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(54) **TRAILER DOOR STATUS DETECTION FROM TRACTOR**

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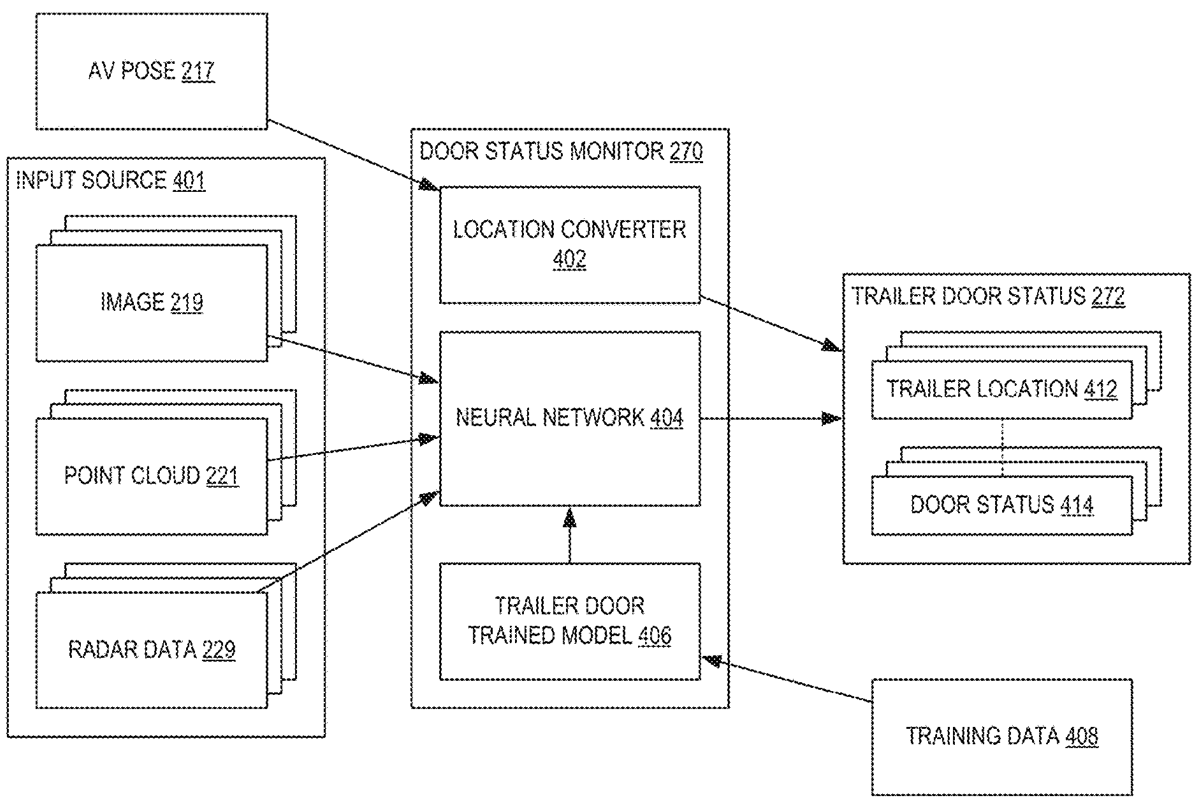
(57) **ABSTRACT**

A door status monitor determines a status of a rear door of a trailer from a tractor. The door status monitor receives an input source including information of the trailer. The input source includes at least one of an image, a LIDAR point cloud, and a RADAR point cloud from at least one of a camera, a LIDAR, and a RADAR, respectively, mounted to the tractor and having a view that includes at least a rear of the trailer. A door status monitor processes the input source through a neural network trained to generate a trailer door status defining the status of the rear door of the trailer. A door status monitor outputs the trailer door status.



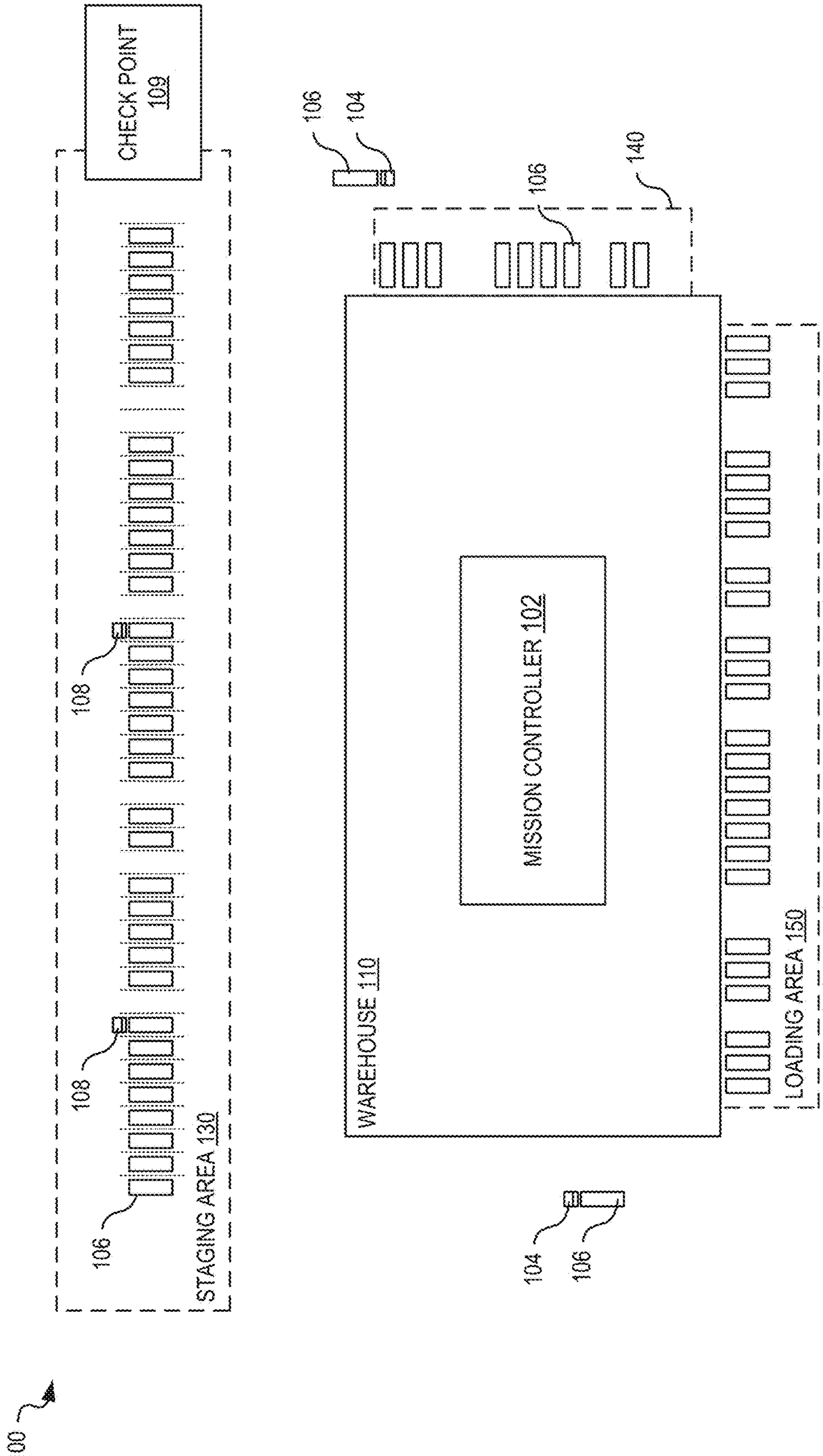

CHECK POINT 109
106
104
140
106
108
108
106
STAGING AREA 130
WAREHOUSE 110
MISSION CONTROLLER 102
LOADING AREA 150
104
106
100

FIG. 1

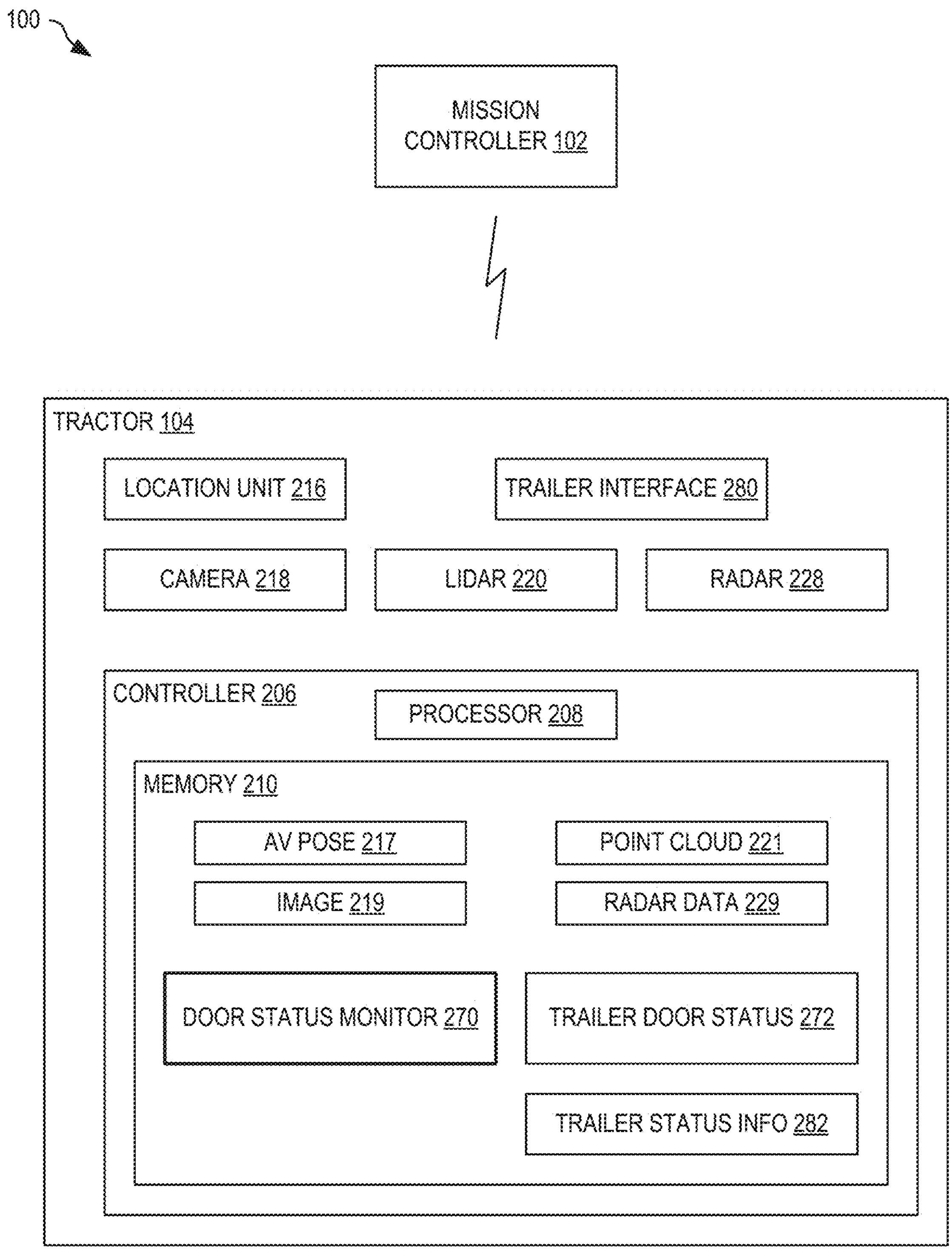

100
MISSION CONTROLLER 102
TRACTOR 104
LOCATION UNIT 216
TRAILER INTERFACE 280
CAMERA 218
LIDAR 220
RADAR 228
CONTROLLER 206
PROCESSOR 208
MEMORY 210
AV POSE 217
POINT CLOUD 221
IMAGE 219
RADAR DATA 229
DOOR STATUS MONITOR 270
TRAILER DOOR STATUS 272
TRAILER STATUS INFO 282

FIG. 2

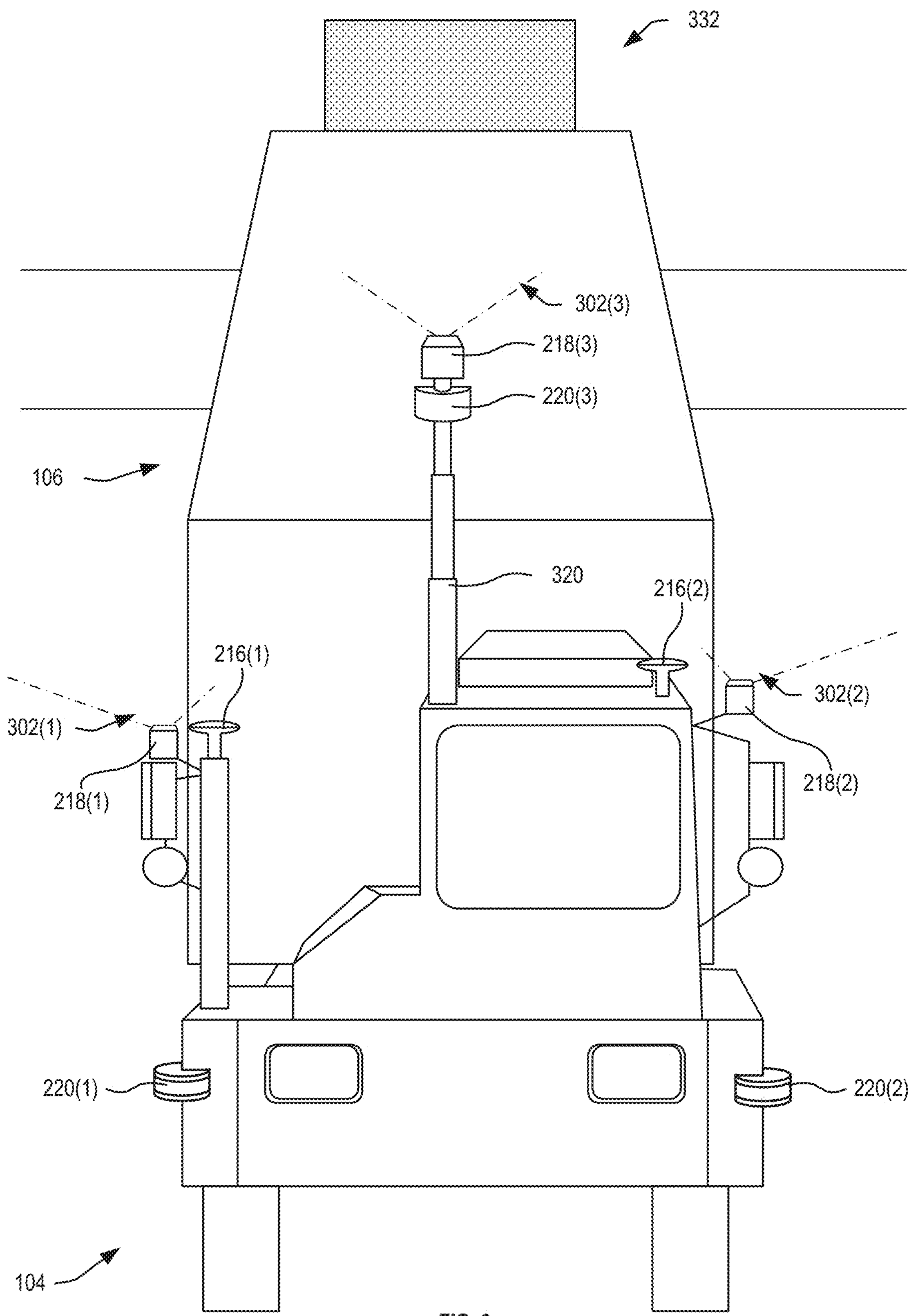

332
302(3)
218(3)
220(3)
106
320
216(2)
216(1)
302(2)
302(1)
218(2)
218(1)
220(1)
220(2)
104

FIG. 3

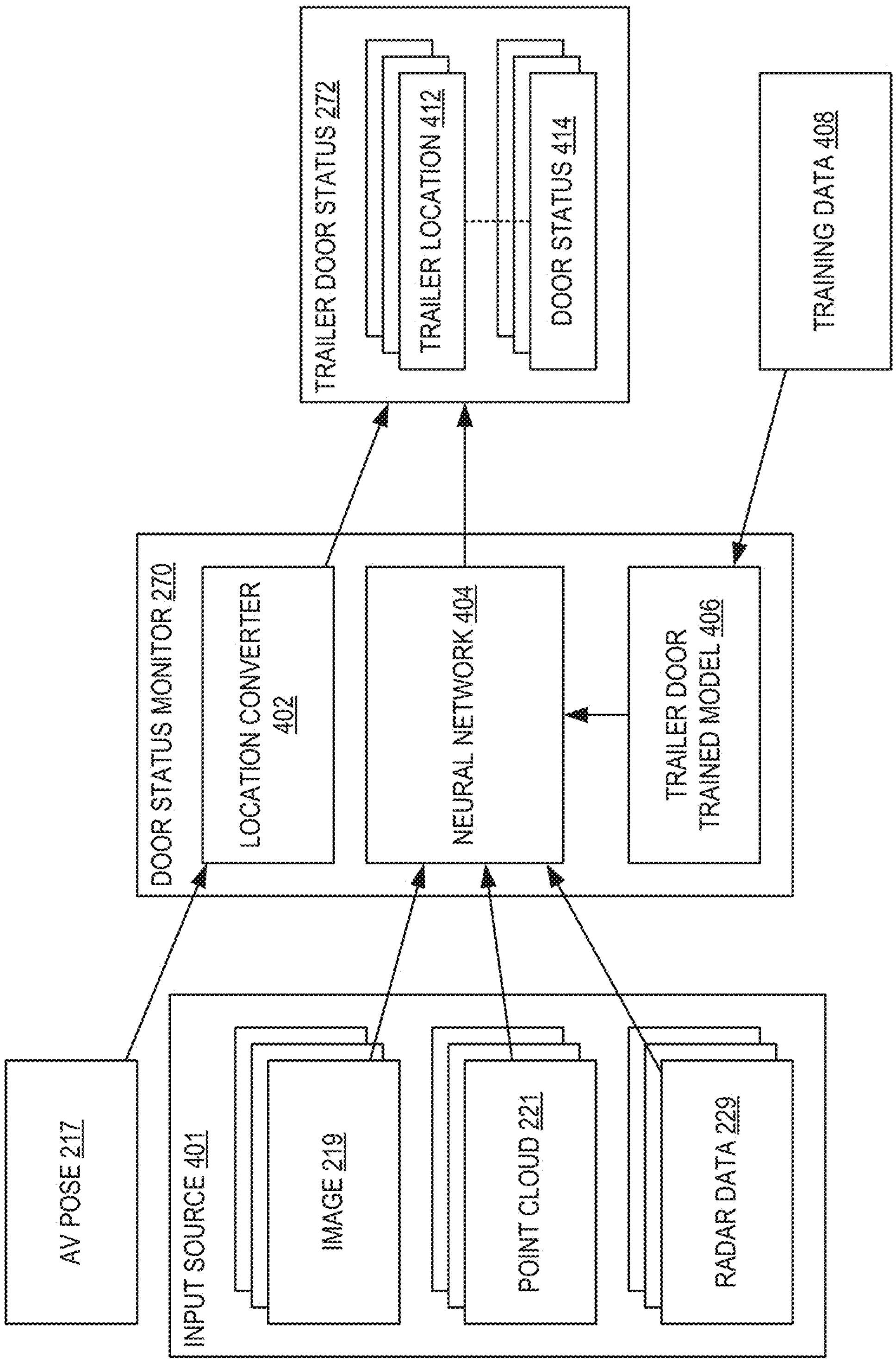

TRAILER DOOR STATUS 272
TRAILER LOCATION 412
DOOR STATUS 414
TRAINING DATA 408
DOOR STATUS MONITOR 270
LOCATION CONVERTER 402
NEURAL NETWORK 404
TRAILER DOOR TRAINED MODEL 406
AV POSE 217
INPUT SOURCE 401
IMAGE 219
POINT CLOUD 221
RADAR DATA 229

FIG. 4

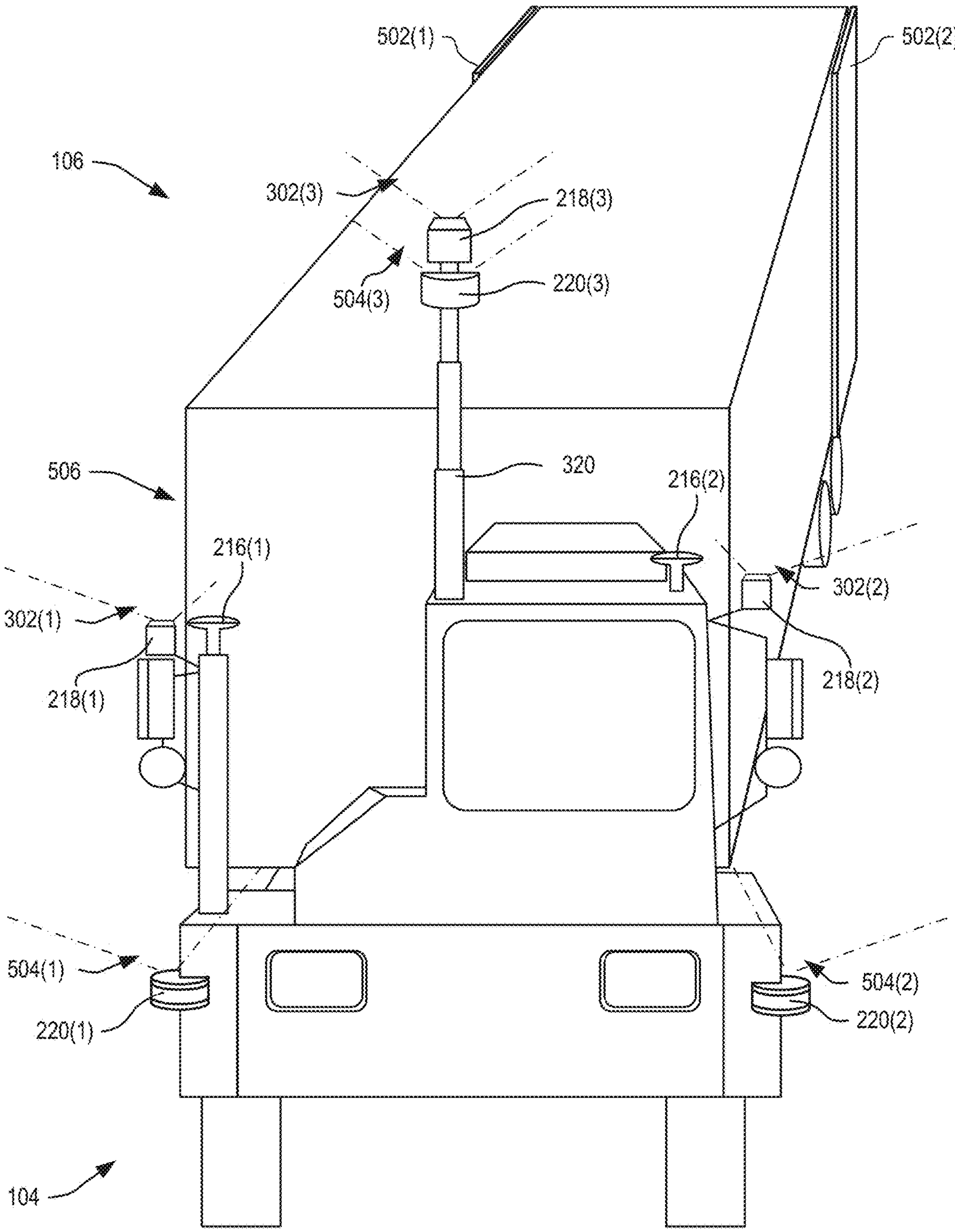

502(1)
502(2)
106
302(3)
218(3)
504(3)
220(3)
506
320
216(2)
216(1)
302(2)
302(1)
218(2)
218(1)
504(1)
504(2)
220(1)
220(2)
104

FIG. 5

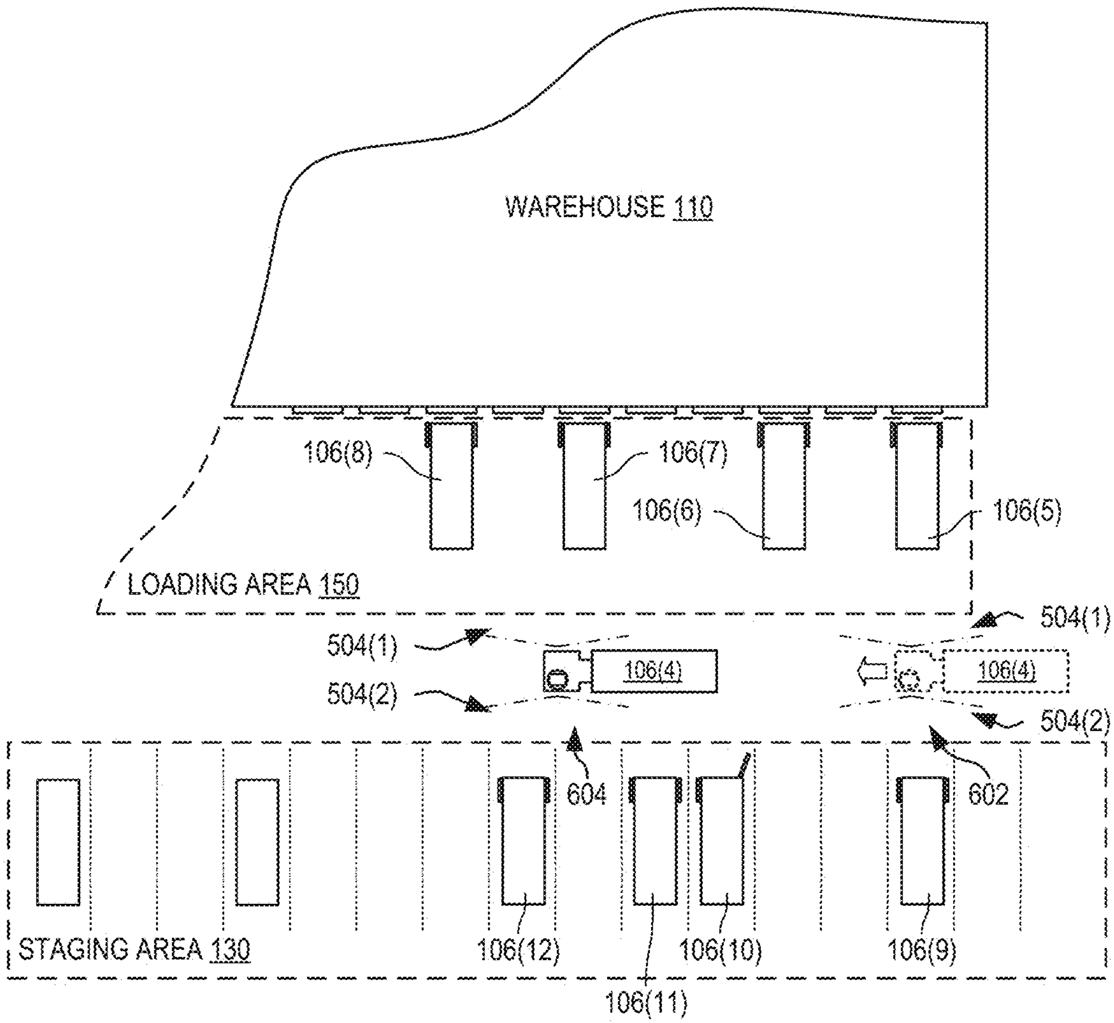

WAREHOUSE 110
106(8)
106(7)
106(6)
106(5)
LOADING AREA 150
504(1)
504(1)
106(4)
106(4)
504(2)
504(2)
604
602
STAGING AREA 130
106(12)
106(11)
106(10)
106(9)

FIG. 6

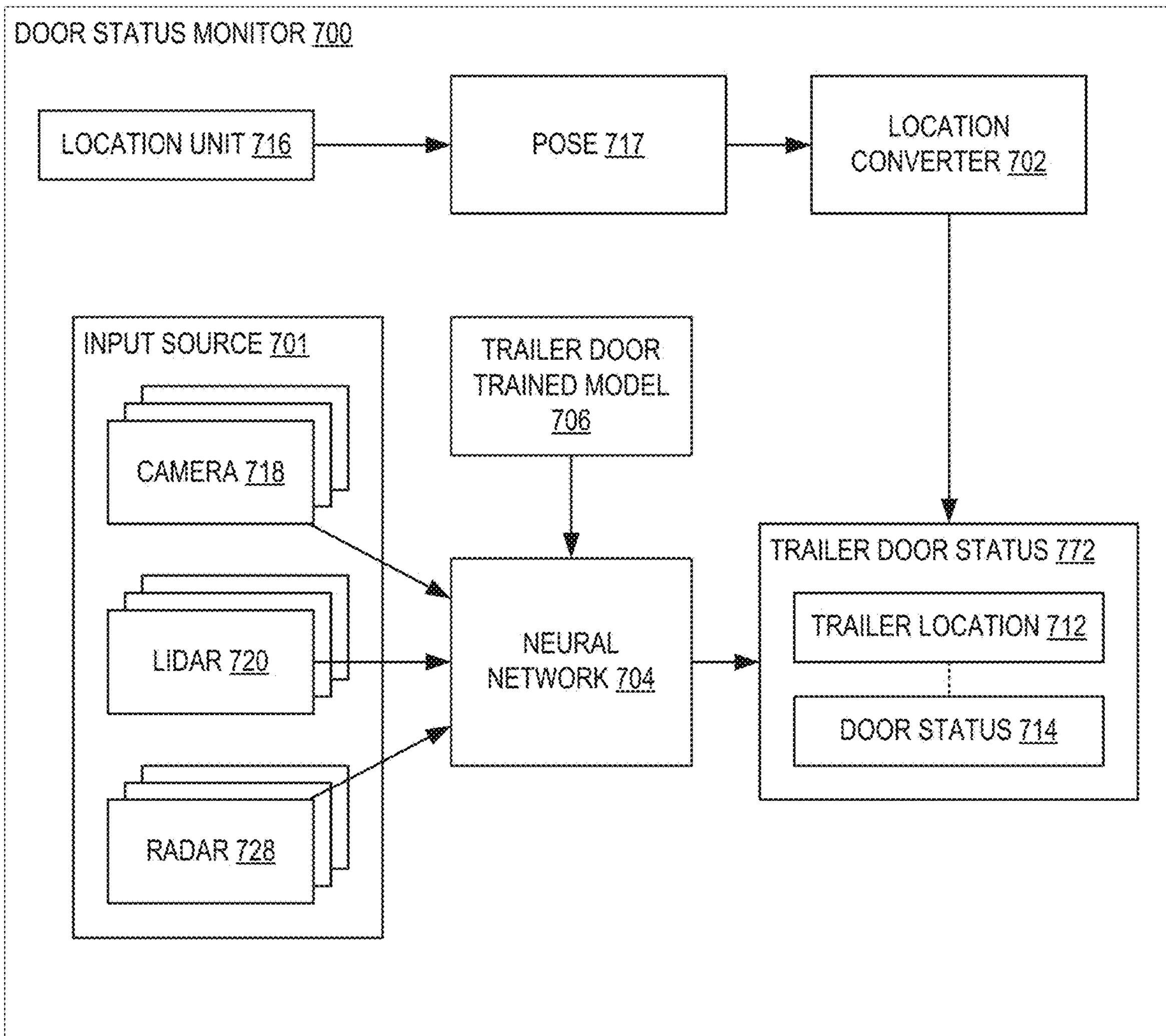

DOOR STATUS MONITOR 700
LOCATION UNIT 716
POSE 717
LOCATION CONVERTER 702
INPUT SOURCE 701
CAMERA 718
LIDAR 720
RADAR 728
TRAILER DOOR TRAINED MODEL 706
NEURAL NETWORK 704
TRAILER DOOR STATUS 772
TRAILER LOCATION 712
DOOR STATUS 714

FIG. 7

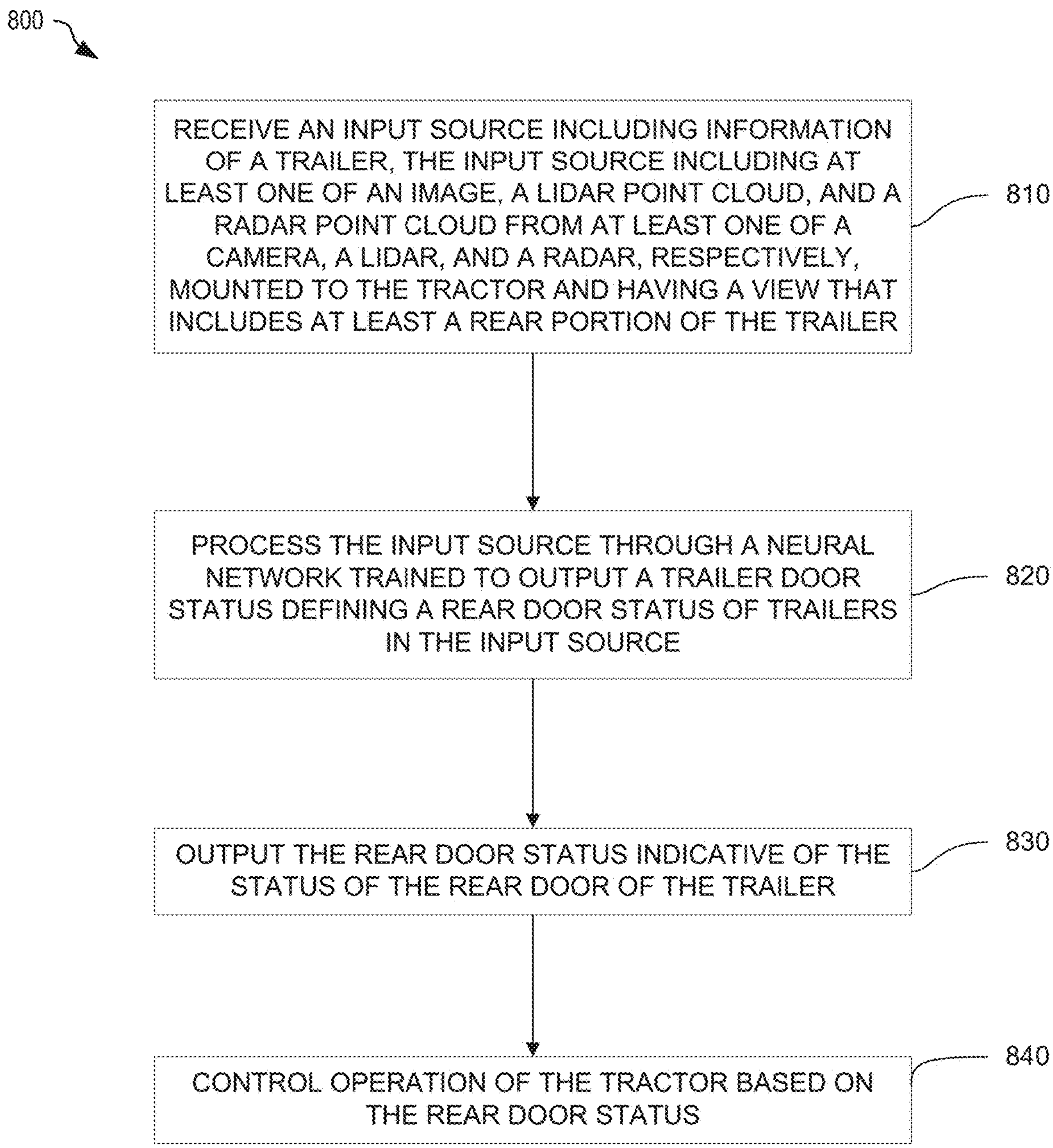
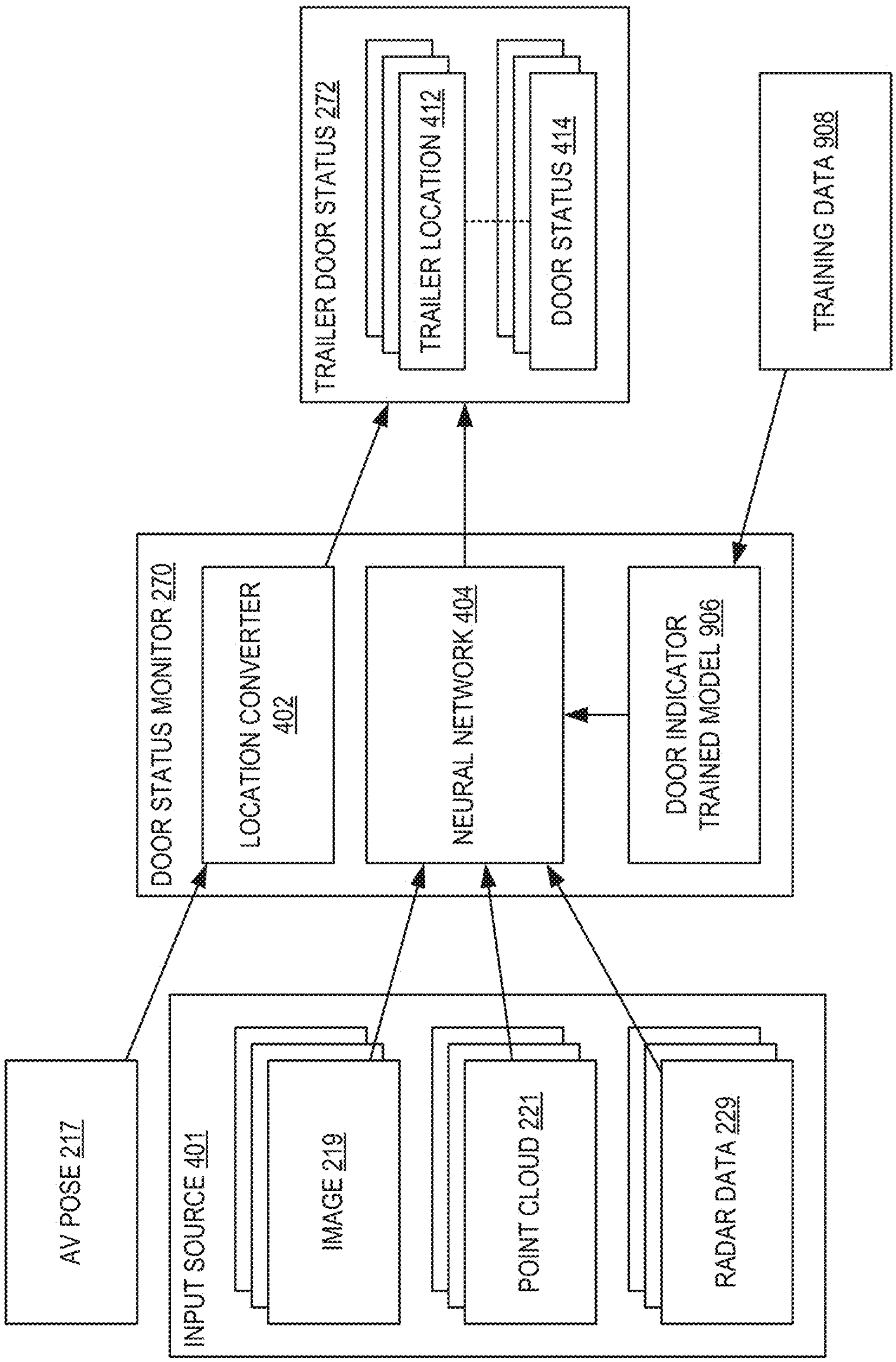

800
RECEIVE AN INPUT SOURCE INCLUDING INFORMATION OF A TRAILER, THE INPUT SOURCE INCLUDING AT LEAST ONE OF AN IMAGE, A LIDAR POINT CLOUD, AND A RADAR POINT CLOUD FROM AT LEAST ONE OF A CAMERA, A LIDAR, AND A RADAR, RESPECTIVELY, MOUNTED TO THE TRACTOR AND HAVING A VIEW THAT INCLUDES AT LEAST A REAR PORTION OF THE TRAILER
810
PROCESS THE INPUT SOURCE THROUGH A NEURAL NETWORK TRAINED TO OUTPUT A TRAILER DOOR STATUS DEFINING A REAR DOOR STATUS OF TRAILERS IN THE INPUT SOURCE
820
OUTPUT THE REAR DOOR STATUS INDICATIVE OF THE STATUS OF THE REAR DOOR OF THE TRAILER
830
CONTROL OPERATION OF THE TRACTOR BASED ON THE REAR DOOR STATUS
840

FIG. 8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TRAILER LOCATION 412
DOOR STATUS 414
TRAINING DATA 908
DOOR STATUS MONITOR 270
LOCATION CONVERTER 402
NEURAL NETWORK 404
DOOR INDICATOR TRAINED MODEL 906
AV POSE 217
INPUT SOURCE 401
IMAGE 219
POINT CLOUD 221
RADAR DATA 229

FIG. 9

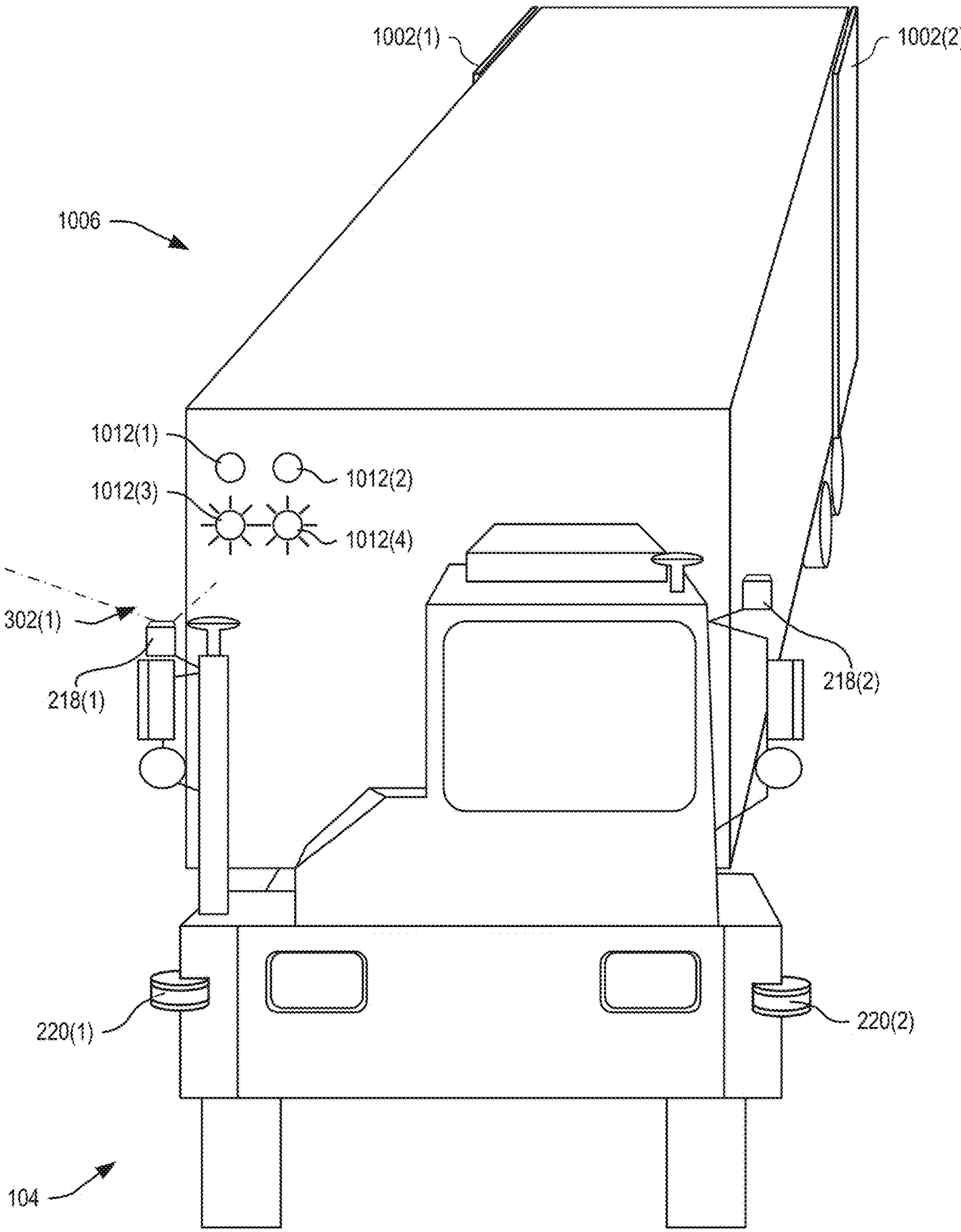
1002(1)
1002(2)
1006
1012(1)
1012(2)
1012(3)
1012(4)
302(1)
218(1)
218(2)
220(1)
220(2)
104

FIG. 10

TRAILER DOOR STATUS DETECTION FROM TRACTOR

RELATED APPLICATION

[0001] This application claim priority to U.S. Patent Application Ser. No. 63/551,795, titled "Trailer Door Status Detection from Tractor," filed Feb. 9, 2024, and included herein by reference in its entirety.

BACKGROUND

[0002] A rear door of a trailer presents a hazard when unlatched while the trailer is being maneuvered.

SUMMARY

[0003] One aspect of the present embodiments includes the realization that prior to positioning a trailer to a loading dock, the rear doors of the trailer should already be latched open to allow access to the interior of the trailer from the loading dock. Often, it is important for the autonomous tractor to learn whether the rear doors of the trailer are latched open. For example, maneuvering the trailer when the rear doors are open but not latched causes the rear doors to swing wildly, potentially causing damage to the doors and/or other property (e.g., adjacent trailers or infrastructure). The present embodiments solve this problem by detecting the rear doors of a hitched trailer from the tractor prior to and during maneuvering of the trailer. Advantageously, the tractor autonomously detects the status of the rear doors without manual intervention prior to maneuvering the trailer within the yard. For example, when collecting the trailer from a staging area, the rear doors of the trailer should be already latched open. However, when the rear doors are not opened, or are not latched open correctly, time is often wasted resolving the problem at or near the loading dock. By detecting the status of the rear doors from the tractor, the tractor may stop maneuvering when the doors are not latched open but swinging, and may request assistance to latch the doors open when they are not latched open correctly. Advantageously, by detecting unlatched doors, the tractor improves safety during maneuvering of the trailer within the autonomous yard. Accordingly, the tractor may thereby prevent the trailer being positioned at a loading dock with the doors closed, which often requires additional maneuvering of the trailer clear of the loading dock and any adjacent trailers to allow the doors to be opened fully and latched and may prevent damage caused by swinging doors during maneuvering.

[0004] In certain embodiments, the techniques described herein relate to a method for determining a status of a rear door of a trailer from a tractor, including: receiving an input source including information of the trailer, the input source including at least one of an image, a LIDAR point cloud, and a RADAR point cloud from at least one of a camera, a LIDAR, and a RADAR, respectively, mounted to the tractor; processing the input source through a neural network using a trailer door trained model to generate a trailer door status defining the status of the rear door of the trailer; and outputting the trailer door status.

[0005] In certain embodiments, the techniques described herein relate to a method for determining a status of a rear door of a smart trailer from a tractor, including: receiving, by a controller of the tractor and from the smart trailer, a signal encoding trailer status information of the smart trailer; decoding, by the controller, the trailer status information to determine a status of a rear door of the smart trailer; and outputting, from the tractor, the trailer door status.

[0006] In certain embodiments, the techniques described herein relate to a door status monitor, including: a rigid body for attaching to a vehicle; at least one of a camera, a LIDAR, and a RADAR having fixed positional and orientational relationship by the rigid body; a neural network having a trailer door trained model that processes an input source including at least one of an image, a point cloud, and RADAR data captured by at least one of the camera, the LIDAR, and the RADAR to generate a trailer door status defining the status of a rear door of a trailer included in the input source; and outputting the trailer door status to an external device.

BRIEF DESCRIPTION OF THE FIGURES

[0007] FIG. **1** is an aerial view showing one example autonomous yard that uses an autonomous tractor to move trailers between a staging area and loading docks of a warehouse, in embodiments.

[0008] FIG. **2** is a block diagram illustrating key functional components of the tractor of FIG. **1**, in embodiments.

[0009] FIG. **3** is a schematic diagram showing the autonomous tractor of FIGS. **1** and **2** reversing the trailer up to a loading dock, in embodiments.

[0010] FIG. **4** is a block diagram illustrating the door status monitor of FIG. **2** in further example detail, in embodiments.

[0011] FIG. **5** is a schematic diagram illustrating example use of the camera, the LIDAR device, and/or the radar by the door status monitor of FIG. **4** to determine the trailer door status of the trailer being towed by the tractor, in embodiments.

[0012] FIG. **6** is a schematic diagram illustrating example use of the camera, the LIDAR device, and/or the radar by the door status monitor of FIG. **4** to determine the trailer door status of other trailers encountered within the autonomous yard, in embodiment.

[0013] FIG. **7** is a block diagram illustrating one example stand-alone door status monitor, in embodiments.

[0014] FIG. **8** is a flowchart illustrating one example method for determining a status of a rear door of a trailer from a tractor, in embodiments.

[0015] FIG. **9** is a block diagram illustrating the door status monitor of FIG. **2** in further example detail, in embodiments.

[0016] FIG. **10** is a schematic diagram illustrating example use of the camera **218**(**2**) of FIG. **2** by the door status monitor of FIG. **9** to determine the trailer door status of a trailer being towed by the tractor that includes door-status indicators, in embodiments.

DETAILED DESCRIPTION OF THE EMBODIMENTS

[0017] FIG. **1** is an aerial view showing one example autonomous yard **100** (e.g., a goods handling facility, shipping facility, etc.) that uses an autonomous tractor **104** to move trailers **106** between a staging area **130** and loading docks of a warehouse **110**. The autonomous tractor **104** may be an electric vehicle, or may use a combustion-based engine such as a diesel tractor. For example, over-the-road (OTR) tractors **108** deliver goods-laden trailers **106** from remote locations and retrieve trailers **106** for return to such locations (or elsewhere—such as a storage depot). In a standard operational procedure, OTR tractor **108** arrives with trailer **106** and checks-in at a facility entrance checkpoint **109**. A guard/attendant enters information (e.g., trailer number or QR (ID) code scan-embedded information already in the system, which would typically include: trailer make/model/year/service connection location, etc.) into a mission controller **102** (e.g., a computer software server that may be located offsite, in the cloud, fully onsite, or partially located within a facility building complex, shown as a warehouse **110**). Warehouse **110** includes perimeter loading docks (located on one or more sides of the building), associated (typically elevated) cargo portals and doors, and floor storage, all arranged in a manner familiar to those of skill in shipping, logistics, and the like.

[0018] By way of a simplified operational example, after arrival of OTR tractor **108** and trailer **106**, the guard/attendant at checkpoint **109** directs the driver to deliver trailer **106** to a specific numbered parking space in a designated staging area **130**, which may include a large array of side-by-side trailer parking locations, arranged as appropriate for the facility's overall layout.

[0019] Once the driver has parked the trailer in the designated parking space of the staging area **130**, he/she disconnects the service lines and ensures that connectors are in an accessible position (e.g., when adjustable/sealable), and decouples OTR tractor **108** from trailer **106**. When trailer **106** is equipped with swing doors, this decoupling also provides an opportunity for the driver to unlatch and clip trailer doors in the open position, when directed (e.g., by yard personnel) to do so.

[0020] Later, (e.g., when warehouse **110** is ready to process the trailer) mission controller **102** directs (e.g., commands or otherwise controls) tractor **104** to automatically couple (e.g., hitch) with trailer **106** at an indicated pick-up spot in staging area **130** and move trailer **106** to a drop-off spot at an assigned unloading dock in unloading area **140** for example. Accordingly, tractor **104** couples with trailer **106** at the pick-up spot, moves trailer **106** to unloading area **140**, and then backs trailer **106** into the assigned loading dock at the drop-off spot such that the rear of trailer **106** is positioned in close proximity with the portal and cargo doors of warehouse **110**. The pick-up spot and drop-off spot may be any designated trailer parking location in staging area **130**, any loading dock in unloading area **140**, and any loading dock within loading area **150**.

[0021] Manual and/or automated techniques are used to offload the cargo from trailer **106** and into warehouse **110**. During unloading, tractor **104** may remain hitched to trailer **106** or may decouple (e.g., unhitch) to perform other tasks. After unloading, mission controller **102** directs tractor **104** to move trailer **106** from a pick-up spot in unloading area **140** and to a drop-off spot, either returning trailer **106** to staging area **130** or delivering trailer **106** to an assigned loading dock in a loading area **150** of warehouse **110**, where trailer **106** is then loaded for example. Once loaded, mission controller **102** directs tractor **104** to move trailer **106** from a pick-up spot in loading area **150** to a drop-off spot in staging area **130** where it may await collection by another (or the same) OTR tractor **108**. Given the pick-up spot and the drop-off spot, tractor **104** may autonomously move trailer **106**.

[0022] FIG. **2** is a block diagram illustrating functional components of tractor **104**. Tractor **104** includes a controller **206** with at least one digital processor **208** communicatively coupled with memory **210** that may include one or both of volatile memory (e.g., RAM, SRAM, etc.) and non-volatile memory (e.g., PROM, FLASH, Magnetic, Optical, etc.). Memory **210** stores a plurality of software modules including machine-readable instructions that, when executed by the at least one processor **208**, cause the at least one processor **208** to implement functionality of tractor **104** as described herein. In certain embodiments, tractor **104** operates autonomously within autonomous yard **100** under direction from mission controller **102**.

[0023] Tractor **104** also includes a location unit **216** that determines an AV pose **217** (e.g., an absolute geographic location and orientation) of tractor **104**, a plurality of cameras **218** for capturing images of objects around tractor **104**, at least one Light Detection and Ranging (LIDAR) device **220** for determining a point cloud **221** of objects around tractor **104**, and at least one radar **228** for generating radar data **229** of objects around tractor **104**. In certain embodiments, at least one radar **228** is rear facing. Location unit **216**, the plurality of cameras **218**, radar **228**, and the at least one LIDAR device **220**, cooperate with controller **206** to enable autonomous maneuverability and safety of tractor **104**.

[0024] Tractor **104** also include a door status monitor **270**, implemented as machine-readable instructions stored in memory **210** and executable by processor **208**, that is activated to determine a trailer door status **272** that indicates one or more of a rear door status of a trailer hitched to tractor **104** and/or a location and rear door status of trailers around (e.g., within detection range of at least one of camera **218**, LIDAR device **220**, or radar **228**) tractor **104**. Functionality of door status monitor **270** is described below with reference to FIG. **4**. Door status monitor **270** may represent, or be part of, a perception module that perceives other information (e.g., trailer angle, trailer length, etc.) of tractor **104** and/or trailer **106** based on multiple input sources (see input source **401**, described below).

[0025] FIG. **3** is a schematic showing autonomous tractor **104** reversing trailer **106** up to a loading dock **332**. In this example, tractor **104** uses multiple rear facing cameras **218** and/or LIDAR devices **220** to assist with maneuvering, however, trailer **106** obscures any view tractor **104** has of an area immediately behind trailer **106**. Although, as described above, many different safety procedures (e.g., drive by) may be implemented, when reversing, any object that moves into the area behind trailer **106** is not detected by tractor **104**.

[0026] As shown in FIG. **3**, tractor **104** has two rear-facing cameras **218(1)**-**(2)**, one positioned at each side of tractor **104**, near wing mirrors for example, such that each has a rearward field-of-view **302** that includes a corresponding side of trailer **106**. As tractor **104** is reversing trailer **106** into loading dock **332**, controller **206** evaluates images **219** captured by cameras **218**, identifies any fiducial markings or other structures of loading dock **332** captured in the images, and computes a relative navigation solution for tractor **104** relative to loading dock **332** and its position within the images. That is, controller **206** may use images **219** to improve location and orientation estimates of tractor **104** and/or trailer **106**, as compared to location and orientation determined by location unit **216** from an inertial navigation system and/or odometry where drift errors may occur, and from availability of GPS signals where discontinuities and canyon effect errors may occur. As shown in FIG. **3**, tractor **104** may have two location units **216**(**1**) and **216**(**2**) positioned apart to facilitate determination of AV pose **217**.

[0027] In certain embodiments, another camera **218**(**3**) may be fitted to an extendable mast **320** coupled with tractor **104**. As trailer **106** approaches loading dock **332**, mast **320** may be extended to provide camera **218**(**3**) with a higher vantage point thereby providing camera **218**(**3**) with a field-of-view **302**(**3**) over trailer **106**. For example, where building structure, other adjacent trailers, etc. prevent cameras **218**(**1**) and **218**(**2**) from capturing useful images of loading dock **332**, camera **218**(**3**), positioned on extendable mast **320**, may have an unobstructed view of loading dock **332**, thereby allowing images **219** captured, at intervals or substantially continuously, by camera **218**(**3**) may be used to provide a local frame of reference for tractor **104** that allows controller **206** to more accurately estimate a location and orientation of tractor **104** and trailer **106**. Similarly, a LIDAR device **220**(**3**) may be attached to mast **320**, such that mast **320** provides LIDAR device **220**(**3**) with a field-of-view **504**(**3**) over trailer **106**.

Trailer Door Status Detection

[0028] FIG. **4** is a block diagram illustrating door status monitor **270** of FIG. **2** in further example detail, in embodiments. FIG. **5** is a schematic diagram illustrating example use of camera **218**(**2**), LIDAR device **220**(**2**), and/or radar **228** by door status monitor **270** of FIG. **4** to determine trailer door status **272** of trailer **106** being towed by tractor **104**, in embodiments. FIG. **6** is a schematic diagram illustrating example use of camera **218**(**2**), LIDAR device **220**(**2**), and/or radar **228** by door status monitor **270** of FIG. **4** to determine trailer door status **272** of other trailers encountered within autonomous yard **100**. FIGS. **4**, **5**, and **6** are best viewed together with the following description.

[0029] Door status monitor **270** includes a neural network **404** that uses a trailer door trained model **406** to process an input source **401** that include one or more of images **219**, point clouds **221**, and radar data **229** to determine a trailer door status **272** that defines both (a) a trailer location **412** and (b) a corresponding door status **414**. Input source **401** is captured by one or more of camera **218**, LIDAR device **220**, and radar **228** of tractor **104**, where camera **218**, LIDAR device **220**, and radar **228** are configured in a fixed positional and orientational relationship with one another and with tractor **104**. Trailer location **412** may define one or more of a distance of the door (e.g., rear door **502**(**1**) or rear door **502**(**2**)) and trailer **106** from tractor **104**, a GPS global position of the door and/or the trailer, and a position of the door and/or the trailer on a previously-built environment map. Door status **414** may define one or more of open, close, and partially open.

[0030] Trailer door trained model **406** is generated for certain positions of cameras **218**, LIDAR devices **220**, and radar **228**, where the position and orientation of each camera **218**, LIDAR device **220**, and radar **228** does not change relative to tractor **104**. Accordingly, the field-of-view of each camera **218**, LIDAR device **220**, and radar **228** allows door status monitor **270** to determine trailer location **412** based on AV pose **217**. As described below, neural network **404** is trained using a large amount of training data **408** that includes a multitude of trailers and trailer doors of different types, colors, wear conditions and status (open, close, partially-open, and so on).

[0031] In certain embodiments, door status monitor **270** determines trailer location **412** as a position relative to tractor **104**, and a location converter **402** of door status monitor **270** converts trailer location **412** into a geographic location based on a current (e.g., most recently determined) AV pose **217**. That is, location converter **402** converts each relative trailer position identified within **272** into a geographic location (e.g., latitude/longitude) that may, for example, be used to identify a parking spot occupied by the trailer.

[0032] For clarity of illustration, FIGS. **5** and **6** show two separate scenarios where FIG. **5** illustrates use of camera **218**(**2**) to determine door status **414** of latched open rear door **502**(**2**) of trailer **106** being towed by tractor **104** and FIG. **6** illustrates use of LIDAR devices **220** to detect trailer location **412** and door status **414** of trailer **106** around tractor **104**. Advantageously, door status monitor **270** may process input source **401** to detect door status **414** of multiple trailers **106** simultaneously, where door status **414** indicates a status of each identified rear door.

[0033] In the example of FIG. **5**, trailer **106** is at a slight angle relative to tractor **104** such that field-of-view **302**(**2**) of camera **218**(**2**) includes latched open rear door **502**(**2**), but rear field-of-view **302**(**1**) of camera **218**(**1**) does not include latched open rear door **502**(**1**), since it is blocked by front corner **506** of trailer **106**. However, since latched open rear door **502**(**1**) may be included in images **219** and/or point cloud **221** from camera **218**(**3**) and LIDAR device **220**(**3**), respectively, on extendable mast **320**, door status monitor **270** may still detect door status **414** of latched open rear door **502**(**1**). In embodiments where extendable mast **320** and camera **218**(**3**) and LIDAR device **220**(**3**) are not included, door status monitor **270** may detect door status **414** of latched open rear door **502**(**1**) as tractor **104** makes a right turn when maneuvering trailer **106** through autonomous yard **100**, causing latched open rear door **502**(**1**) to become positioned within rear field-of-view **302**(**1**) of camera **218**(**1**) and/or within field-of-view **504**(**1**) of LIDAR device **220**(**1**).

[0034] In the example of FIG. **6**, door status monitor **270** determines a status of rear doors of trailers **106** around tractor **104**, such as trailers **106** positioned within autonomous yard **100**. Camera field-of-views **302** and radar field-of-views are omitted from FIG. **6** for clarity of illustration, and LIDAR field-of-views **504**(**1**) and **504**(**2**) are shown relative to tractor **104** as it performs a task (e.g., moving trailer **106**(**4**)) within autonomous yard **100**. Tractor **104** is shown in dashed outline at a first location **602** and in solid outline at a second location **604**, thereby representing movement of tractor **104** from first location **602** to second location **604** over time.

[0035] In certain embodiments, door status monitor **270** runs as a service that is activated and deactivated by controller **206**. When active, door status monitor **270** may continuously, or at intervals, autonomously determines trailer door status **272** of both hitched trailer **104**(**4**) (e.g., see FIG. **5**) and near-by (FIG. **6**) trailers **106**(**5**)-(**12**) captured within images **219**, point cloud **221**, and radar data **229**. For example, door status monitor **270** may receive images **219**, point cloud **221**, and radar data **229** substantially continuously from multiple cameras **218**, LIDAR devices **220**, and radars **228** configured with tractor **104**, both when tractor

104 is stationary and while tractor **104** is moving. In one example, controller **206** activates door status monitor **270** in response to a mission plan received from mission controller **102** to determine trailer door status **272** of trailer **106** hitched to tractor **104** (a) prior to moving trailer **106** (e.g., after hitching but before moving trailer **106**), (b) shortly after trailer **106** begins moving (e.g., during forward acceleration of trailer **106**), (c) at turns in the path (e.g., as tractor **104** makes a first left turn and a first right turn), (d) when trailer **106** is decelerated (e.g., when tractor **104** is braking), (e) when tractor **104** transitions between forward and backwards movements, and (f) prior to reversing trailer **106** into a parking space or loading dock. Particularly, controller **206** may activate door status monitor **270** to determine door status **414** corresponding to hitched trailer **106** at times when the maneuvering of trailer **106** may cause unlatched doors to swing, and when an unlatch door status may cause problems, such as when reversing into a parking spot of staging area **130** or positioning trailer **106** at a loading dock (e.g., within loading area **150**). In another example of operation, controller **206** activates door status monitor **270** to determine trailer door status **272** of trailers being passed as tractor **104** maneuvers within autonomous yard **100**. Controller **206** sends trailer door status **272** to mission controller **102**, which autonomously updates its stored status information on both trailer location **412** and corresponding door status **414**. Advantageously, mission controller **102** receives trailer door status **272** continuously, or at intervals, as one or more tractors **104** move through autonomous yard **100**, thereby maintaining a current status of trailer location and door status.

[0036] Using the example of FIG. **5**, door status monitor **270** processes images **219** from cameras **218** to generate trailer door status **272** indicating door status **414** of trailer **106** being towed by tractor **104**, where trailer location **412** indicates a current location of trailer **106** and whether trailer **106** is being towed by tractor **104**. Door status monitor **270** generates trailer door status **272** relatively quickly such that any distance traveled by trailer **106** from the instant of capture of input source **401** is considered negligible, or may be taken into account when the data is used by other functions.

[0037] In another example of operation, as tractor **104** passes staging area **130**, door status monitor **270** processes AV pose **217** and point cloud **221** to generate trailer door status **272** for one or more trailers **106(9)-(12)** parked in staging area **130**, where trailer door status **272** defines trailer location **412** and corresponding door status **414** for each detected trailer **106**. Similarly, and concurrently in the example of FIG. **6**, as tractor **104** passes loading area **150**, door status monitor **270** processes AV pose **217** and radar data **229** to generate trailer door status **272** for one or more trailers **106** parked in loading area **150**, where trailer door status **272** defines trailer location **412** and corresponding door status **414** for each detected trailer **106**. For example, when tractor **104** and trailer **106(4)** are at first location **602**, LIDAR field-of-view **504(1)** includes information of at least trailers **106(5)** and **106(6)**, and LIDAR field-of-view **504(2)** includes information of at least trailers **106(9)** and **106(10)**. Accordingly, where input source **401** includes sufficient information, door status monitor **270** generates trailer door status **272** to include trailer location **412** and door status **414** for each of trailers **106(5)**, **106(6)**, **106(9)**, and **106(10)**. Since door status monitor **270** operates continuously or at frequent intervals, as tractor **104** moves other trailers **106** fall within LIDAR field-of-views **504** and door status monitor **270** determines respective trailer door status **272**. For example, when tractor **104** and trailer **106(4)** are at second location **604**, LIDAR field-of-view **504(1)** includes information of at least trailers **106(7)** and **106(8)**, and LIDAR field-of-view **504(2)** includes information of at least trailers **106(10)**. **106(11)**, and **106(12)**. Accordingly, where input source **401** includes sufficient information, as tractor **104** moves from first location **602** to second location **604** for example, door status monitor **270** generates trailer door status **272** to include trailer location **412** and door status **414** for each of trailers **106(7)**, **106(8)**, **106(10)**, **106(11)**, and **106(12)**.

Trailer Door Status Detection Training

[0038] Neural network **404** uses trailer door trained model **406** that is generated by training neural network **404** using a large volume of training data **408** (e.g., a training set). Training data **408** includes images **219**, point clouds **221**, and radar data **229** collected from at least one capture device (e.g., tractor **104**) operating in multiple yards and under various use cases (e.g., performing different tasks within different yards) and various environmental conditions (e.g., different weather conditions, different seasons, different times of the day, etc.), where trailers are parked, moving, or being towed with doors in various states including closed, open, latched, and so on. Training data **408** may define one or more of a distance of a captured trailer door and its trailer from the tractor capturing training data **408**, a geographical location (e.g., GPS coordinates), and a previously-built environment map position. Training data **408** may also include 3D annotation of captured trailers and captured trailer doors and extensive human-annotated attributes including a door type (e.g. roll-on, latchet etc.), a door status (e.g., open, close, partially open, etc.). When possible, training data **408** may include accurate annotation in 3D of the captured door and a corresponding door frame. Particularly, training data **408** (e.g., images **219**, point clouds **221**, and radar data **229**) is collected in weather conditions and at sites that are relevant to expected operation of trailer door status **272** (e.g., for a particular the business case). The capture devices (e.g., vehicles or tractors **104**) are configured with cameras **218**, LIDAR devices **220**, and radars **228**, at the same position and orientation relative to tractor **104** using door status monitor **270** such that the captured training data **408** is consistent with input source **401**. For example, tractor **104** may be used to capture images **219**, point clouds **221**, and radar data **229** as it travels through autonomous yard **100**, where the images, point clouds, and radar data are used to form training data **408**.

[0039] Training data **408** (e.g., captured images **219**, point clouds **221**, and radar data **229**) may be stored and then annotated to define a ground truth for operating neural network **404** to perform the desired task. In one example, annotations are added to training data **408** to indicate trailers and doors (e.g., in images **219**, and in 3D within point clouds **221** and radar data **229**) by humans interacting with a user interface that facilitates annotation. In another example, prior to capturing images **219**, point clouds **221**, and radar data **229**, the trailers and trailer doors within the yard are marked using fiducial markers (e.g. adhesive stickers defining trailer and door conditions) or other forms of markings, that are recognized by a software algorithm that autonomously adds the annotations to training data **408**. For example, the fiducial markers are attached to the trailer rear doors such they will be captured within training data **408** and recognized by the software algorithm which adds corresponding annotation to the training data **408**. Training data **408** is then uses to train neural network **404** and generate trailer door trained model **406** for use during operation of door status monitor **270**.

Stand Alone Door Status Monitor

[0040] FIG. **7** is a block diagram illustrating one example stand-alone door status monitor **700**, in embodiments. Stand-alone door status monitor **700** operates similar to trailer door status **272** of FIG. **4**, does not use input from external sources, and thereby may operate independently on any vehicle or platform to determine trailer door status **772** (e.g., trailer location **712** and door status **714**). Accordingly, stand-alone door status monitor **700** may be easily used in scenarios or locations other than autonomous yards, such as any of a harbor, an airport, with a storage system, and at intermodal freight transfer facilities.

[0041] Stand-alone door status monitor **700** includes a neural network **704** controlled by a trailer door trained model **706**, a location unit **716**, and one or more of: a camera **718**, a LIDAR device **720**, and a radar **728** that function as an input source **701** for neural network **704**. Neural network **704** is similar to neural network **404** of FIG. **4**. In on example, stand-alone door status monitor **700** is configured with two LIDAR devices **720**. In another example, stand-alone door status monitor **700** is configured with one LIDAR device **720** and one camera **718**. Location unit **716** may include a global navigation satellite system (GNSS) receiver that determines a current location of stand-alone door status monitor **700**, and may also include one or more of a magnetic compass, gyroscope, and accelerometer, that determines a pose **717**, defining orientation of stand-alone door status monitor **700**, that allows a location converter **702** to convert a relative trailer location (e.g., relative to stand-alone door status monitor **700**) into a geographic location (e.g., latitude/longitude).

[0042] Stand-alone door status monitor **700** has a single rigid body (e.g., a bar or a box that is mountable to a vehicle) that supports one or more of cameras **718**, LIDAR devices **720**, and radars **728** in a fixed positional and orientational relationship. The body may also support other components of stand-alone door status monitor **700**. Trailer door trained model **706** is created using images, point clouds, and radar data captured by camera **718**, LIDAR device **720**, and radar **728** and then annotated as described above. For example, when multiple units are similarly constructed (e.g., similar positioning, orientation, and fixed relationship of camera **718**, LIDAR device **720**, and radar **728**), any one or more of the units may be used to capture training data.

[0043] Stand-alone door status monitor **700** operates similar to door status monitor **270** described above and generates trailer door status **772** for external processing. For example, stand-alone door status monitor **700** may send trailer door status **772** to an external device (e.g., a cloud service, a computer server, etc.) for further processing. However, stand-alone door status monitor **700** uses one or more of camera **718**, LIDAR device **720**, and radar **728** instead of cameras **218**, LIDAR devices **220**, radars **228** of tractor **104** and determines pose **717** using location unit **716**.

[0044] FIG. **8** is a flowchart illustrating one example method **800** for determining a status of a rear door of a trailer from a tractor, in embodiments. Method **800** is implemented by door status monitor **270** of FIG. **2** and/or stand-alone door status monitor **700** of FIG. **7**, for example.

[0045] In block **810**, method **800** receives an input source including information of the trailer, where the input source includes at least one of an image, a LIDAR point cloud, and a RADAR point cloud from at least one of a camera, a LIDAR, and a RADAR, respectively, mounted to the tractor and having a view that includes at least a rear portion of the trailer. In one example of block **810**, door status monitor **270** receives input source **401** that include images **219** from camera **218(1)**, a point cloud **221** from LIDAR device **220(1)**, and radar data **229** from radar **228**. In another example of block **810**, stand-alone door status monitor **700** controls one or more of camera **718**, LIDAR device **720**, and radar **728** to capture input source **701**.

[0046] In block **820**, method **800** processes the input source through a neural network trained to output a trailer door status defining a rear door status of trailers in the input source. In one example of block **820**, door status monitor **270** processes input source **401** through neural network **404** using trailer door trained model **406** to generate trailer door status **272** that includes trailer location **412** and door status **414** for each trailer with sufficient information within input source **401**. In another example of block **820**, stand-alone door status monitor **700** processes input source **701** through neural network **704** using trailer door trained model **706** to generate trailer door status **772** that includes trailer location **712** and door status **714**.

[0047] In block **830**, method **800** outputs the rear door status indicative of the status of the rear door of the trailer. In one example of block **830**, door status monitor **270** outputs trailer door status **272** and controller **206** sends trailer door status **272** to mission controller **102**, which autonomously updates its stored status information on both trailer location **412** and corresponding door status **414**. In another example of block **830**, stand-alone door status monitor **700** sends trailer door status **772** to an external device for further processing.

[0048] Block **840** is optional. When included, in block **840**, method **800** controls operation of the tractor based on the rear door status. In one example of block **840**, where door status **714** indicates that one of rear doors **502** is not latched open as tractor **104** maneuvers trailer **106** through autonomous yard **100**, tractor **104** stops and/or inhibits further maneuvering of trailer **106** to allow the door to be latched. In another example of block **840**, where door status **714** indicates that rear doors **502** are not latched open, tractor **104** inhibits reversing of trailer **106** into a loading dock within loading area **150**. For example, tractor **104** may stop and generate a request for manual assistance to lath the rear doors prior to further movement. Method **800** then repeats until deactivated by controller **206**.

Trailer Door Status Indicators

[0049] FIG. **9** is a block diagram illustrating door status monitor **270** of FIG. **2** in further example detail, in embodiments. FIG. **10** is a schematic diagram illustrating example use of camera **218(2)** by door status monitor **270** of FIG. **9** to determine trailer door status **272** of a trailer **1006** being towed by tractor **104** that includes door-status indicators **1012**, in embodiments.

[0050] Trailer **1006** may include at least one sensor (not shown) that detects a status of each rear door **1002**(**1**) and **1002**(**2**) and indicates the status on at least one door-status indicator **1012**. In this example, trailer **1006** includes a first sensor that detects when rear door **1002**(**1**) is latched closed, a second sensor that detects when rear door **1002**(**2**) is latched closed, a third sensor that detects when rear door **1002**(**1**) is latched open, and a fourth sensor that detects when rear door **1002**(**2**) is latched open. Rear-door status indicator **1012**(**1**), indicates rear door **1002**(**1**) is latched closed, rear-door status indicator **1012**(**2**) indicates rear door **1002**(**2**) is latched closed, rear-door status indicator **1012**(**3**) indicates rear door **1002**(**1**) is latched open, and rear-door status indicator **1012**(**4**) indicates rear door **1002**(**2**) is latched open. In this example, door-status indicators **1012** illuminate to indicate the corresponding detected status. In the example shown, rear-door status indicator **1012**(**3**) and **1012**(**4**) are illuminated to indicate that both rear doors **1002**(**1**) and **1002**(**2**) are latched open. Where none of door-status indicators **1012** are illuminated, neither of trailer doors **1002**(**1**) or **1002**(**2**) are latched.

[0051] In this embodiment, neural network **404** uses a door indicator trained model **906** to process input source **401** to determine trailer door status **272** that defines both (a) trailer location **412** and (b) corresponding door status **414**. Door indicator trained model **906** is generated for certain positions of cameras **218**, LIDAR devices **220**, and radar **228**, where the position and orientation of each camera **218**, LIDAR device **220**, and radar **228** does not change relative to tractor **104**. Accordingly, the field-of-view of each camera **218**, LIDAR device **220**, and radar **228** allows door status monitor **270** to determine trailer location **412** based on AV pose **217**. As described above, neural network **404** is trained using a large amount of training data **908** that, in this embodiment, also includes a multitude of trailers with door-status indicators **1012** in various combinations of activation based on trailer doors of different types, colors, wear conditions and status (open, close, partially-open, and so on).

[0052] As described above, door status monitor **270** may determine trailer location **412** as a position relative to tractor **104** where location converter **402** of door status monitor **270** converts trailer location **412** into a geographic location based on current AV pose **217**. In this example, training data **908** includes ground truths corresponding to the indicated status of door-status indicators **1012**. In certain embodiments, training data **908** includes trailers that have door-status indicators **1012** and trailers that do not have door-status indicators **1012**. Accordingly, door indicator trained model **906** is generated to allow neural network **404** to determine a status of trailer doors **1002** irrespective of whether the trailer includes door-status indicators **1012**.

[0053] In certain embodiments, tractor **104** includes a trailer interface **280** (see FIG. **2**) that receives trailer status information **282** from trailer **1006**, where trailer **1006** is a smart trailer. Trailer interface **280** may implement wired and/or wireless communication with a corresponding interface of trailer **1006**. For example, the wired communication may be implemented by one or more of an autonomous electrical connection and/or an electrical connection implemented through a fifth-wheel of tractor **104**. See, for example, US patent application number US2023/0145675 A1, filed Nov. 9, 2022, titled "Autonomous trailer connectivity," and incorporated herein by reference for enablement purposes. Trailer status information **282** may include at least one of a trailer door status (e.g., latched or unlatched status of open and/or closed rear doors of trailer **1006**), a geographic location (e.g., determine by GPS receiver of trailer **1006**), a dock door status (e.g., when trailer **1006** is positioned at a dock door), a loaded or unloaded status of trailer **1006**, trailer damage information (e.g., collision logs), and tire pressure information.

Combination of Features

[0054] Features described above as well as those claimed below may be combined in various ways without departing from the scope hereof. The following enumerated examples illustrate some possible, non-limiting combinations:

[0055] (A1) A method for determining a status of a rear door of a trailer from a tractor, including: receiving an input source including information of the trailer, the input source including at least one of an image, a LIDAR point cloud, and a RADAR point cloud from at least one of a camera, a LIDAR, and a RADAR, respectively, mounted to the tractor; processing the input source through a neural network using a trailer door trained model to generate a trailer door status defining the status of the rear door of the trailer; and outputting the trailer door status.

[0056] (A2) In embodiments of (A1), the trailer door trained model is trained to generate the trailer door status when the trailer is being towed by the tractor.

[0057] (A3) Either of embodiments (A1) or (A2), the trailer door trained model is trained to generate the trailer door status when the trailer is parked and the tractor is passing the trailer.

[0058] (A4) In any of embodiments (A1)-(A3), the trailer door status including a trailer location indicative of a location of the trailer, wherein the trailer location defines one of a relative location of the trailer with respect to the tractor and a geographic location of the trailer.

[0059] (A5) Any of embodiments (A1)-(A4) further including inhibiting operation of the tractor when the trailer door status indicates one or more of the rear doors of the trailer and not latched open or latched closed.

[0060] (A6) Any of embodiments (A1)-(A5) further including receiving a first geographic location and orientation of the tractor corresponding to capture of the input source; and converting the relative location into a second geographic location of the trailer based on and the first geographic location and the orientation.

[0061] (A7) Any of embodiments (A1)-(A6) further including collecting, by at least one capture device during various environmental conditions and for various use cases, training data including one or more of a plurality of images, a plurality of point clouds, and a plurality of radar data; adding annotations to the training data to define a ground truth; and training the neural network using the training data to generate the trailer door trained model.

[0062] (A8) In any of embodiments (A1)-(A7), the training data includes a view of a rear door of a trailer, the various use cases comprising parked trailers, moving trailers, and towed trailers, where rear doors of each of the parked trailers, the moving trailers, and the towed trailers are one of closed, open, latched open, and latched closed.

[0063] (A9) In any of embodiments (A1)-(A8), the further training data includes a view of a rear door of a trailer, the adding further comprise defining, within the annotations, one or more of a distance of the rear door to a capture device that captured the training data, a distance of the trailer to the capture device, a geographical location of the trailer, and a position of the trailer on a previously-built environment map.

[0064] (A10) In any of embodiments (A1)-(A9), the training data includes a view of a rear door of a trailer, the adding further comprises interacting with a human using a user interface to define, within the annotations, a location of each of the trailers and a corresponding status of the rear door of the trailer.

[0065] (A11) In any of embodiments (A1)-(A10), the interacting further comprising capturing 3D annotations of the trailer and the rear door.

[0066] (A12) In any of embodiments (A1)-(A11), the 3D annotations further defining a door frame of the rear door.

[0067] (A13) In any of embodiments (A1)-(A12), the interacting comprising capturing attributes including a door type, and a door status defining one of closed, open, latched open, and latched closed.

[0068] (A14) In any of embodiments (A1)-(A13), the training data includes a view of a rear door of a trailer, the adding comprising: recognizing, by an algorithm, fiducial markers in the training data; and annotating, by the algorithm, the training data based on the recognized fiducial marker, wherein the fiducial markers are positioned on at least one of the trailer and the rear door and define the status of the rear door.

[0069] (A15) In any of embodiments (A1)-(A14), the training data includes a front face of the trailer, the adding comprising interacting with a human using a user interface to define, within the annotations, a location of a door-status indicator on the front face of the trailer and a status of the rear door.

[0070] (B1) A method for determining a status of a rear door of a smart trailer from a tractor, including: receiving, by a controller of the tractor and from the smart trailer, a signal encoding trailer status information of the smart trailer; decoding, by the controller, the trailer status information to determine a status of a rear door of the smart trailer; and outputting, from the tractor, the trailer door status.

[0071] (B2) In the embodiment (B1), the status information indicates one of: the rear door is latched closed and the rear door is latched open.

[0072] (B3) In either of embodiments (B1) or (B2), the signal is received over a wired connection between the smart trailer and the tractor via one or both of a fifth-wheel and an autonomous electrical connection.

[0073] (B4) In any of embodiments (B1)-(B3), the signal is received wirelessly.

[0074] (C1) A door status monitor, including: a rigid body for attaching to a vehicle; at least one of a camera, a LIDAR, and a RADAR having fixed positional and orientational relationship by the rigid body; a neural network having a trailer door trained model that processes an input source including at least one of an image, a point cloud, and RADAR data captured by at least one of the camera, the LIDAR, and the RADAR to generate a trailer door status defining the status of a rear door of a trailer included in the input source; and outputting the trailer door status to an external device.

[0075] Changes may be made in the above methods and systems without departing from the scope hereof. It should thus be noted that the matter contained in the above description or shown in the accompanying drawings should be interpreted as illustrative and not in a limiting sense. The following claims are intended to cover all generic and specific features described herein, as well as all statements of the scope of the present method and system, which, as a matter of language, might be said to fall therebetween.

What is claimed is:

1. A method for determining a status of a rear door of a trailer from a tractor, comprising:

receiving an input source including information of the trailer, the input source including at least one of an image, a LIDAR point cloud, and a RADAR point cloud from at least one of a camera, a LIDAR, and a RADAR, respectively, mounted to the tractor;

processing the input source through a neural network using a trailer door trained model to generate a trailer door status defining the status of the rear door of the trailer; and

outputting the trailer door status.

2. The method of claim **1**, wherein the trailer door trained model is trained to generate the trailer door status when the trailer is being towed by the tractor.

3. The method of claim **1**, wherein the trailer door trained model is trained to generate the trailer door status when the trailer is parked and the tractor is passing the trailer.

4. The method of claim **1**, the trailer door status including a trailer location indicative of a location of the trailer, wherein the trailer location defines one of a relative location of the trailer with respect to the tractor and a geographic location of the trailer.

5. The method of claim **4**, further comprising inhibiting operation of the tractor when the trailer door status indicates one or more of the rear doors of the trailer and not latched open or latched closed.

6. The method of claim **5**, further comprising:

receiving a first geographic location and orientation of the tractor corresponding to capture of the input source; and

converting the relative location into a second geographic location of the trailer based on and the first geographic location and the orientation.

7. The method of claim **1**, further comprising:

collecting, by at least one capture device during various environmental conditions and for various use cases, training data including one or more of a plurality of images, a plurality of point clouds, and a plurality of radar data;

adding annotations to the training data to define a ground truth; and

training the neural network using the training data to generate the trailer door trained model.

8. The method of claim **7**, where the training data includes a view of a rear door of a trailer, the various use cases comprising parked trailers, moving trailers, and towed trailers, where rear doors of each of the parked trailers, the moving trailers, and the towed trailers are one of closed, open, latched open, and latched closed.

9. The method of claim **7**, where the training data includes a view of a rear door of a trailer, the adding further comprise defining, within the annotations, one or more of a distance of the rear door to a capture device that captured the training data, a distance of the trailer to the capture device, a geographical location of the trailer, and a position of the trailer on a previously-built environment map.

10. The method of claim **7**, where the training data includes a view of a rear door of a trailer, the adding further comprises interacting with a human using a user interface to define, within the annotations, a location of each of the trailers and a corresponding status of the rear door of the trailer.

11. The method of claim **10**, the interacting further comprising capturing 3D annotations of the trailer and the rear door.

12. The method of claim **11**, the 3D annotations further defining a door frame of the rear door.

13. The method of claim **10**, the interacting comprising capturing attributes including a door type, and a door status defining one of closed, open, latched open, and latched closed.

14. The method of claim **7**, where the training data includes a view of a rear door of a trailer, the adding comprising:

recognizing, by an algorithm, fiducial markers in the training data; and

annotating, by the algorithm, the training data based on the recognized fiducial marker, wherein the fiducial markers are positioned on at least one of the trailer and the rear door and define the status of the rear door.

15. The method of claim **7**, where the training data includes a front face of the trailer, the adding comprising interacting with a human using a user interface to define, within the annotations, a location of a door-status indicator on the front face of the trailer and a status of the rear door.

16. A method for determining a status of a rear door of a smart trailer from a tractor, comprising:

receiving, by a controller of the tractor and from the smart trailer, a signal encoding trailer status information of the smart trailer;

decoding, by the controller, the trailer status information to determine a status of a rear door of the smart trailer; and

outputting, from the tractor, the trailer door status.

17. The method of claim **16**, wherein the status information indicates one of: the rear door is latched closed and the rear door is latched open.

18. The method of claim **16**, wherein the signal is received over a wired connection between the smart trailer and the tractor via one or both of a fifth-wheel and an autonomous electrical connection.

19. The method of claim **16**, wherein the signal is received wirelessly.

20. A door status monitor, comprising:

a rigid body for attaching to a vehicle;

at least one of a camera, a LIDAR, and a RADAR having fixed positional and orientational relationship by the rigid body;

a neural network having a trailer door trained model that processes an input source including at least one of an image, a point cloud, and RADAR data captured by at least one of the camera, the LIDAR, and the RADAR to generate a trailer door status defining the status of a rear door of a trailer included in the input source; and

outputting the trailer door status to an external device.

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