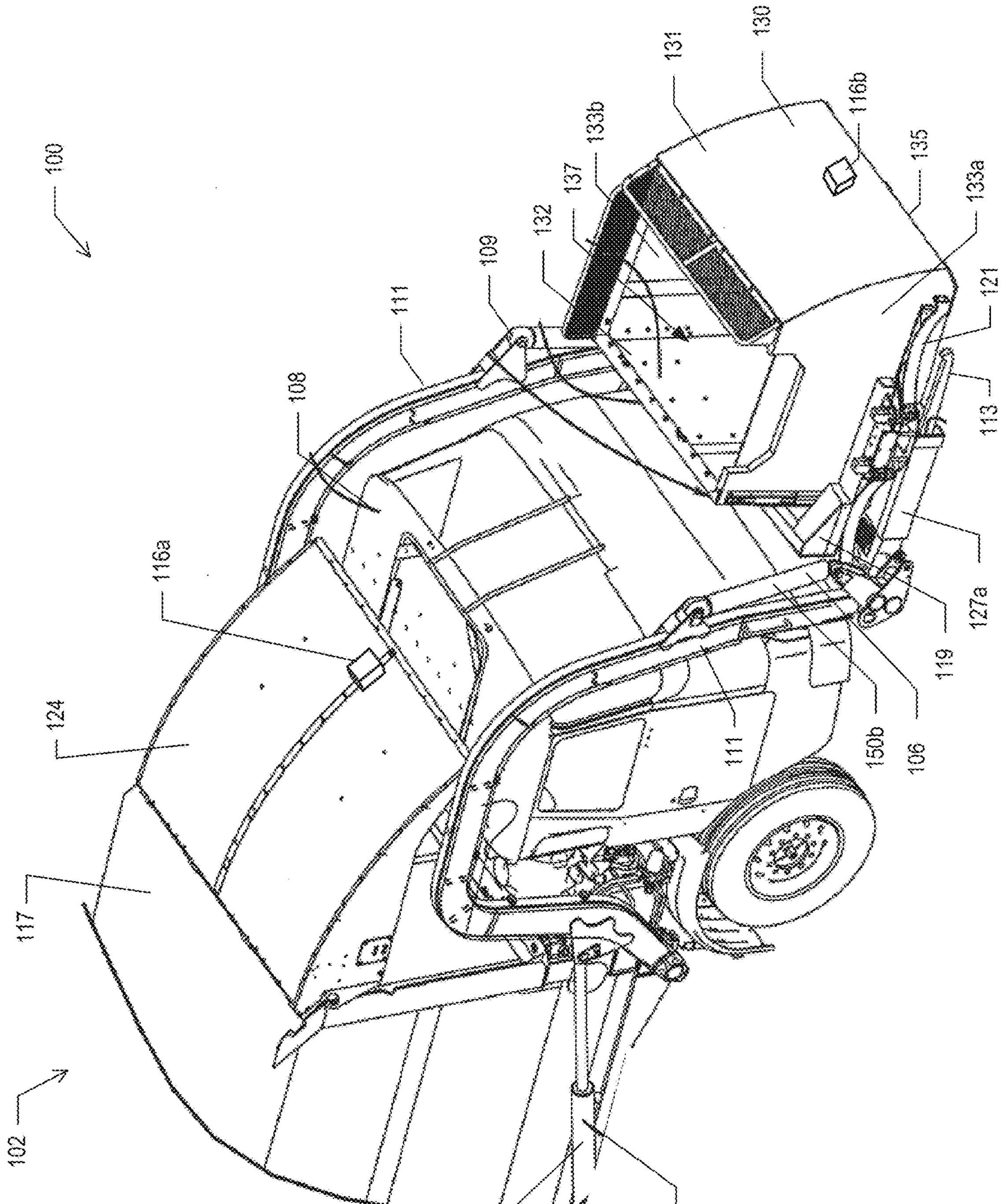
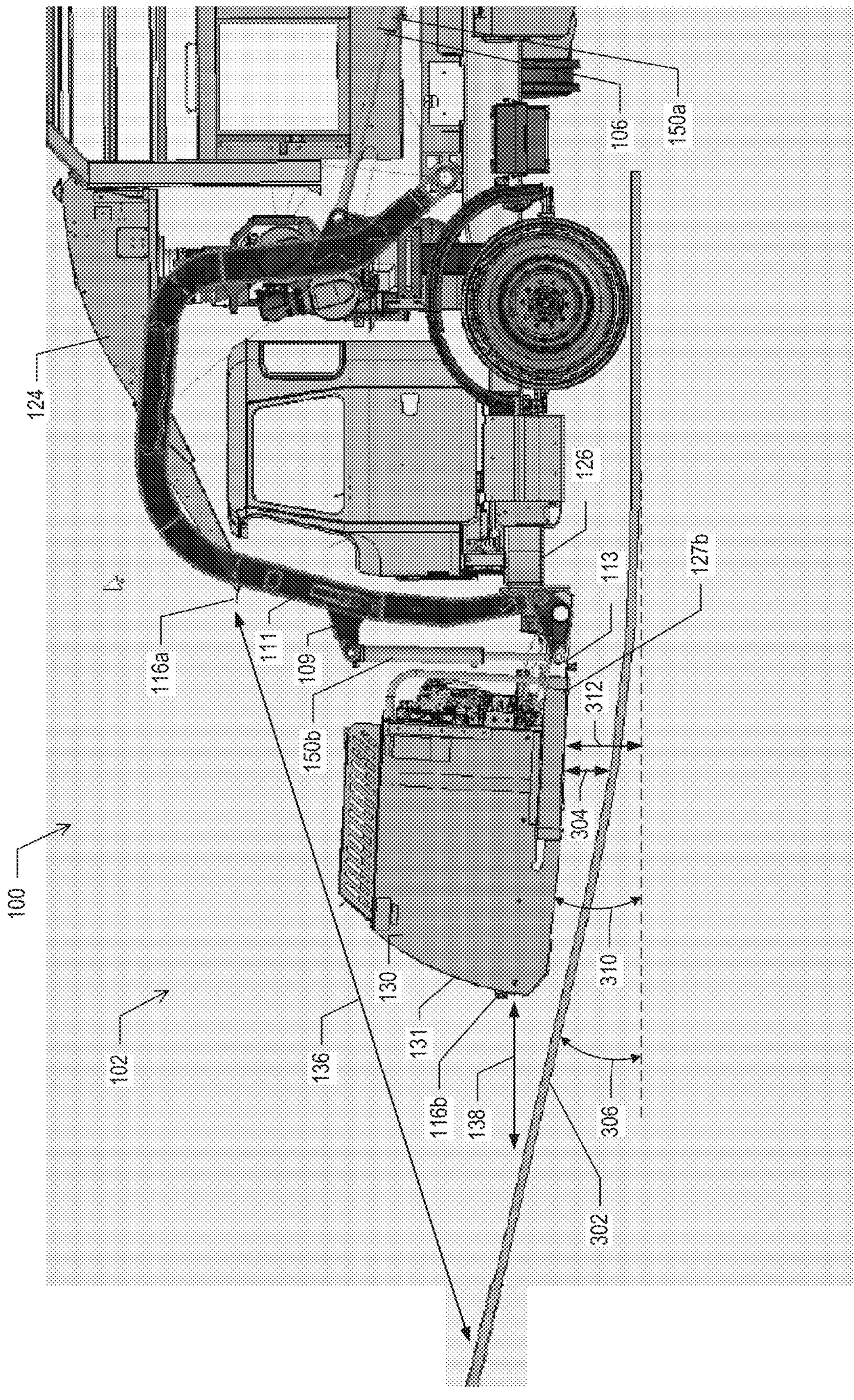

100
102
106
106
108
109
111
111
113
116a
116b
117
119
121
124
127a
130
131
132
133a
133b
135
137
150a
150b

FIG. 2



100
102
106
150a
124
126
113
127b
116a
111
109
150b
312
304
310
130
131
136
116b
138
306
302


FIG. 3

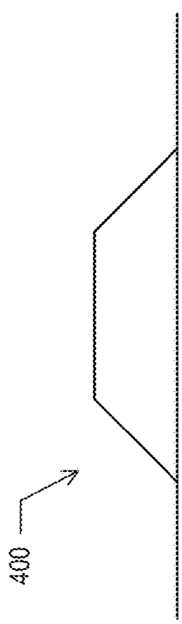



FIG. 4A

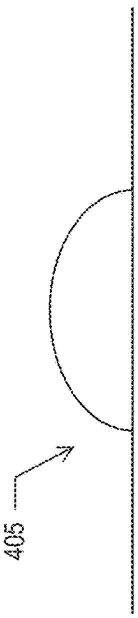



FIG. 4B

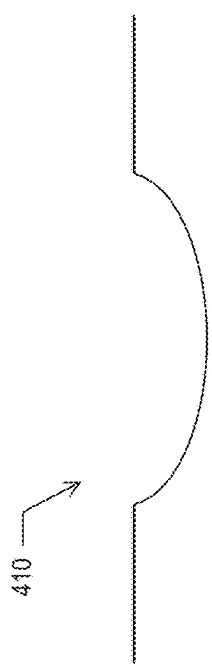



FIG. 4C

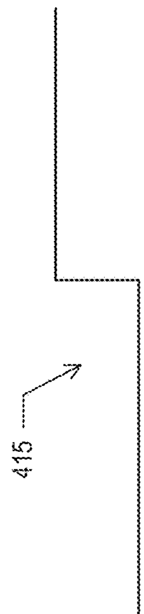



FIG. 4D

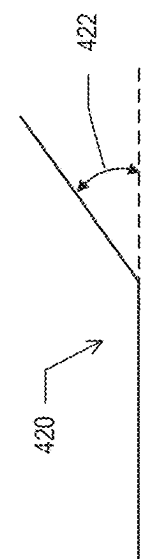



FIG. 4E

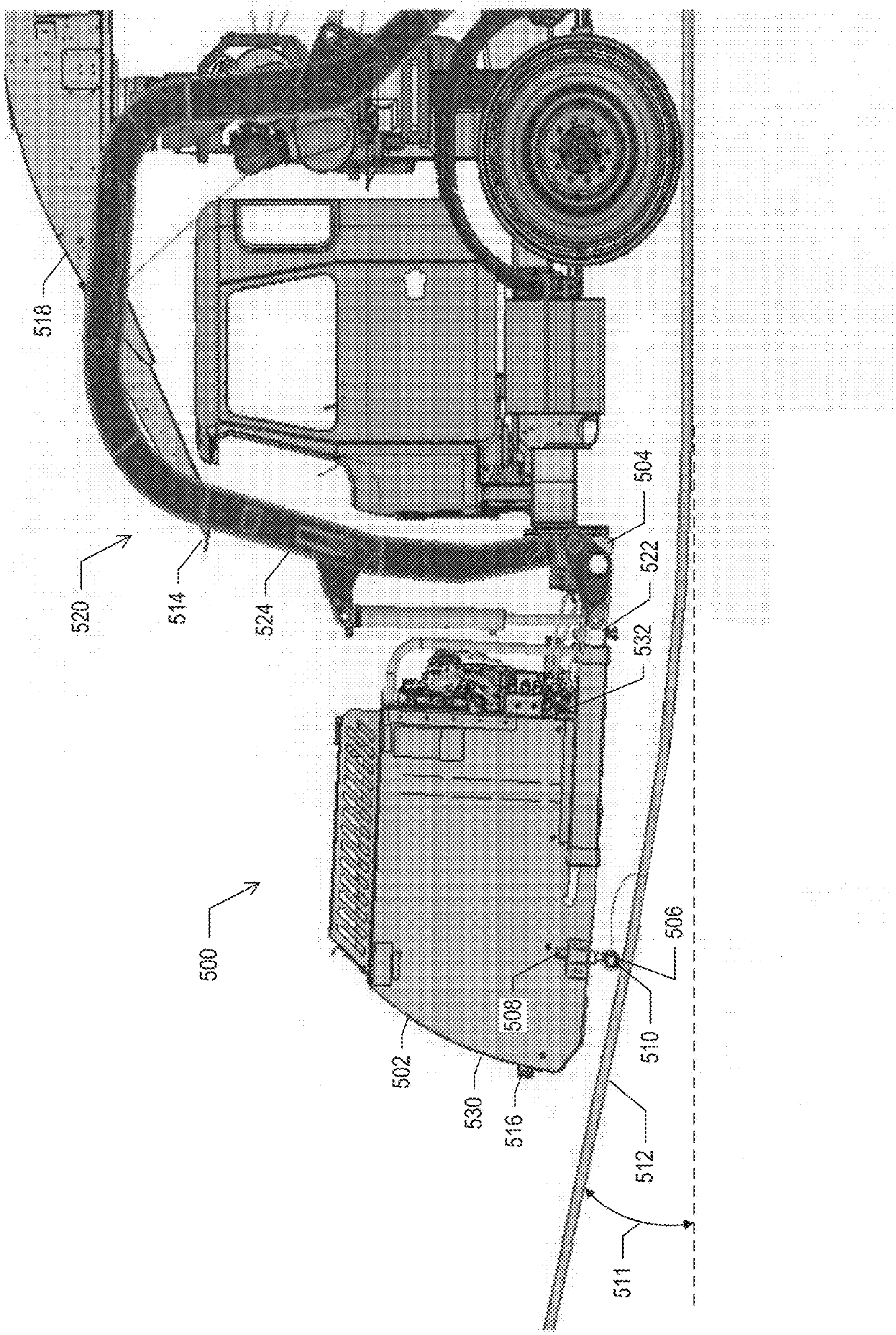
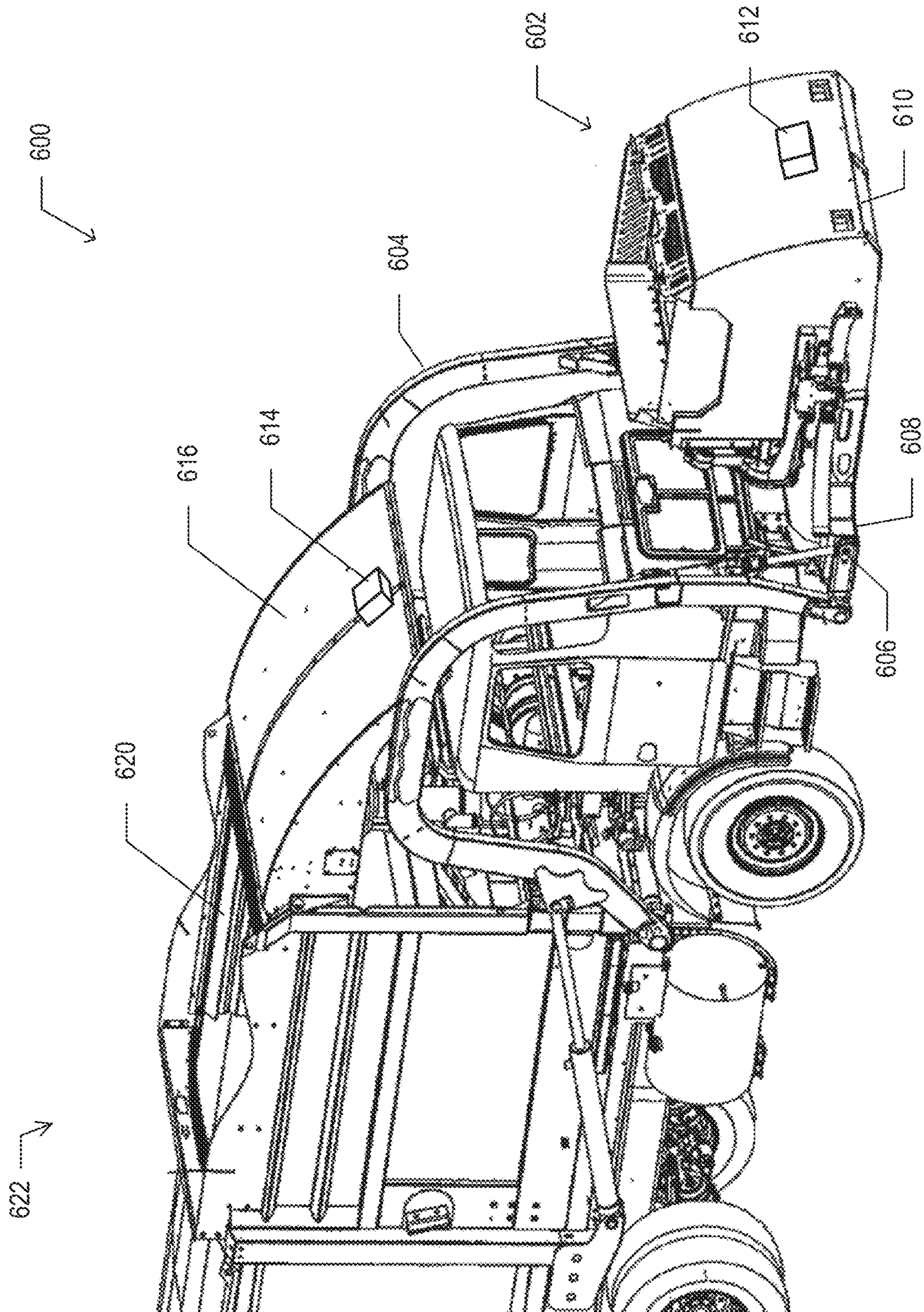



FIG. 5




600

FIG. 6

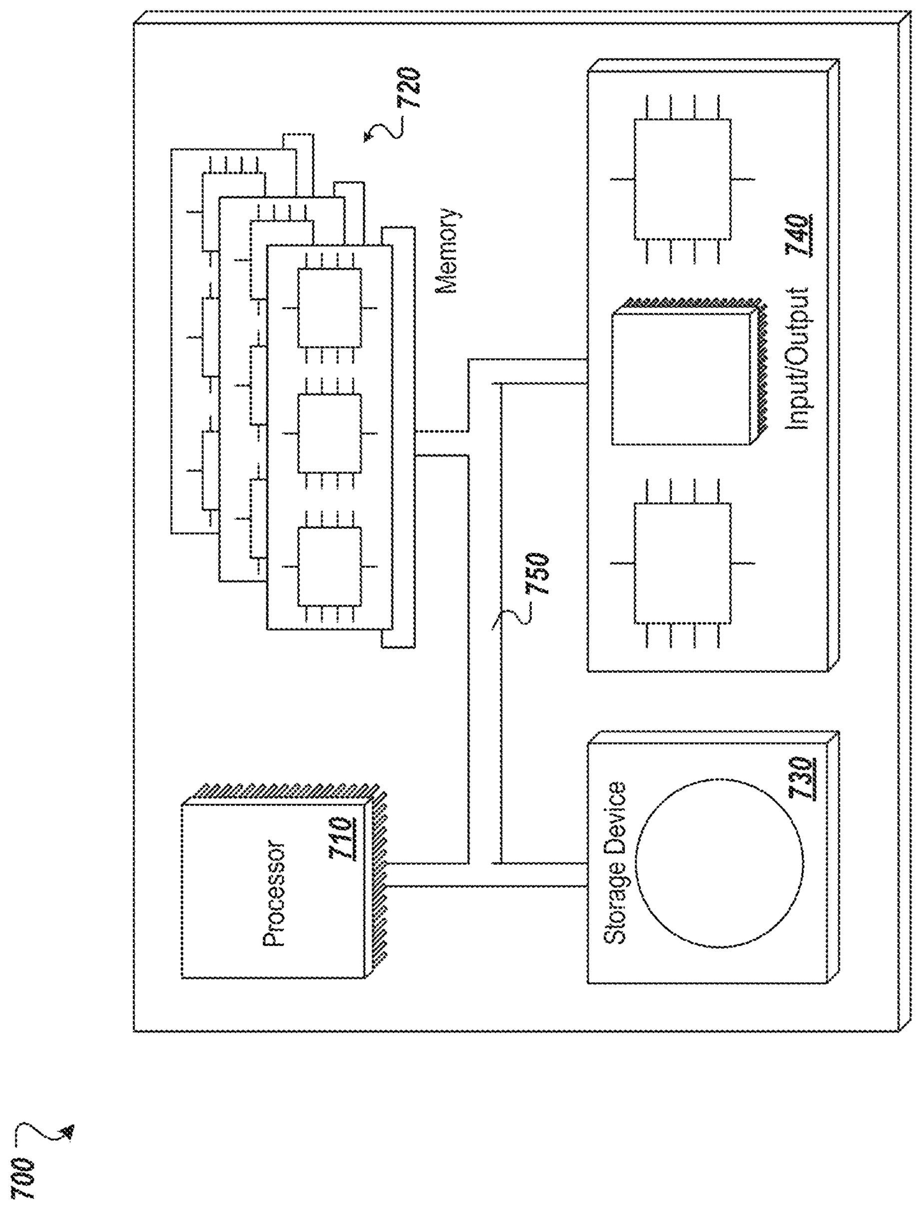

720
Memory
740
Input/Output
750
710
Processor
730
Storage Device
700

FIG. 7

# PREVENTING DAMAGE TO AN INTERMEDIATE CONTAINER COUPLED WITH A REFUSE COLLECTION VEHICLE

## CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims the benefit under 35 U.S.C. § 119(e) of U.S. Patent Application No. 63/554,453, entitled "Preventing Damage to an Intermediate Container Coupled with a Refuse Collection Vehicle," filed Feb. 16, 2024, which is incorporated herein by reference in its entirety.

## TECHNICAL FIELD

[0002] This disclosure relates to systems and methods for operating 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 elevation changes in the road surface such as traffic calming devices (e.g., speed bumps), potholes in the road, and hills. An intermediate container for collecting refuse extending in front of the refuse collection vehicle reduces the vehicle approach angle increasing the potential for contact between the elevation changes of the road surface and the intermediate container. This contact can damage the intermediate container and the refuse collection vehicle.

## SUMMARY

[0004] In an example implementation, a refuse collection system includes a refuse collection vehicle including a chassis; a refuse collecting body supported by the chassis; and a front loading arm assembly coupled to the refuse collecting body; an intermediate container for receiving refuse positioned in front of the refuse collection vehicle and coupled to the front loading arm assembly; at least one sensor coupled to a portion of the refuse collection vehicle or to a portion of the intermediate container, the at least one sensor oriented toward a road surface in front of the refuse collection vehicle; and at least one processor communicably coupled to the at least one sensor, the at least one processor configured to perform operations including receiving a signal from the at least one sensor; and in response to receiving the signal, determining an elevation change of the road surface in front of the refuse collection vehicle.

[0005] In an aspect combinable with the example implementation, at least one sensor is coupled to the portion of the refuse collection vehicle and a detection distance of the at least one sensor is greater than a distance between a front side of the intermediate container and a front bumper of the refuse collection vehicle.

[0006] In another aspect combinable with any of the previous aspects, the detection distance is determined based at least in part on a speed of the refuse collection vehicle.

[0007] In another aspect combinable with any of the previous aspects, the detection distance is increased when the speed of the refuse collection vehicle exceeds a threshold speed.

[0008] In another aspect combinable with any of the previous aspects, the at least one sensor includes at least one of a radar sensor, a lidar sensor, a laser sensor, a stereo camera, a three-dimensional camera, or an ultrasonic sensor.

[0009] In another aspect combinable with any of the previous aspects, the elevation change includes a vertical deflection traffic calming device.

[0010] In another aspect combinable with any of the previous aspects, the elevation change includes an increase in the elevation of the road surface.

[0011] In another aspect combinable with any of the previous aspects, the operations further include in response to determining the elevation change, controlling the front loading arm assembly to change a position of the intermediate container.

[0012] In another aspect combinable with any of the previous aspects, controlling the front loading arm assembly to change the position of the intermediate container comprises controlling the front loading arm assembly to adjust at least one of the height and the angle of the intermediate container.

[0013] In another aspect combinable with any of the previous aspects, controlling the front loading arm assembly to change the position of the intermediate container occurs while the refuse collection vehicle is in motion.

[0014] In another aspect combinable with any of the previous aspects, controlling the front loading arm assembly to change the position of the intermediate container includes adjusting at least one of the height of the intermediate container or the angle of the intermediate container to a predetermined value.

[0015] In another aspect combinable with any of the previous aspects, the operations further include determining that the determined elevation change of the road surface in front of the refuse collection vehicle exceeds a threshold value, and in response, controlling the front loading arm assembly to change a position of the intermediate container.

[0016] In another aspect combinable with any of the previous aspects, the at least one sensor includes a sensor coupled to the portion of the intermediate container.

[0017] In another aspect combinable with any of the previous aspects, the sensor coupled to the portion of the intermediate container includes a mechanical sensor configured to be in contact with a surface on which the refuse collection vehicle is positioned when the intermediate container is in a lowered position.

[0018] In another aspect combinable with any of the previous aspects, the sensor coupled to the intermediate container is coupled to a front surface of the intermediate container.

[0019] In another aspect combinable with any of the previous aspects, the at least one processor includes an onboard computing device located in the refuse collection vehicle.

[0020] In another example implementation, a refuse collection system includes a refuse collection vehicle including a chassis; a refuse collecting body supported by the chassis; and a front loading arm assembly coupled to the refuse collecting body; an intermediate container for receiving refuse positioned in front of the refuse collection vehicle and coupled to the front loading arm assembly; at least one sensor coupled to a portion of the refuse collection vehicle or to a portion of the intermediate container, the at least one sensor oriented toward a road surface; and at least one processor communicably coupled to the at least one sensor, the at least one processor configured to perform operations

including receiving a signal from the at least one sensor; and in response to receiving the signal, controlling the refuse collection vehicle to prevent damage to the intermediate container coupled to the front loading arm assembly of the refuse collection vehicle.

**[0021]** In another aspect combinable with the example implementation, the front loading arm assembly includes one or more position sensors; and the operations further include receiving signals from the one or more position sensors; and determining at least one of a height and an angle of the intermediate container with respect to a road surface on which the refuse collection vehicle is positioned.

**[0022]** In another aspect combinable with any of the previous aspects, controlling the refuse collection vehicle to prevent damage to the intermediate container comprises controlling the front loading arm assembly to adjust at least one of the height and the angle of the intermediate container.

**[0023]** In another aspect combinable with any of the previous aspects, controlling the refuse collection vehicle occurs while the refuse collection vehicle is in motion.

**[0024]** In another aspect combinable with any of the previous aspects, the controlling the front loading arm assembly includes adjusting at least one of the height of the intermediate container or the angle of the intermediate container to a predetermined value.

**[0025]** In another aspect combinable with any of the previous aspects, the operations further include determining that the determined elevation change of the road surface in front of the refuse collection vehicle exceeds a threshold value; and in response, controlling the front loading arm assembly to change a position of the intermediate container.

**[0026]** In another aspect combinable with any of the previous aspects, the at least one sensor includes at least one of a radar sensor, a lidar sensor, a laser sensor, a stereo camera, a three-dimensional camera, or an ultrasonic sensor.

**[0027]** In another aspect combinable with any of the previous aspects, the at least one sensor includes a sensor coupled to the portion of the intermediate container.

**[0028]** In another aspect combinable with any of the previous aspects, the sensor coupled to the portion of the intermediate container includes a mechanical sensor configured to be in contact with a surface on which the refuse collection vehicle is positioned when the intermediate container is in a lowered position.

**[0029]** In another aspect combinable with any of the previous aspects, the sensor coupled to the intermediate container is coupled to a front surface of the intermediate container.

**[0030]** In another aspect combinable with any of the previous aspects, the at least one sensor is coupled to the portion of the refuse collection vehicle and a detection distance of the at least one sensor is greater than a distance between a front side of the intermediate container and a front bumper of the refuse collection vehicle.

**[0031]** In another aspect combinable with any of the previous aspects, the detection distance is determined based at least in part on a speed of the refuse collection vehicle.

**[0032]** In another aspect combinable with any of the previous aspects, the detection distance is increased when the speed of the refuse collection vehicle exceeds a threshold speed.

**[0033]** In another aspect combinable with any of the previous aspects, the at least one processor is further configured to determine, based on the signal, an elevation change of the road surface in front of the refuse collection vehicle; and based on the elevation change of the road surface, control the refuse collection vehicle to change a position of the intermediate container to prevent contact between the intermediate container and the road surface.

**[0034]** In another aspect combinable with any of the previous aspects, the elevation change includes a vertical deflection traffic calming device.

**[0035]** In another aspect combinable with any of the previous aspects, the elevation change includes an increase in the elevation of the road surface.

**[0036]** In another aspect combinable with any of the previous aspects, the at least one processor includes an onboard computing device located in the refuse collection vehicle.

**[0037]** In another example implementation, a method of operating a refuse collection vehicle includes receiving a signal from at least one sensor coupled to a portion of the refuse collection vehicle or to a portion of the intermediate container, the at least one sensor oriented toward a road surface in front of the refuse collection vehicle; in response to receiving the signal, determining an elevation change of a road surface on which the refuse collection vehicle is positioned; and in response to determining an elevation change, controlling the refuse collection vehicle to prevent damage to an intermediate container for collecting refuse coupled to a front loading arm assembly of the refuse collection vehicle.

**[0038]** In another aspect combinable with any of the previous aspects, controlling the refuse collection vehicle to prevent damage to the intermediate container includes controlling the front loading arm assembly to raise the intermediate container.

**[0039]** Another aspect combinable with any of the previous aspects includes receiving a signal from one or more position sensors of the front loading arm assembly; and in response to receiving the signal from the one or more position sensors, determining at least one of a height of the intermediate container and an angle of the intermediate container with respect to a road surface on which the refuse collection vehicle is positioned.

**[0040]** In another aspect combinable with any of the previous aspects, raising the intermediate container includes adjusting at least one of the angle of the intermediate container relative to the road surface on which the refuse collection vehicle is positioned or the height of the intermediate container relative to the road surface on which the refuse collection vehicle is positioned to a predetermined value.

**[0041]** In another aspect combinable with any of the previous aspects, the at least one sensor includes at least one of a radar sensor, a lidar sensor, a laser sensor, a stereo camera, a three-dimensional camera, or an ultrasonic sensor.

**[0042]** Another aspect combinable with any of the previous aspects includes in response to receiving the signal, generating a visual alert or an audible alert.

**[0043]** In another aspect combinable with any of the previous aspects, the at least one sensor is coupled to the portion of the refuse collection vehicle and the detection distance is greater than a distance between a front side of the intermediate container and a front bumper of the refuse collection vehicle.

[0044] In another aspect combinable with any of the previous aspects, a detection distance of the at least one sensor depends on a current speed of the refuse collection vehicle.

[0045] In another aspect combinable with any of the previous aspects, the detection distance is increased when the speed of the refuse collection vehicle exceeds a threshold speed.

[0046] In another aspect combinable with any of the previous aspects, the at least one sensor is coupled to the portion of the intermediate container.

[0047] In another aspect combinable with any of the previous aspects, the at least one sensor coupled to the portion of the intermediate container includes a mechanical sensor in contact with the road surface.

[0048] In another aspect combinable with any of the previous aspects, receiving a signal includes receiving a signal indicating a deflection of the mechanical sensor in response to a change in elevation of the road surface.

[0049] Particular implementations of the subject matter described in this specification can be implemented so as to realize one or more of the following advantages.

[0050] For example, the refuse collection vehicle of the present disclosure can reduce the risk of damage to the vehicle by detecting elevation changes in surfaces proximate the refuse collection vehicle (e.g., road surfaces) using one or more distance sensors. In some implementations, the refuse collection vehicle of the present disclosure prevents damage to a coupled intermediate container carried by the vehicle by automatically controlling the angle and/or height of the intermediate container based on the detected elevation change.

[0051] 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.

[0052] 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

[0053] FIG. **1** depicts an example system for collecting refuse.

[0054] FIG. **2** is a perspective view of a front-loader refuse collection vehicle with an integrated intermediate container.

[0055] FIG. **3** is a side, schematic view of the refuse collection vehicle of FIG. **2**.

[0056] FIGS. **4**A-**4**E are schematic illustrations of example traffic calming devices and elevation changes in the road surface.

[0057] FIG. **5** is a side, schematic view of a refuse collection vehicle with a mechanical distance sensor.

[0058] FIG. **6** is a perspective view of a refuse collection vehicle with an intermediate container integrated with the front loading arm assembly of the refuse container.

[0059] FIG. **7** is a schematic illustration of an example control system or controller for a refuse collection vehicle.

## DETAILED DESCRIPTION

[0060] The refuse collection system of the present disclosure includes one or more distance sensors. The distance sensor(s) of the refuse collection system can be used to detect one or more elevation changes of a surface (e.g., a road surface) proximate the refuse collection vehicle.

[0061] FIGS. **1-3** depict an example system **100** for collection of refuse including a refuse collection vehicle **102** and an intermediate container **130** coupled to the vehicle **102**. 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.

[0062] The vehicle **102** can include various body components **104** that are appropriate for the particular type of vehicle **102**. For example, a front-loading vehicle (such as vehicle **102** of FIGS. **1-3**) includes various body components **104** including, but not limited to: a front loading arm assembly **109** which includes a lift arm **111** and forks **113**, a back gate or tailgate **115**, and a hopper **117** to collect refuse for transportation. The vehicle **102** may include other types of components that operate to bring garbage into a hopper **117** of the vehicle **102**, compress and/or arrange the garbage in the vehicle **102**, and/or expel the garbage from the vehicle **102**.

[0063] Front end loading refuse collection vehicles (such as vehicle **102**) are typically used for commercial refuse collection, where large bins of garbage or recyclables are engaged with the front forks of the vehicle and lifted overhead to be emptied into a hopper behind the cab of the vehicle. In order to service residential refuse containers (also referred to herein as residential bins), an intermediate container, such as intermediate container **130**, can be coupled to the forks of a front end loading refuse collection vehicle and used to collect refuse from residential refuse containers. U.S. Pat. Nos. 7,210,890 and 7,553,121, which are incorporated by reference in their entirety herein, describe example intermediate containers which can be positioned on the front forks of a front end loading refuse collection vehicle. An example intermediate container for collecting refuse is sold under the brand Curotto-Can®.

[0064] Referring to FIGS. **1-3**, an intermediate container **130** for collecting refuse is coupled to the front loading arm assembly **109** of the vehicle **102**. The intermediate container **130** has an overall box shape with a front wall **131**, a rear wall **132**, sidewalls **133***a*, **133***b*, a bottom **135** and an open top **137**. Refuse can be positioned into the intermediate container **130** through the open top **137**. The intermediate container **130** includes a pair of channels **127***a*, **127***b* extending along the sidewalls **133***a*, **133***b* that allow the forks **113** to pass through to enable the vehicle **102** to lift and transport the intermediate container **130**. The intermediate container **130** can remain coupled to the front loading arm assembly **109** while the vehicle **102** is in motion.

[0065] The intermediate container includes a collection arm **119** is coupled to the intermediate container **130** and configured to engage, lift, and invert a refuse container (e.g., a residential refuse bin) to empty the contents of the refuse container into the intermediate container **130**. A portion of the collection arm **119** is positioned inside of the intermediate container **130**. The collection arm **119** includes a grabber assembly **121**. The grabber assembly **121** can be extended, retracted, and rotated to grab refuse cans (e.g., residential refuse bins) and empty the refuse cans into the intermediate container **130**. The refuse is retained in the intermediate container **130** until it is dumped into the hopper **117** of the vehicle **102**. Once the intermediate container **130** is sufficiently full, the lift arm **111** and front loading arm assembly **109** of the vehicle **102** lift the intermediate container **130** to dump its contents into the hopper **117** of the vehicle **102**.

**[0066]** 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 can 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 as the front loading arm assembly **109**, the lift arm **111**, the forks **113**, and so forth.

**[0067]** Body sensor devices **106** can include, but are not limited to, an analog sensor, a digital sensor, a 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, or additionally, the body sensor devices **106** may be separate from the body components.

**[0068]** The system **100** can also include one or more distance sensors **116***a*, **116***b* (collectively referred to herein as distance sensors **116**) that can be used to detect elevation changes of the surface on which the vehicle **102** is positioned (e.g., a road surface). For example, as will be described in further detail herein, the distance sensor(s) **116** can be used to detect vertical deflection traffic calming devices (e.g., speed bumps, speed tables, speed cushions, etc.), dips, and inclines (e.g., hills, entrances to driveways or parking lots, etc.). Distance sensors **116** can include sensors similar to the body sensor devices **106**. For example, the distance sensors **116** can include radar sensors, LIDAR sensors, ultrasonic sensors, laser-based distance sensors, stereo camera sensors, three-dimensional cameras (e.g., plenoptic cameras), and mechanical displacement sensors. Distance sensors **116** can be positioned on the vehicle **102** and/or on the intermediate container **130**. For example, as depicted in FIGS. **1-3**, a first distance sensor **116***a* can be coupled to an upper surface of the cab protector **124** of the vehicle **102** and a second distance sensor **116***b* can be coupled to a front surface **131** of the intermediate container **130**. In some implementations, one or more body components **104** of the vehicle **102** can be controlled based on the output of the distance sensors **116**.

**[0069]** In some implementations, the distance sensors **116** are radar sensors configured to generate radar sensor data, such as a point cloud. The point cloud generated by the radar sensors 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 has a set of Cartesian coordinates (X, Y) and represents a single point on a surface proximate the vehicle **102** (e.g., road surface) detected by the respective radar sensor. The Cartesian coordinates of the data points in the point cloud can be used to determine the angle and distance of the surface relative to the radar sensor. The point clouds generated by the radar sensors **116** can be processed in order to detect and identify elevation changes in surfaces proximate the vehicle **102**, such as curbs, dips, speed bumps, and hills. In some implementations, point clouds are generated at a predefined time interval based on updated data received from the radar sensors to create a set of point clouds, and the set of point clouds can be processed to detect elevation changes 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, and two or more point clouds generated consecutively can be processed in combination to detect elevation changes of surfaces proximate the vehicle **102** as the vehicle **102** moves through an environment.

**[0070]** In some implementations, the body sensor data **110** and distance sensor data **140** is communicated from the body sensor devices **106** and the distance sensors **116** 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** can be placed in some other suitable location in or on the vehicle. The body sensor data **110** and distance sensor data **140** can be communicated from the body sensor devices **106** and the distance 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 body sensor devices **106** and the distance 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 **112**. In some implementations, body sensor devices **106** and/or the distance sensors **116** 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.

**[0071]** The analysis of the body sensor data **110** and the distance 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 distance sensor data **140** to detect elevation changes of surfaces proximate the vehicle **102**. In some implementations, an onboard programable logic controller or an onboard mobile controller perform analysis of the distance sensor data **140** to detect elevation changes of surfaces proximate the vehicle **102**.

**[0072]** 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.

**[0073]** In some implementations, the vehicle **102** includes a body controller that manages and/or monitors various body components **104** of the vehicle **102**. 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.

**[0074]** 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.

**[0075]** 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 the intermediate container **130** before, after, and/or during the operations of body components **104** to engage and empty the intermediate 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**. 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 elevation changes detected by the distance sensors **116** coupled to the refuse collection vehicle **102**.

**[0076]** 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**.

**[0077]** 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 intermediate container **130** into the vehicle **102**. In some implementations, the body sensor device(s) **106** are located in one or more cylinders **150***a*, **150***b* (collectively referred to herein as cylinders **150**) of the refuse collection vehicle **102**. In some examples, body sensor device **106** is located inside a cylinder **150***a* used for raising the lift arm **111** and a body sensor device **106** is located inside a cylinder **150***b* used for moving the front loading arm assembly **109**. In some implementations, body sensor device **106** is located on the outside of a housing containing the cylinder **150***a* coupled to the lift arm **111**. In some examples, the body sensor devices **106** are in-cylinder, magnetostrictive sensors.

**[0078]** 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 cameras **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**. In some implementations, the image data or video data captured by the camera(s) **134** can be combined with data captured by the distance sensors **116** to detect and track elevation changes in the road surface proximate the vehicle **102**. In some implementations, the image data **128** and the distance sensor data **140** are combined to generate a map of elevation changes in the road surface.

**[0079]** Referring to FIGS. **1-3**, the system **100** includes a first distance sensor **116***a* coupled to an upper surface of the cab protector **124** of the vehicle **102** and a second distance sensor **116***b* coupled to a front surface **131** of the intermediate container **130**. The distance sensors **116** are oriented toward the road surface **302** in front of the vehicle **102** and are configured to detect changes in elevation in the road surface **302** in front of the vehicle **102**. Distance sensors **116** can include radar sensors, LIDAR sensors, ultrasonic sensors, laser-based distance sensors, stereo camera sensors, three-dimensional cameras (e.g., plenoptic cameras), and mechanical displacement sensors. The distance sensors **116** can each be the same type of distance sensor or different types of distance sensors. In addition, the distance sensors **116** can each have similar sensitivities or can have different sensitivities. For example, distance sensor **116***b* can have a higher sensitivity than distance sensor **116***a* or vice versa.

**[0080]** In some implementations, the data from the distance sensors **116***a*, **116***b* can be processed to triangulate elevation changes in the road surface **302**, for example, when distance sensors **116** are configured to detect the road surface **302** at the same distance in front of the vehicle **102**. In some implementations, the distance sensors **116***a*, **116***b* can be directed toward different portions of the road surface **302**. For example, the distance sensor **116***a* can be directed at a location further in front of vehicle **102** than distance sensor **116***b*. Distance sensor **116***a* can measure a first elevation at a first location, and distance sensor **116***b* can measure a second elevation at a second location that is closer to the vehicle **102** that then first location, and changes in elevation of the road surface **302** can be determined based on a difference between the first elevation and the second elevation and the known distance between the first location and the second location. In some implementations, the distance sensors **116** and onboard computing device **112** measure and store distances at multiple instances in time. For example, a first distance is detected at a first time, and a second distance is detected at a second time. The onboard computing device **112** can determine an elevation change based on a difference between the first distance and the second distance. For example, if the second distance is smaller than the first distance, the onboard computing system can determine that there is an increasing elevation.

**[0081]** FIGS. **4**A-**4**E depict various types of elevation changes in a road surface that can be detected by the distance sensors **116**. FIGS. **4**A-**4**C are schematic examples of vertical deflection traffic calming devices that cause elevation changes in the road surface. Vertical deflection traffic calming devices include, for example, speed tables **400**, speed bumps or speed humps **405**, and dips **410**. Vertical deflection traffic calming devices are engineered to help reduce speeds on a road by raising or lowering the road surface to cause discomfort to passengers if traversed at a too high of a speed.

**[0082]** FIGS. **4**D-**4**E are schematic examples of other elevation changes that can occur on a road surface. FIG. **4**D shows a vertical step **415** change in the elevation of the road surface. The vertical step **415** can be caused by, for example, a curb along the edge of a road or at the end of a cul-de-sac. FIG. **4**E shows an angled incline **420** with an inclination angle **422** relative to a horizontal plane. The angled incline **420** can represent elevation changes resulting from topographical features (e.g., hills, valleys) of the Earth or structural features of the roadway (e.g., bridges, on/off ramps). Angled incline **420** can also occur, for example, at an entrance to a parking lot or driveway that the refuse collection vehicle may need to enter to collect refuse.

**[0083]** In implementations, one or more of distance sensors **116** are radar sensors and an antenna of each of the radar sensors emits radio waves (e.g., electromagnetic radiation) outwards from the respective radar sensor toward the road surface **302** in front of the vehicle **102**. The radio waves emitted by the radar sensors contact and reflect off of the road surface **302**. The reflected radio waves are detected by a receiver of the respective radar sensor. For example, a radio wave emitted from a radar sensor (e.g., distance sensor **116***b*) positioned on the front surface **131** of the intermediate container **130** can reflect off of the road surface **302** and return to the radar sensor, and the reflected radio wave can be analyzed to detect changes in the elevation of the road surface **302**.

**[0084]** In some implementations, the distance sensors **116** are configured to take measurements at a predefined time interval. For example, the distance sensors **116***a*, **116***b* can be configured to take distance measurements every **30** milliseconds or less.

**[0085]** In some implementations, the distance sensors **116** are laser-based distance sensors, and a laser beam of the laser-based distance sensors is oriented toward the road surface **302** in order to detect changes in elevation in the road surface **302** in front of the vehicle **102**. For example, light from the laser beam generated by the distance sensors **116** reflects off the road surface **302** and returns to a light detector of the laser-based distance sensor **116**. The laser-based distance sensor can determine the distance to the road surface **302** based on the round trip time-of-flight of the light.

**[0086]** In some implementations, one or more distance sensors **116** is a camera. Image data or video data captured by the camera can be used to detect elevation changes in the road surface. For example, the image data or video data can be processed by a machine learning model to detect elevation changes. The machine learning model can be trained by training data including images labeled with appropriate labels indicating a type and height of the elevation change. The image data or video data can be processed by the onboard computing device **112** to determine an elevation change in front of the vehicle **102**.

**[0087]** Referring to FIG. **3**, the distance sensors **116***a* and **116***b* can be configured to detect elevation changes within a particular detection distance **136** and **138**, respectively, relative to the distance sensor **116***a* and **116***b*. In some implementations, the distance sensors **116***a*, **116** have the same detection distance **136**, **138**. In some implementations, the distance sensors **116***a*, **116** have the different detection distances **136**, **138**. For example, the detection distances **136**, **138** of the distance sensors **116***a*, **116***b* can depend on the location of the distance sensor **116** on the vehicle. For example, in some implementations, the detection distance **136** of the distance sensor **116***a* coupled to the cab protector **124** is greater than the detection distance **138** of the distance sensor **116***b* coupled to the intermediate container **130**. In some implementations, the distance sensor **116***a* has a detection distance **136** that is greater than the distance between the front side **131** of the intermediate container **130** and the front bumper **126** of the vehicle **102**.

**[0088]** In some implementations, the detection distance **136**, **138** for each distance sensor **116** is a fixed distance away from the respective distance sensor **116***a*, **116***b*. In implementations, the sensors **116***a* and **116***b* can have detection distances **136**, **138** that enable detection of the road surface at different points relative to the front bumper **126** of the vehicle **102**. For example, distance sensor **116***a* can have a detection distance **136** that enables detection of elevation changes in the road surface further in front of the vehicle **102** than distance sensor **116***b*. In some implementations, distance sensor **116***b* coupled to the intermediate container can be a distance sensor with a shorter detection distance and/or a higher sensitivity than the distance sensor **116***a* coupled to the cab protector **124**. A higher sensitivity for distance sensor **116***b* can be beneficial to detect smaller elevation changes in the road surface. For example, at an incline, the elevation change is relatively small over the detection distance **138**, which may need a higher sensitivity to detect, as compared with the elevation change over the detection distance **136**.

**[0089]** In some implementations, the detection distance **136**, **138** of the distance sensors **116***a*, **116***b* can be adjusted based on a speed of the vehicle **102**. For example, the detection distance **136**, **138** can be increased when the speed of the vehicle **102** exceeds a threshold speed. For example, a laser beam from a laser-based distance sensor can be directed further in front of the vehicle **102** when it is detected that the vehicle **102** is traveling at higher speeds.

**[0090]** In some implementations, the distance sensors **116** are the same type of sensor. In some implementations, the distance sensors **116** are different types of distance sensors. For example, distance sensor **116***a* can be a radar sensor, and distance sensor **116***b* can be a laser-based sensor. Alternatively, or additionally, distance sensor **116***a* can be a laser-based sensor and distance sensor **116***b* can be an ultrasonic sensor. Other combinations of distance sensors are also possible.

**[0091]** In some implementations, multiple distance sensors **116** are positioned on the intermediate container **130**. By including multiple distance sensors **116** positioned on the intermediate container **130**, data from the multiple distance sensors can be used to triangulate elevation changes in the road surface **302** and determine features of the surface including, for example, inclination angle **306** and heights of vertical deflection traffic calming devices (e.g., traffic calming devices **400-415**).

**[0092]** In some implementations, a user (e.g., an operator of the vehicle **102**) can set the detection distance **136**, **138** of the distance sensors **116**. For example, the user can increase or decrease the distance relative to a default detection distance.

**[0093]** In some implementations, one or more distance sensors **116** can transmit a CAN message to the onboard computing device **112** of the vehicle **102** indicating a detected elevation change in the road surface. For example, a distance sensor **116***a* can transmit a CAN message to the onboard computing device **112** of the vehicle **102** indicating the road surface in front of the vehicle **102** has an increasing elevation within the detection distance **136** of the distance sensor **116***a*. Similarly, the distance sensor **116***b* can transmit a CAN message to the onboard computing device **112** of the vehicle **102** indicating a change in elevation in front of the vehicle **102** within the detection distance **138** of the distance sensor **116***b*. In some implementations, the distance sensors **116***a*, **116***b* transmit a CAN message to the onboard computing device **112** of the vehicle **102** indicating an angle **306** of elevation change in the road surface relative to the vehicle **102**. In some implementations, in response to detecting an elevation change, the distance 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 an elevation change occurs within the respective detection distance **136**, **138** of the distance sensors **116***a*, **116***b*.

**[0094]** In response to receiving a signal from one or more of the distance sensors **116***a*, **116***b* indicating that the road surface has an elevation change, the onboard computing device **112** can perform one or more actions to respond to the detected elevation change. In some implementations, the onboard computing device **112** controls one or more body components **104** of the vehicle **102** in order to prevent or mitigate contact between the intermediate container **130** and the road surface **302**.

**[0095]** For example, in response to receiving a signal from the distance sensor **116***a* or **116***b*, the onboard computing device **112** can determine whether an elevation change of the road surface **302** is greater than a threshold elevation change. For example, the onboard computing device **112** can determine that the elevation change of the road surface exceeds a threshold angle (e.g., the vehicle approach angle). In some implementations, the threshold elevation change corresponds to an amount of elevation change that would likely result in contact between the intermediate container **130** and the road surface **302**.

**[0096]** In response to determining that an elevation change of the road surface **302** detected by the distance sensors **116** exceeds a threshold elevation change, the onboard computing device **112** can control the front loading arm assembly **109** to change a position of the intermediate container **130**. For example, in response to determining that an elevation change of the road surface **302** detected by the distance sensors **116** exceeds a threshold elevation change, the onboard computing device **112** can generate commands to raise the intermediate container **130**. The commands to raise the intermediate container **130** can include, for example, changing an angle of the intermediate container **130** by actuating cylinder **150***b* to tilt the forks **113**. The onboard computing device **112** can also raise the intermediate container by moving lift arms **111** by actuating cylinder **150***a*.

**[0097]** In some implementations, the onboard computing device **112** determines a target angle and/or height of the intermediate container. For example, the onboard computing device **112** determines a target angle and/or height of the intermediate container **130** that will prevent contact between a detected elevation change and the intermediate container **130**. In some implementations, the target angle and/or height is a predetermined value (e.g., a fixed value). The target angle and/or height can be based, for example, on the vehicle approach angle of the vehicle **102** without the intermediate container **130** extending in front of the vehicle **102**. In some implementations, the onboard computing device **112** includes a maximum angle and/or height to which the intermediate container can be adjusted in response to detecting an elevation change to, for example, prevent the intermediate container **130** from blocking the view of the driver while vehicle **102** is in motion. In some implementations, the predetermined value of the target angle and/or height is equal to the maximum allowed angle and/or height of the intermediate container **130** while the vehicle is in motion.

**[0098]** In some implementations, the onboard computing device **112** determines the target angle/height based on a minimum ground clearance (e.g., a smallest allowed distance) between the bottom of the intermediate container **130** and the road surface **302**. For example, the onboard computing device **112** determines a current ground clearance **304** of the intermediate container **130** relative to the ground surface **302** on which the vehicle **102** is currently positioned based on the size and position of the intermediate container **130** and data received from on one or more body sensors **106** indicating the position of the front loading arm assembly **109**. The onboard computing device **112** can determine an angle **306** of the road surface **302** in front of the vehicle **102** based on signals from the distance sensors **116**. The onboard computing device **112** can then determine a predicted ground clearance of the intermediate container **130** when positioned over the detected surface **302** in front of the vehicle based on the current amount of ground clearance **304** of the intermediate container **130** over the road surface upon which the vehicle **102** is presently positioned and the angle **306** of the road surface **302** that is detected by the distance sensors **116**. The onboard computing device **112** can determine the target angle and/or height to which to raise the intermediate container **130**, for example, based on the difference between the predicted ground clearance **304** and the minimum ground clearance. For example, in response to determining that the predicted ground clearance **304** for the intermediate container **130** for the detected ground surface **302** is below a threshold value (e.g., minimum ground clearance), the onboard computing device **112** determines a target angle and/or height of the intermediate container **130** that will result in the predicted ground clearance **304** meeting or exceeding the minimum ground clearance.

**[0099]** In response to determining the target angle and/or height, the onboard computing system controls the cylinders **150** to achieve the target angle and/or height based on feedback including position data from body sensors **106**. For example, 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 controls the lift arm **111** and/or forks **113** to achieve the target angle. The onboard computing device **112** can continue to raise the intermediate container **130** until the onboard computing device has determined the target angle and/or height of the intermediate container **130** based on signals received from one or more body sensors **106**. For example, the onboard computing device **112** can determine that the target angle and/or height of the intermediate container **130** has been achieved based on receiving a signal from the one or more body sensors **106** indicating that the current position of the lift arm **111** and/or forks **113** correspond to the target height and/or angle, respectively. In some implementations, controlling the lift arm **111** and/or the forks **113** to change the position of the intermediate container occurs while the vehicle **102** is in motion.

**[0100]** In some implementations, in response to receiving a signal from the distance sensor **116** indicating that an elevation change exceeding an elevation change threshold is within the detection distance **136**, **138** of the distance sensors **116**, 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 over the elevation change.

**[0101]** In some implementations, the onboard computing device **112** stores geographical locations (e.g., global positioning system (GPS) coordinates) of detected elevation changes in a database. Entries in the database can include, for example, the location of the elevation change, the height of the elevation change, and/or an indicator of whether the elevation change can be traversed without damage to the intermediate container **130**. In some implementations, a computing device (e.g., onboard computing device **112** or a remote computing device) accesses entries of the database during route planning for vehicles, for example, to plan routes that avoid road surfaces with elevation changes above a threshold value and/or impassable elevation changes. In some implementations, the onboard computing device **112** accesses one or more entries of the database while the vehicle **102** is in motion and determines target angles and/or heights of the intermediate container based on the one or more database entries.

**[0102]** An example process for detecting an elevation change of a road surface **302** in front of the vehicle **102**, will now be described with reference to FIGS. **1**-**3**. As depicted in FIG. **3**, while driving along a refuse collection route, a vehicle **102** may approach a hill (or other feature) causing an elevation change in the road surface **302** (e.g., as represented by angle **306**) that may potentially cause damage to vehicle **102** or intermediate container **130**. As the vehicle **102** travels along the road surface **302**, the distance sensors **116** are oriented toward the road surface **302** and generate signals indicating a distance between the respective distance sensor **116** and the road surface **302** (e.g., within the respective detection distances **136**, **138**) in front of the vehicle **102**. In some implementations, the onboard computing device **112** increases the detection distance of the distance sensors **116** when the speed of the vehicle **102** exceeds a threshold speed.

**[0103]** The onboard computing device **112** receives a signal from at least one distance sensor **116** coupled to the vehicle **102**, and in response to receiving the signal, the onboard computing device **112** determines an elevation change **306** of the road surface **302** in front of the refuse collection vehicle **102**. For example, the onboard computing device **112** can determine an elevation change of the road surface **302** based on a signal indicating a distance that is different than an expected distance. The elevation change can be determined based on a difference in distances indicated by two or more distance sensors **116**. For example, the distance sensor **116*a*** can be directed at a different location in front of vehicle **102** than distance sensor **116*b***. Distance sensor **116*a*** can measure a first elevation at the first location, and distance sensor **116*b*** can measure a second elevation at the second location, and changes in elevation in the road surface **302** in front of the vehicle **102** can be determined based on the distance between the first location and the second location and the difference between the first elevation at the first location and the second elevation at the second location.

**[0104]** In some implementations, the elevation change is determined based on the signal indicating a distance that is different than a previously received signal. For example, a first distance is detected at a first time by a distance sensor **116**, and a second distance is detected at a second time by the distance sensor **116**, and the onboard computing device **112** can determine an elevation change based on a difference between the first distance and the second distance detected by the distance sensor **116**. For example, if the second distance is smaller than the first distance, the onboard computing system can determine that there is an increasing elevation. In some implementations, the distance sensors

116 send signals to the onboard computer at predefined time intervals, for example, every 30 milliseconds or less, every 50 milliseconds or less, or every 100 milliseconds or more. The onboard computing device 112 can record in memory or storage the distances indicated by distance sensors at each moment in time that a signal is received.

**[0105]** In some implementations, the onboard computing device **112** compares the detected elevation change **306** with a threshold elevation change. For example, the threshold elevation change can indicate a maximum elevation change that can be traversed without damaging the intermediate container **130**. For elevation changes below the threshold elevation change, the onboard computing device can determine that no further action is necessary to prevent contact between the intermediate container **130** and the road surface **302**.

**[0106]** In response to determining an elevation change of the road surface **302** exceeds a threshold elevation change, the onboard computing device **112** controls the refuse collection vehicle **102** to prevent damage to the intermediate container **130**. Controlling the refuse collection vehicle **102** to prevent damage to the intermediate container **130** includes controlling the lift arm **111** and/or the front loading arm assembly **109** to raise the intermediate container **130**. For example, the onboard computing device receives a signal from one or more position sensors **106** of the front loading arm assembly **109**. In response to receiving the signal from the one or more position sensors **106**, the onboard computing device determines at least one of a height and an angle of the intermediate container **130** with respect to the road surface **302** on which the refuse collection vehicle **102** is positioned.

**[0107]** Raising the intermediate container **130** can include adjusting at least one of the angle **310** of the intermediate container **130** relative to the road surface on which the refuse collection vehicle is positioned and the height **312** of the intermediate container **130** relative to the road surface on which the refuse collection vehicle **102** is positioned. For example, the angle **310** of the intermediate container **130** can be adjusted by rotating the forks **113**. The height **312** of the intermediate container **130** can be adjusted by raising or lowering the lift arms **111**.

**[0108]** In some implementations, in response to receiving the signal from the distance sensor **116**, the onboard computing device **112** generates a visual alert or an audible alert to notify the operator of the vehicle **102** of the upcoming elevation change in the road surface **302**. For example, in response to receiving the signal from the distance sensor **116**, the onboard computing device **112** can generate an alert that displays on graphical display **120** positioned within the cab **108** of the vehicle **102** and can be viewed by an operator (e.g., driver) of the vehicle **102**. In some implementations, the onboard computing device **112** generates an alert when the detected elevation change in the road surface **302** in front of the vehicle **102** exceeds a threshold elevation change.

**[0109]** In some implementations, a user (e.g., vehicle driver) can override the control signals sent by the onboard computing device. For example, an operator of the vehicle **102** can stop movement of the front loading arm assembly **109** or change the position of the intermediate container to a different position.

**[0110]** While certain embodiments have been described, other embodiments are possible.

**[0111]** For example, while the distance sensors **116** have been described as electronic distance measuring sensors, in some implementations, one or more of the distance sensors used to detect changes in elevation in the road surface is a mechanical sensor. FIG. **5** is a side view of an example system **500** for refuse collection that includes a refuse collection vehicle **520**, an intermediate container **502** coupled to the front loading arm assembly **504** of the vehicle **520**, and a mechanical displacement sensor **506** coupled to the intermediate container **502**. The mechanical displacement sensor **506** includes a telescoping arm **508** and a contact end **510**. The contact end **510** can be, for example, a roller or a wheel that is in contact with the road surface **512**. The telescoping arm **508** is spring biased to maintain contact between the contact end **510** and the road surface **512**. A change in elevation of the road surface **512** relative to the intermediate container **502** causes the telescoping arm **508** to displace (e.g., extend or compress), and the amount displacement of the telescoping arm **508** can be used to detect changes in elevation in the road surface **302** in front of the vehicle **102**.

**[0112]** While the mechanical displacement sensor **506** is shown as being coupled to the underside of the intermediate container **502** between a front surface **530** of the intermediate container **502** and a rear surface **532** of the intermediate container **502**, one or more mechanical displacement sensors can be coupled to other portions of the intermediate container **502**. For example, the mechanical displacement sensor **506** can be coupled to a front surface **530** of the intermediate container **502** or coupled to the underside of the intermediate container **502** near the front surface **530**.

**[0113]** The mechanical displacement sensor **506** can send a signal (e.g., a CAN message) to an onboard computing device (e.g., onboard computing device **112**) indicating a change in elevation (e.g., elevation angle **511**) of the road surface **512**. For example, the mechanical displacement sensor **506** can send a signal indicating a distance that the telescoping arm **508** has been displaced by the road surface. The onboard computing device can compare the distance displaced with a threshold elevation change.

**[0114]** In response to determining that the indicated elevation change exceeds a threshold elevation change, the onboard computing device can raise the intermediate container **502** to prevent damage to the intermediate container **502** resulting from elevation changes in the road surface **512**. For example, the onboard computing device can raise the intermediate container until a signal is received from the mechanical displacement sensor **506** indicating a displacement of the telescoping arm is smaller than the threshold displacement.

**[0115]** The onboard computing device can control the position of the intermediate container **502** to maintain at least a specified distance between the bottom of the intermediate container **502** and the road surface **512** based on the signal received from the mechanical displacement sensor **506**. For example, the mechanical displacement sensor can indicate displacement relative to a nominal position (e.g., the vehicle **520** on a flat road surface with the intermediate container in a lowered position). A threshold displacement of the mechanical displacement sensor **506** can be determined based on the specified distance. When the mechanical displacement sensor sends a signal indicating a displacement greater than the threshold, the onboard computing device can raise the intermediate container **502** by at least the amount of the indicated displacement by, for example, rotating the forks **522** and/or raising the lift arms **524**.

**[0116]** Refuse collection system **500** includes additional distance sensors **514**, **516** that can provide redundant distance measurements to further confirm changes in elevation in the road surface **512** detected by the mechanical displacement sensor **506**. Distance sensors **514**, **516** can include, for example, radar sensors, LIDAR sensors, ultrasonic sensors, laser-based distance sensors, stereo camera sensors, or three-dimensional cameras. Distance sensor **514** is coupled to the cab protector **518**. Distance sensor **516** is coupled to intermediate container **502**.

**[0117]** In addition, while the intermediate container **130** has been described as being coupled to the vehicle **102** via forks **113** of the vehicle **102** being inserted in channels **127** along the side of the intermediate container **130**, in some implementations, the vehicle includes an integrated intermediate container. FIG. **6** is a perspective view of an example refuse collection system **600** with a refuse collection vehicle **622**, an integrated intermediate container **602**, and distance measurement sensors **612**, **614**. The front loading arms **604** of the vehicle **622** terminate at a connection end **606**. The integrated intermediate container **602** is pivotally coupled to the front loading arms **604** at the connection end **606**. The integrated intermediate container **602** includes substantially two parts: a frame assembly **608** and a collection bin **610**. The frame assembly **608** attaches to the front loading arms **604** at connection end **606**. The collection bin **610** receives and holds refuse. The intermediate container **602** can be emptied into hopper **620** by operating the front loading arms **604** similar to the process of emptying intermediate container **130** described herein. Refuse collection system **600** includes two distance sensors **612**, **614** substantially similar to distance sensors **116***a*, **116***b* of FIGS. **1-3**. Distance sensor **612** is coupled to a front surface of the collection bin **610**. Distance sensor **614** is coupled to the cab protector **616** of the vehicle **622**. Similar to distance sensors **116***a*, **116***b*, distance sensors **612**, **614** are oriented toward the road surface in front of the refuse collection vehicle **622** and are configured to detect changes in elevation in changes in the road surface in front of the vehicle **622**.

**[0118]** Further, while the refuse collection systems **100**, **500**, **600** have been described as including two distance sensors **116***a*, **116***b*, **514**, **516**, **612**, **614**, other numbers of distance sensors are possible (e.g., 1, 3, 4, 5 or more, etc.). In addition, while the distance sensors **116***a*, **116***b*, **514**, **516**, **612**, **614** have been described as being coupled to a cab protector **124**, **518**, **616** of the vehicle **102**, **520**, **622** and a front surface **131** of the intermediate container **130**, **502**, **602**, respectively, distance sensors can be attached to other portions of the vehicle **102**, **520**, **622**, including, but not limited to, a surface of the cab of the vehicle (e.g., the roof of the cab **108**, the front of the cab **108**, the top of the refuse collection body proximate the hopper **117**), or a surface of the lift arm of the vehicle.

**[0119]** 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.

**[0120]** 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 **750**. 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.

**[0121]** 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**.

**[0122]** 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.

**[0123]** 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.

**[0124]** 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.

**[0125]** 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.

[0126] 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.

[0127] The singular forms "a", "an" and "the" include plural referents, unless the context clearly dictates otherwise.

[0128] 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.

[0129] 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 refuse collection system comprising:
a refuse collection vehicle comprising:
a chassis;
a refuse collecting body supported by the chassis; and
a front loading arm assembly coupled to the refuse collecting body;
an intermediate container for receiving refuse positioned in front of the refuse collection vehicle and coupled to the front loading arm assembly;
at least one sensor coupled to a portion of the refuse collection vehicle or to a portion of the intermediate container, the at least one sensor oriented toward a road surface in front of the refuse collection vehicle; and
at least one processor communicably coupled to the at least one sensor, the at least one processor configured to perform operations comprising:
receiving a signal from the at least one sensor; and
in response to receiving the signal, determining an elevation change of the road surface in front of the refuse collection vehicle.

**2**. The refuse collection system of claim **1**, wherein the at least one sensor is coupled to the portion of the refuse collection vehicle and a detection distance of the at least one sensor is greater than a distance between a front side of the intermediate container and a front bumper of the refuse collection vehicle.

**3**. The refuse collection system of claim **2**, wherein the detection distance is determined based at least in part on a speed of the refuse collection vehicle.

**4**. The refuse collection system of claim **1**, wherein the at least one sensor comprises at least one of a radar sensor, a lidar sensor, a laser sensor, a stereo camera, a three-dimensional camera, or an ultrasonic sensor.

**5**. The refuse collection system of claim **1**, wherein the elevation change comprises a vertical deflection traffic calming device or the elevation change comprises an increase in the elevation of the road surface.

**6**. The refuse collection system of claim **1**, wherein the operations further comprise:
in response to determining the elevation change, controlling the front loading arm assembly to change a position of the intermediate container.

**7**. The refuse collection system of claim **6**, wherein controlling the front loading arm assembly to change the position of the intermediate container comprises controlling the front loading arm assembly to adjust at least one of a height and an angle of the intermediate container.

**8**. The refuse collection system of claim **7**, wherein controlling the front loading arm assembly to change the position of the intermediate container occurs while the refuse collection vehicle is in motion.

**9**. The refuse collection system of claim **7**, wherein controlling the front loading arm assembly to change the position of the intermediate container comprises adjusting at least one of the height of the intermediate container or the angle of the intermediate container to a predetermined value.

**10**. The refuse collection system of claim **1**, wherein the at least one sensor comprises a mechanical sensor configured to be in contact with a surface on which the refuse collection vehicle is positioned when the intermediate container is in a lowered position.

**11**. The refuse collection system of claim **1**, wherein the at least one processor comprises an onboard computing device located in the refuse collection vehicle.

**12**. A refuse collection system comprising:
a refuse collection vehicle comprising:
a chassis;
a refuse collecting body supported by the chassis; and
a front loading arm assembly coupled to the refuse collecting body;
an intermediate container for receiving refuse positioned in front of the refuse collection vehicle and coupled to the front loading arm assembly;
at least one sensor coupled to a portion of the refuse collection vehicle or to a portion of the intermediate container, the at least one sensor oriented toward a road surface; and
at least one processor communicably coupled to the at least one sensor, the at least one processor configured to perform operations comprising:
receiving a signal from the at least one sensor; and
in response to receiving the signal, controlling the refuse collection vehicle to prevent damage to the intermediate container coupled to the front loading arm assembly of the refuse collection vehicle.

**13**. The refuse collection system of claim **12**, wherein the front loading arm assembly comprises one or more position sensors; and
wherein the operations further comprise:
receiving signals from the one or more position sensors;
determining at least one of a height and an angle of the intermediate container with respect to a road surface on which the refuse collection vehicle is positioned.

**14**. The refuse collection system of claim **13**, wherein controlling the refuse collection vehicle to prevent damage to the intermediate container comprises controlling the front loading arm assembly to adjust at least one of the height and the angle of the intermediate container.

**15**. The refuse collection system of claim **12**, wherein the at least one processor is further configured to:

determine, based on the signal, an elevation change of the road surface in front of the refuse collection vehicle; and

based on the elevation change of the road surface, control the refuse collection vehicle to change a position of the intermediate container to prevent contact between the intermediate container and the road surface.

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

receiving a signal from at least one sensor coupled to a portion of the refuse collection vehicle or to a portion of an intermediate container, the at least one sensor oriented toward a road surface in front of the refuse collection vehicle;

in response to receiving the signal, determining an elevation change of a road surface on which the refuse collection vehicle is positioned; and

in response to determining an elevation change, controlling the refuse collection vehicle to prevent damage to an intermediate container for collecting refuse coupled to a front loading arm assembly of the refuse collection vehicle.

**17**. The method of claim **16**, wherein controlling the refuse collection vehicle to prevent damage to the intermediate container comprises controlling the front loading arm assembly to raise the intermediate container.

**18**. The method of claim **17**, further comprising:

receiving a signal from one or more position sensors of the front loading arm assembly;

in response to receiving the signal from the one or more position sensors, determining at least one of a height of the intermediate container and an angle of the intermediate container with respect to a road surface on which the refuse collection vehicle is positioned.

**19**. The method of claim **18**, wherein raising the intermediate container comprises:

adjusting at least one of the angle of the intermediate container relative to the road surface on which the refuse collection vehicle is positioned or the height of the intermediate container relative to the road surface on which the refuse collection vehicle is positioned to a predetermined value.

**20**. The method of claim **16**, further comprising in response to receiving the signal, generating a visual alert or an audible alert.

**21**. The method of claim **16**, wherein the at least one sensor comprises a mechanical sensor coupled to the portion of the intermediate container and in contact with the road surface, and

wherein receiving a signal comprises receiving a signal indicating a deflection of the mechanical sensor in response to a change in elevation of the road surface.

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