US 20250263279A1

(19) United States

(12) Patent Application Publication

(10) Pub. No.: US 2025/0263279 A1

(43) Pub. Date: Aug. 21, 2025

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(54) SYSTEMS AND METHODS FOR AN EXTENDED SIDE-SHIFT ASSEMBLY FOR HANDLING PALLETS

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(21) Appl. No.: **19/060,329**

(22) Filed: **Feb. 21, 2025**

Related U.S. Application Data

(60) Provisional application No. 63/556,144, filed on Feb. 21, 2024.

Publication Classification

(51) **Int. Cl.**

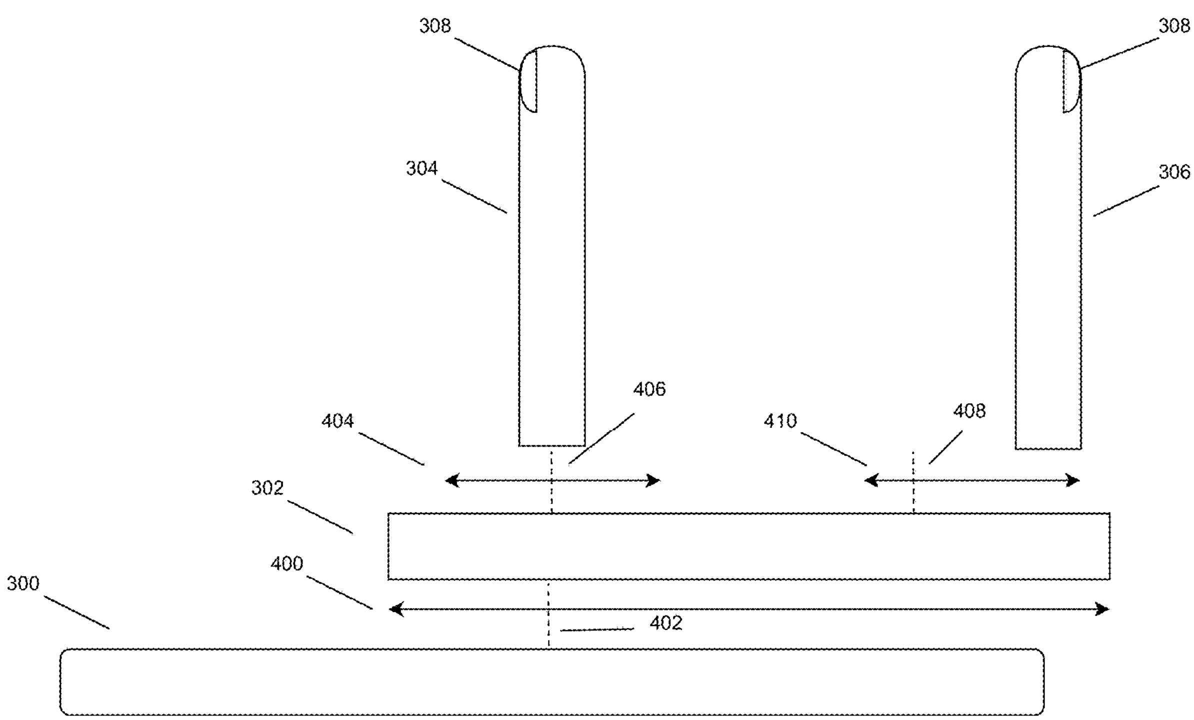
B66F 9/14	(2006.01)
B66F 9/06	(2006.01)
B66F 9/075	(2006.01)

(52) **U.S. Cl.**

CPC ***B66F 9/144*** (2013.01); ***B66F 9/0755*** (2013.01); *B66F 9/063* (2013.01)

(57) **ABSTRACT**

The present invention relates, in general, to systems and methods for controlling autonomous forklifts, and specifically, for extending a lateral range of motion and side shifting ability for a load handling assembly. The present invention allows for independent control and lateral actuation of a backplate mounted on a fixed carriage, as well as independent control and lateral actuation of right and left forks mounted on the backplate.



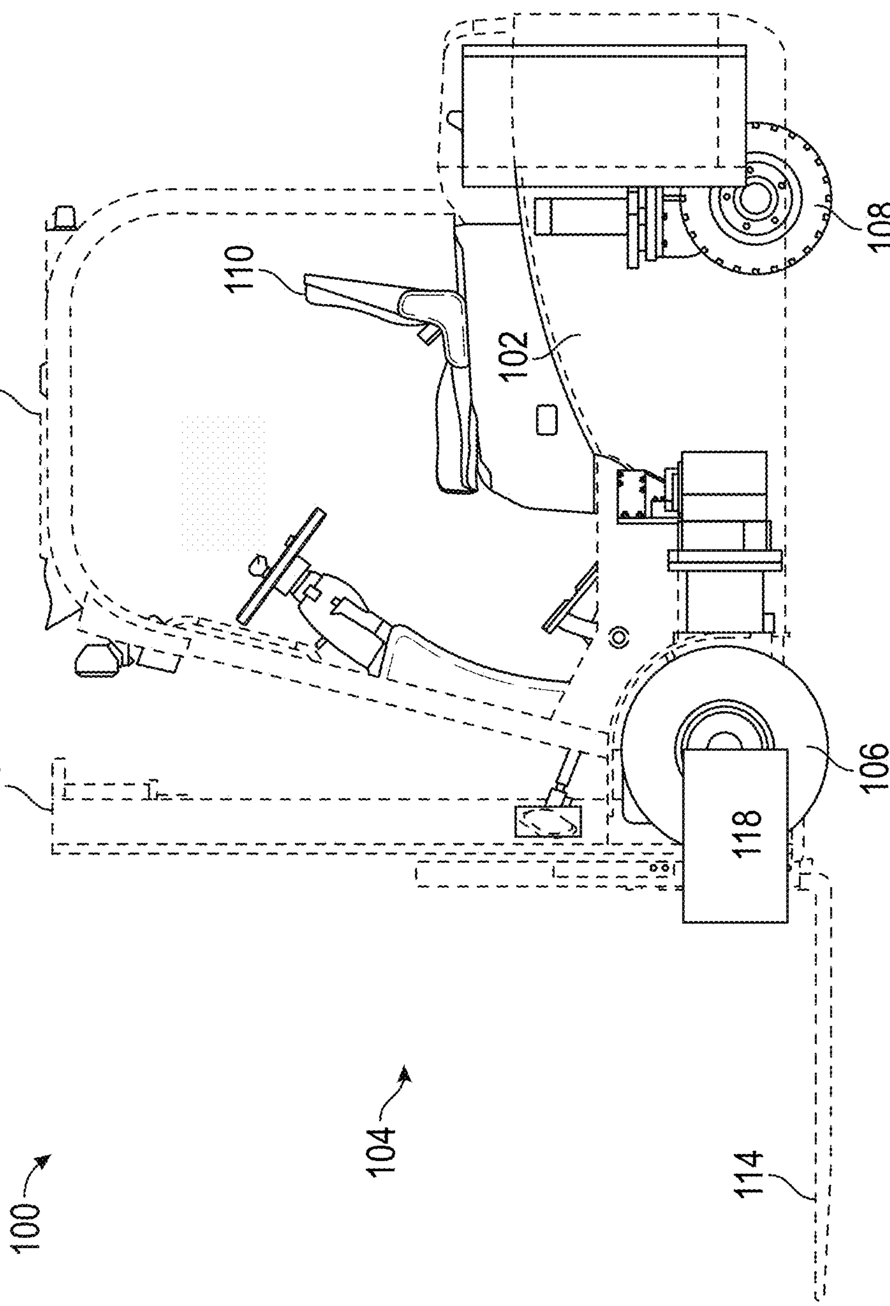


FIG. 1A

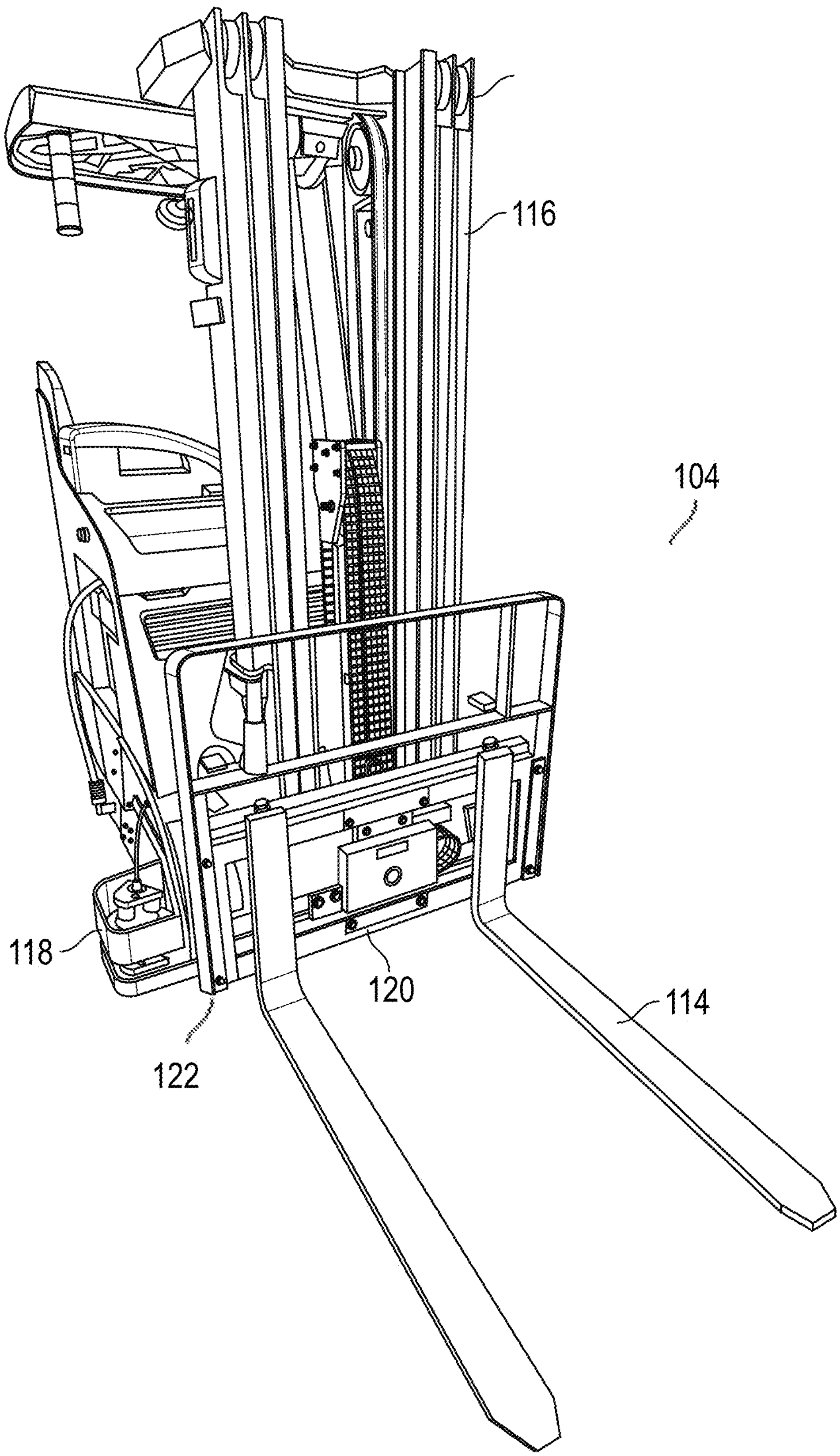


FIG. 1B

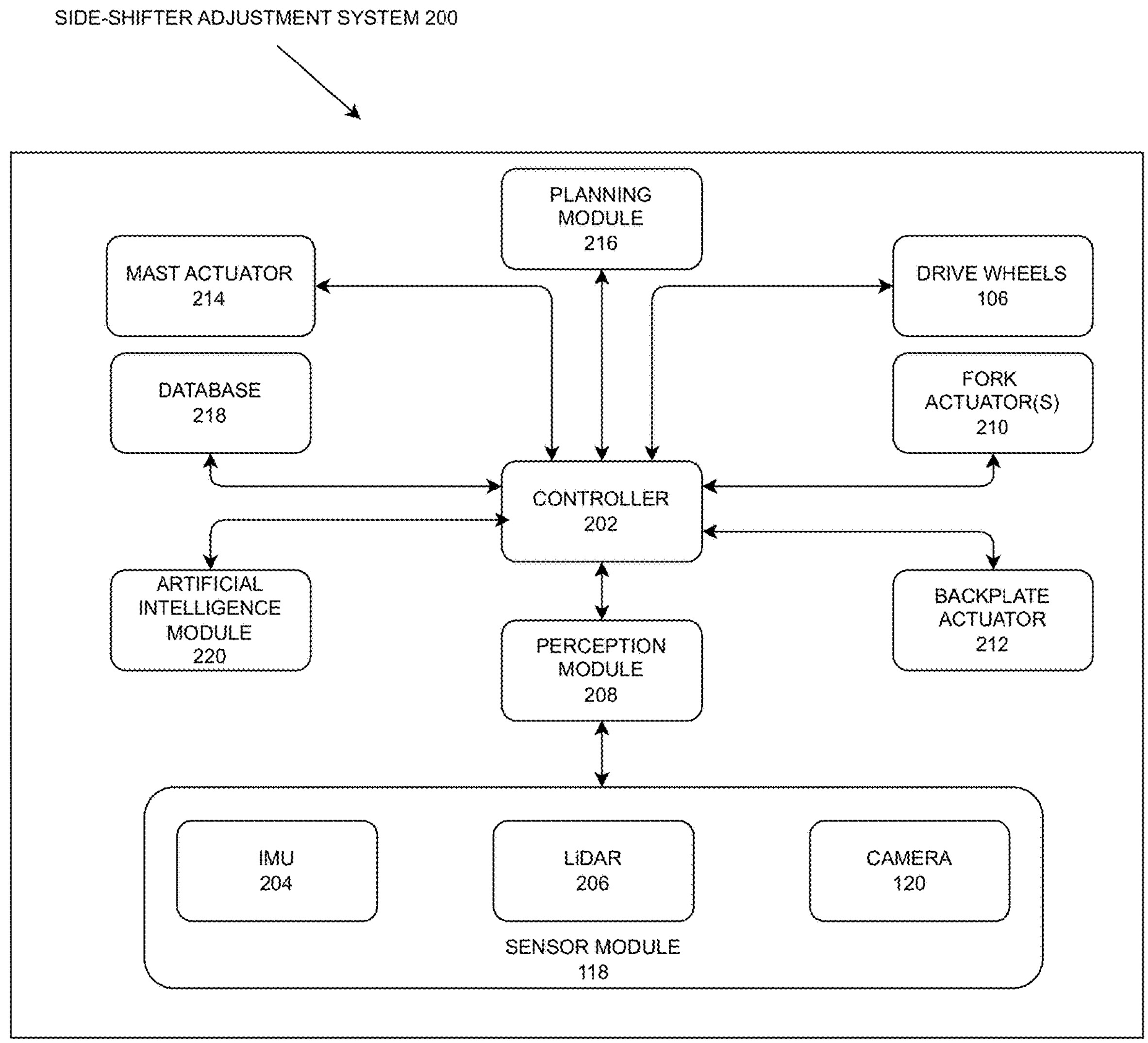

SIDE-SHIFTER ADJUSTMENT SYSTEM 200
PLANNING MODULE 216
MAST ACTUATOR 214
DRIVE WHEELS 106
DATABASE 218
FORK ACTUATOR(S) 210
CONTROLLER 202
ARTIFICIAL INTELLIGENCE MODULE 220
PERCEPTION MODULE 208
BACKPLATE ACTUATOR 212
IMU 204
LiDAR 206
CAMERA 120
SENSOR MODULE 118

FIG. 2

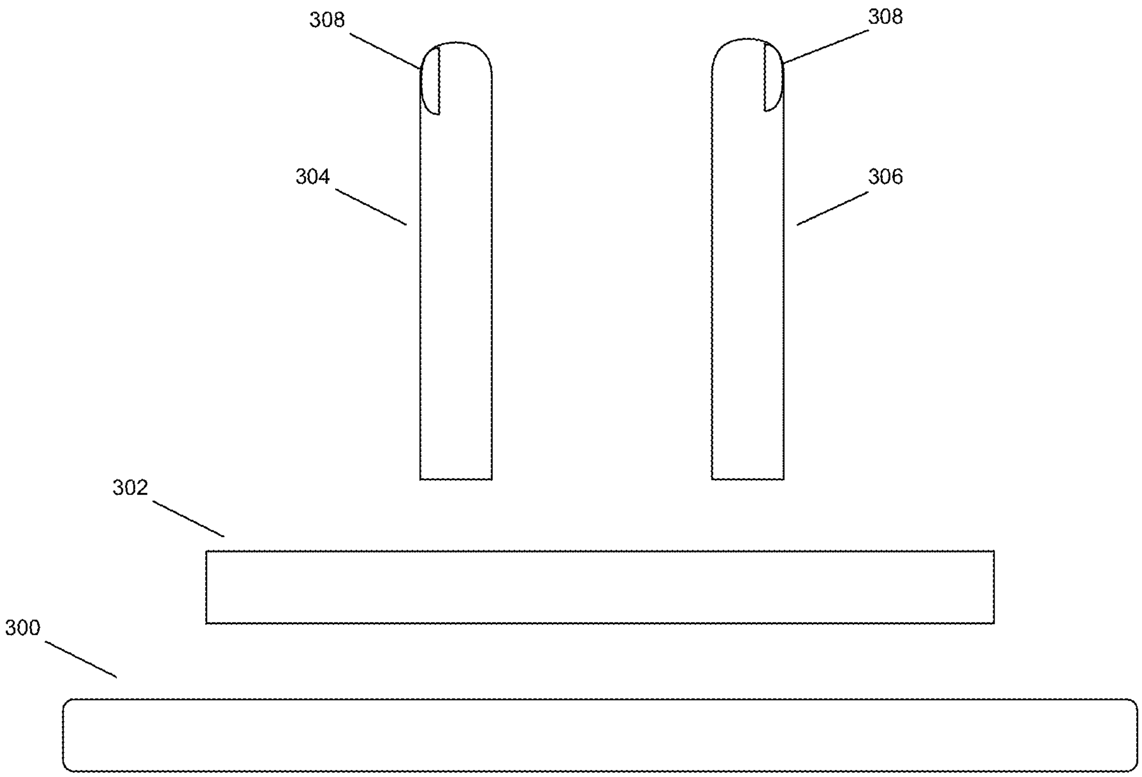


FIG. 3

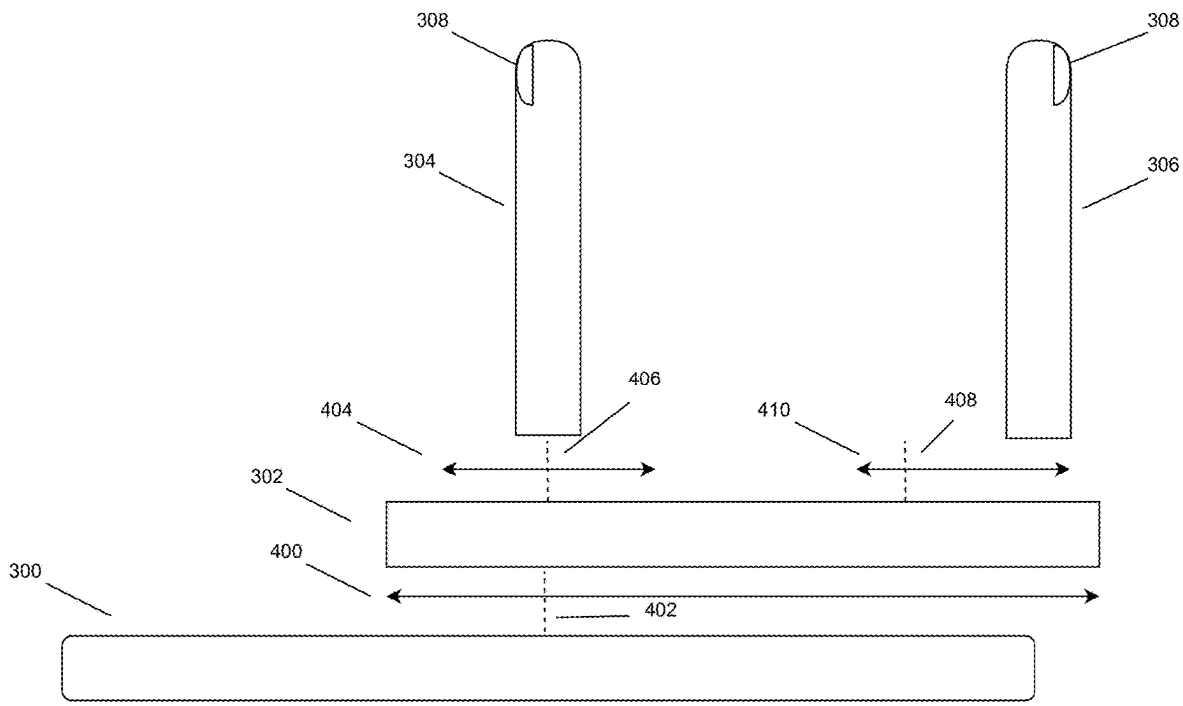


FIG. 4

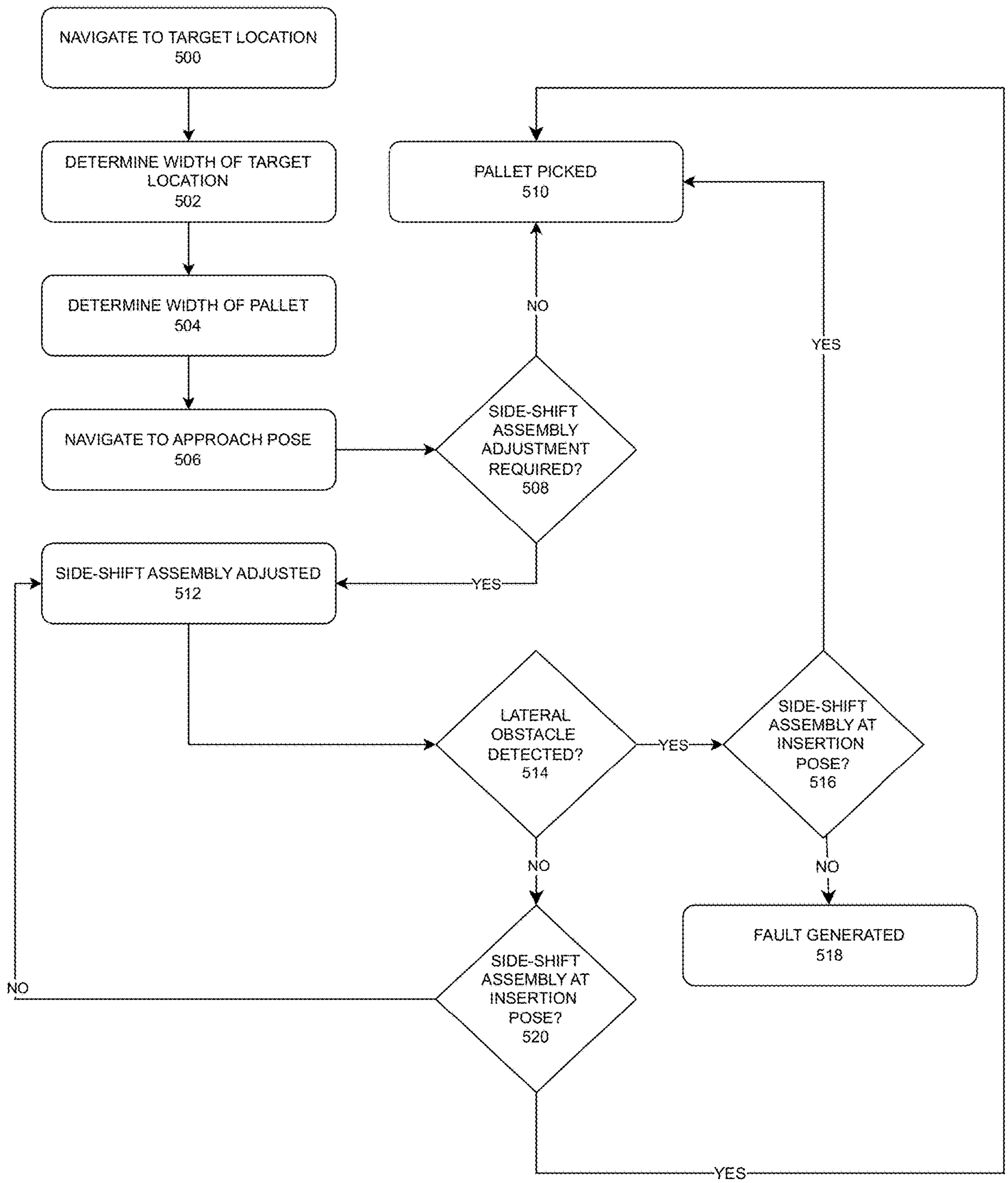

NAVIGATE TO TARGET LOCATION
500
DETERMINE WIDTH OF TARGET LOCATION
502
DETERMINE WIDTH OF PALLET
504
NAVIGATE TO APPROACH POSE
506
SIDE-SHIFT ASSEMBLY ADJUSTMENT REQUIRED?
508
NO
YES
PALLET PICKED
510
SIDE-SHIFT ASSEMBLY ADJUSTED
512
LATERAL OBSTACLE DETECTED?
514
YES
NO
SIDE-SHIFT ASSEMBLY AT INSERTION POSE?
516
YES
NO
FAULT GENERATED
518
SIDE-SHIFT ASSEMBLY AT INSERTION POSE?
520
NO
YES

FIG. 5

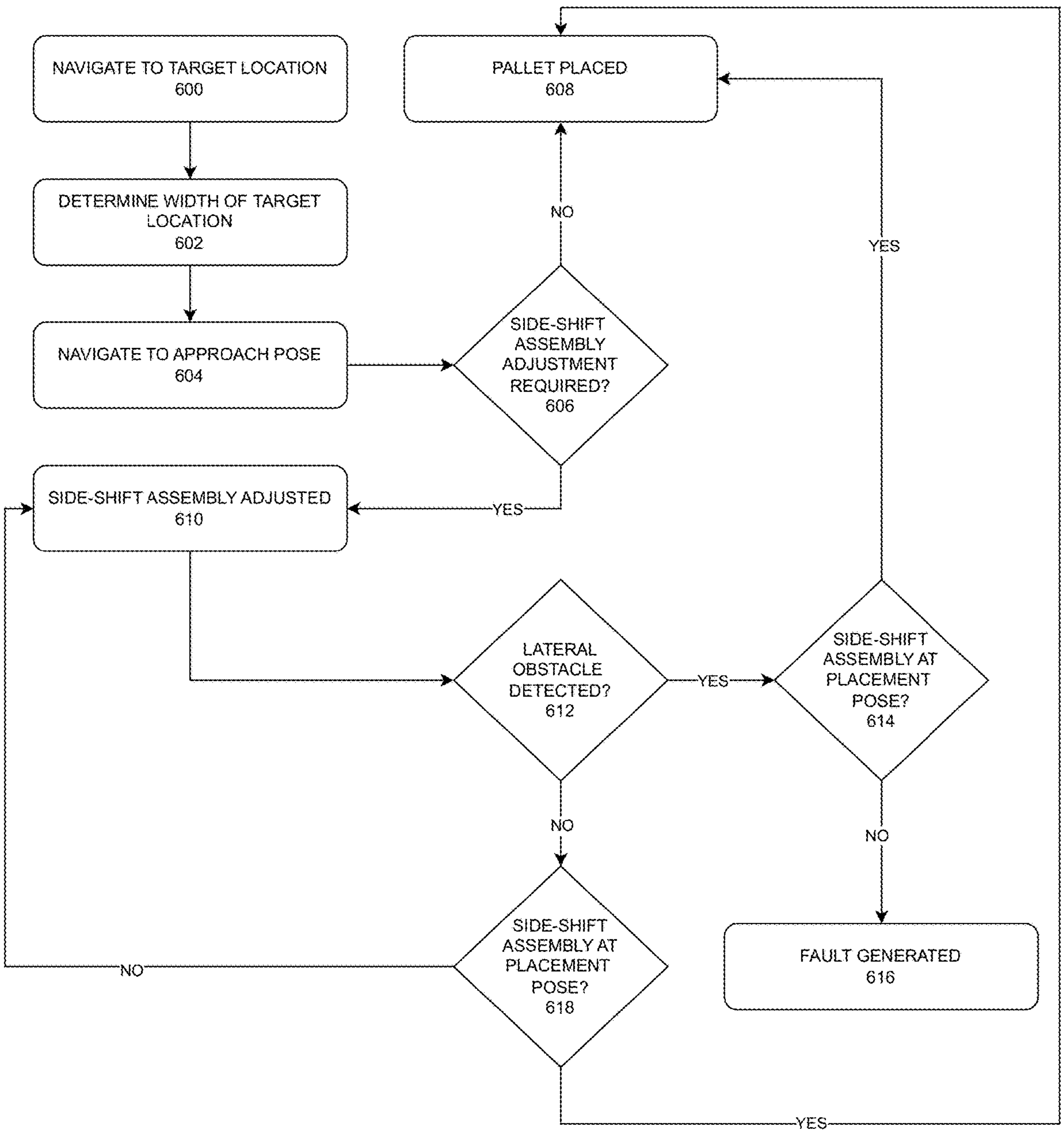

NAVIGATE TO TARGET LOCATION
600
DETERMINE WIDTH OF TARGET LOCATION
602
NAVIGATE TO APPROACH POSE
604
SIDE-SHIFT ASSEMBLY ADJUSTMENT REQUIRED?
606
PALLET PLACED
608
NO
YES
SIDE-SHIFT ASSEMBLY ADJUSTED
610
LATERAL OBSTACLE DETECTED?
612
YES
SIDE-SHIFT ASSEMBLY AT PLACEMENT POSE?
614
YES
NO
FAULT GENERATED
616
NO
SIDE-SHIFT ASSEMBLY AT PLACEMENT POSE?
618
NO
YES

FIG. 6

SYSTEMS AND METHODS FOR AN EXTENDED SIDE-SHIFT ASSEMBLY FOR HANDLING PALLETS

BACKGROUND

Field of the Invention

[0001] The present invention relates, in general, to an extended side-shift assembly for an autonomous vehicle that facilitates the loading and unloading of tail-adjacent pallets on a trailer and other shipping containers.

Description of Related Art

[0002] One of the key challenges for autonomous vehicles, such as autonomous forklifts, operating in warehouse and/or loading dock environments is in picking a first row of pallets in a trailer which are not directly in front of a dock leveler. Particularly in the case of recessed dock levelers or vertical style levelers with side barriers, getting the forks in a position to cleanly extract the first row of pallets is a significant challenge. This is made increasingly difficult by the fact that autonomous forklifts are typically outfitted with additional sensors that widen the overall footprint of the vehicle.

[0003] Forklifts are typically outfitted with a side-shift assembly, which operates by moving a backplate relative to a carriage mounted on the vehicle frame. Forks are then affixed to the backplate, yielding an assembly that can move the forks relative to the forklift body, helping with handling objects located adjacent to walls. The geometry of the backplate and carriage assembly is such that due to technical constraints, they must be the same width, and the degree of shift is limited to some fraction of this width. This constraint poses a challenge for handling objects far to the side of the forklift, as is the case in tail-adjacent pallets, as the backplate size may not exceed the width of the pallet to be picked, which have dimensions of 48"×40" for a standard Grocery Manufacturers Association (GMA) pallet.

[0004] Conventional side-shift assemblies for forklifts do not allow for independent positioning of each fork, as well as independent positioning of the backplate. Rather, existing side-shift assemblies allow for only narrowing or spreading the forks, where both forks are always adjusted simultaneously either towards each other (i.e. narrowing operations) or away from each other (i.e. spreading operations).

[0005] Thus, there is a need for a modified side-shift assembly that overcomes the aforementioned challenges, and which utilizes a combination of independent backplate and fork positioning to yield an increased range of motion suitable for extended side-shift applications, including, but not limited to, handling of tail-adjacent pallets.

SUMMARY

[0006] In an embodiment, the present invention is directed to a side-shift assembly for a forklift, comprising: a carriage mounted on the forklift; a backplate mounted on the carriage, the backplate capable of lateral adjustment relative to the carriage; and a fork assembly mounted on the backplate, wherein the fork assembly includes a first fork and a second fork, each of the first fork and the second fork capable of independent lateral adjustment relative to the backplate.

[0007] In another embodiment, the present invention is directed to a side-shift assembly for a forklift, comprising: a carriage mounted on the forklift; a backplate coupled to the carriage, the backplate capable of lateral adjustment relative to the carriage; a backplate actuator coupled to the backplate, the backplate actuator configured to provide driving force to adjust the backplate; a fork assembly mounted on the backplate, wherein the fork assembly includes a first fork and a second fork, each of the first fork and the second fork capable of independent lateral adjustment relative to the backplate; a fork actuator coupled to the first fork and the second fork, the fork actuator configured to provide driving force to independently adjust the first fork and the second fork; and a controller communicatively coupled to the backplate actuator and the fork actuator.

[0008] In yet another embodiment, the present invention is directed to a side-shift assembly for a forklift, comprising: a carriage mounted on the forklift; a backplate coupled to the carriage, the backplate capable of lateral adjustment relative to the carriage; a backplate actuator coupled to the backplate, the backplate actuator configured to provide driving force to adjust the backplate; a fork assembly mounted on the backplate, wherein the fork assembly includes a first fork and a second fork, each of the first fork and the second fork capable of independent lateral adjustment relative to the backplate, and each of the first fork and the second fork capable of independent lateral adjustment relative to one another; a fork actuator coupled to the first fork and the second fork, the fork actuator configured to provide driving force to independently adjust the first fork and the second fork; and a controller communicatively coupled to the backplate actuator and the fork actuator.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] These and other embodiments of the present invention will be discussed with reference to the following exemplary and non-limiting illustrations, in which like elements are numbered similarly, and where:

[0010] FIGS. **1**A and **1**B depict an autonomous forklift, according to an embodiment of the present invention;

[0011] FIG. **2** is a block diagram of a side-shift adjustment system, according to an embodiment of the present invention;

[0012] FIG. **3** is a diagram of a side-shift assembly, according to an embodiment of the present invention;

[0013] FIG. **4** is a diagram of an adjusted side-shift assembly, according to an embodiment of the present invention;

[0014] FIG. **5** is a flowchart illustrating the steps of operation of the side-shift adjustment system during a pallet picking maneuver, according to an embodiment of the present invention; and

[0015] FIG. **6** is a flowchart illustrating the steps of operation of the side-shift adjustment system during a pallet placing maneuver, according to an embodiment of the present invention.

DEFINITIONS

[0016] The following definitions are meant to aid in the description and understanding of the defined terms in the context of the present invention. The definitions are not meant to limit these terms to less than is described throughout this specification. Such definitions are meant to encompass grammatical equivalents.

[0017] As used herein, the term "autonomous forklift" can refer to, for example, autonomous mobile robots, automatic guided vehicles, vision guided vehicles, semi-autonomous vehicles, and remote-piloted autonomous vehicles, as examples, which serve as equipment, pallet, object, and cargo moving and transport vehicles, including, but not limited to, fork trucks, pallet loaders, side loaders, lift trucks, fork hoists, stacker-trucks, trailer loaders, industrial trucks, pallet jacks, pallet stackers, tow tractors, tugs, and the like.

[0018] As used herein, the terms "sensor" and "detector" can refer to, for example, sensing technologies that utilize Light Detection and Ranging (LiDAR), laser scanners, range finders, radar, infrared sensors, sonar, ultrasonic sensors, optical sensors, such as photoelectric sensors, fiber optic sensors, photoconductive devices, reflective sensors, phototransistors, ambient light sensors, infrared sensors, photodiodes, and optical switches, point sensors, proximity sensors, through beam sensors, light curtains, image and video capturing devices, machine vision systems, any combination thereof, and the like.

[0019] As used herein, the term "inertial measurement unit" and "IMU" can refer to, for example, accelerometers, gyroscopes, magnetometers, pressure sensors, any combination thereof, and the like.

[0020] As used herein, the term "network" can refer to, for example, the Internet, a wide area network (WAN), metropolitan area network (MAN), controller area network (CAN), local area network (LAN), but the network could at least theoretically be of an applicable size or characterized in some other fashion (i.e., personal area network (PAN), home area network (HAN), and the like), a wireless network, a wireless mesh network, a cellular network, a landline network, and/or a short-range connection network (i.e., such as Bluetooth, Zigbee, infrared, and the like). The term "network" can further refer to enterprise private networks, edge networks, and/or virtual private networks.

[0021] As used herein, the term "processor" can refer to, for example, any programmable system including systems using micro-controllers, reduced instruction set circuits (RISC), application specific integrated circuits (ASICs), logic circuits, and any other circuit or processor capable of executing the functions described herein. The above examples are exemplary only and are thus not intended to limit in any way the definition and/or meaning of the term "processor."

[0022] As used herein, the terms "software" and "firmware" are interchangeable, and can refer to, for example, any computer program stored in memory for execution by a processor, including RAM memory, ROM memory, EPROM memory, EEPROM memory, and non-volatile RAM (NVRAM) memory. The above memory types are example only and are thus not limiting as to the types of memory usable for storage of a computer program.

[0023] As used herein, the term "database" can refer to, for example, a persistent data store with indexing capabilities to expedite query processing. The database can implement various database management system types such as relational, object-oriented, hierarchical, document-oriented, flat file, object-relational, and any other structured collection of records. The database can be stored locally, remotely, on a cloud environment, and/or on a distributed ledger.

[0024] As used herein, the term "actuator" can refer to, for example, a machine that creates motion, and includes electric actuators such as electric motors, electric linear actuators, stepper motors, and jack screws, hydraulic actuators such as hydraulic cylinders and hydraulic motors, pneumatic actuators, mechanical actuators such as ball screws, leadscrews, rack and pinion, and cams, piezoelectric actuators, and electromagnetic actuators.

[0025] As used herein, the term "artificial intelligence" can refer to, for example, machine learning, deep-learning, supervised learning, unsupervised learning, semi-supervised learning, generative artificial intelligence, reinforced learning, fuzzy logic, neural networks, historical data and pattern analysis, any combination thereof, and the like.

[0026] As used herein, the term "module" can refer to, for example, hardware components, software components, such as source code, packages, libraries, algorithms, and the like, as well as combinations therein.

[0027] As used herein, the term "bump sensor" can refer to, for example, a bump switch, bumper switch, push-button switch, snap-action switch, limit switch, touch switch, and the like, which provides a signal indicating whether the autonomous forklift is in contact with, or receiving resistance from, an obstacle.

DETAILED DESCRIPTION

[0028] It should be understood that aspects of the present invention are described herein with reference to the figures, which show illustrative embodiments. The illustrative embodiments herein are not necessarily intended to show all embodiments in accordance with the invention but rather are used to describe a few illustrative embodiments. Thus, aspects of the invention are not intended to be construed narrowly in view of the illustrative embodiments. In addition, although the present invention is described with respect to its application for an autonomous forklift operating in a loading dock environment, it is understood that the system could be implemented in any autonomous or semi-autonomous vehicle system operating in any environment where pallets are handled, such as shipping docks, shipping containers, and other storage facilities and containers.

[0029] FIGS. **1**A and **1**B depict an autonomous forklift **100**, according to an embodiment of the present invention. The autonomous forklift **100** includes a body **102** and a load-handling system **104** that is coupled to the front of the body **102**. An operator's compartment **110** can be provided in the center of the body **102**. In one or more embodiments, an operator's compartment **110** may be installed to enable a manual or semi-autonomous operation of the autonomous forklift **100**. Alternatively, in an embodiment, the autonomous forklift **100** may be fully autonomous, without the operator's compartment **110**.

[0030] The body **102** stands on front drive wheels **106** and at least one rear wheel **108**. Specifically, the front pair of wheels are drive wheels **106** and the rear wheel **108** is a steer wheel. The drive wheels **106** provide the power to move the autonomous forklift **100** forward or backwards. In an embodiment, the drive wheels **106** are a plurality of wheels that are mechanically coupled to a chassis of the autonomous forklift **100**. The plurality of drive wheels **106** and the rear wheel **108** enable movement of the chassis along a ground surface. A motor is mechanically coupled to at least one wheel in the plurality of drive wheels **106**. The motor can rotate the at least one wheel and turn the at least one wheel to slow and/or stop the autonomous forklift **100**.

[0031] Further, the drive wheels **106** may move only in two directions (e.g., forward, and backward) or turn under a plurality of angles. Additionally, the rear wheel **108** may be responsible for changing the direction of the autonomous forklift **100**.

[0032] In another embodiment, the rear wheel **108** may serve as a driving force provider, while the two front wheels **106** may serve as stabilizers.

[0033] The autonomous forklift **100** may be powered by an internal combustion engine, an electric motor, a fuel cell, or a combination thereof, such as in a hybrid powered vehicle. The body **102** may include an overhead guard **112** that covers the upper part of the operator's compartment **110**.

[0034] Further, the load-handling system **104** includes a mast **116**. The mast may include inner masts and outer masts, where the inner masts are slidable with respect to the outer masts. In an embodiment, the mast **116** may be movable with respect to the vehicle body **102**. The movement of the mast **116** may be operated by hydraulic tilt cylinders positioned between the body **102** and the mast **116**. The tilt cylinders may cause the mast **116** to tilt forward and rearward around the bottom end portions of the mast **116**. Additionally, a pair of hydraulically operated lift cylinders may be mounted to the mast **116** itself. The lift cylinders may cause the inner masts to slide up and down vertically relative to the outer masts.

[0035] Further, a fork assembly **114** is mounted to the mast **116** through a lift bracket, which is slidable up and down vertically relative to the inner masts. In an embodiment, the inner masts, the fork assembly **114**, and the lift bracket all provide a vertical lifting function. The load-handling system **104** also includes a side-shift assembly **122**, allowing for accurate lateral (i.e., left and right horizontal) positioning of the fork assembly **114**. In an embodiment, the side-shift actuation is performed by hydraulically actuated cylinders, in other embodiments it is driven by electric linear actuators.

[0036] Thus, the load-handling assembly **104** provides a horizontal shifting function of the fork assembly **114** (via the side-shift assembly **122**), as well as a vertical lifting and lowering function of the fork assembly **114**. In an embodiment, each fork can be laterally adjusted independent of the other fork, as described herein.

[0037] In an embodiment, the autonomous forklift **100** includes a sensor module **118**, that includes a plurality of sensors, as well as at least one camera **120**. In an embodiment, the sensor module **118** comprises just a camera or multiple cameras. In another embodiment, the sensor module **118** comprises just the LiDAR system **206**. In yet another embodiment, the sensor module **118** comprises a combination of cameras, LiDAR, and other sensors. For example, the sensor module **118** can incorporate fork sensors **308**, as described herein with reference to FIG. **3**.

[0038] The autonomous forklift **100** is described in more detail in commonly owned application Ser. No. 18/480,214 entitled "Method and system for operating automated forklift", filed on Oct. 3, 2023, and commonly owned application Ser. No. 18/410,774 entitled "Method and system for deep learning-based perception", filed on Jan. 11, 2024, both of which are incorporated by reference herein.

[0039] FIG. **2** is a block diagram of a side-shift adjustment system **200** for the autonomous forklift **100**, according to an embodiment of the present invention. In an embodiment, the side-shift adjustment system **200** includes a controller **202** that is communicatively coupled to the sensor module **118**, a perception module **208**, at least one fork actuator **210**, a backplate actuator **212**, a mast actuator **214**, and a planning module **216**, via a network. The network may be any type of network suitable to allow interaction between the components of the side-shift adjustment system **200**, such as a CAN bus on-board the autonomous forklift **100**. In another embodiment, the network may be a wired network, a wireless network, a mesh network, or any combination thereof.

[0040] In an embodiment, the controller **202** consists of computing hardware, such as a processor, and software which is executed by the processor. In an exemplary embodiment the controller **202** is located on-board the autonomous forklift **100**. In another embodiment, the controller **202** can include a server coupled to the network. In another embodiment, the controller **202** is cloud-based, and located on remote server, such as on a server provided by Google® Cloud Platform or the like. In yet another embodiment, the controller **202** can be distributed across multiple servers.

[0041] In an embodiment, the controller **202** receives input, such as data, from the sensor module **118**, the perception module **208**, the planning module **212**, the fork actuator **210**, the backplate actuator **212**, the mast actuator **214**, the drive wheels **106**, the planning module **216**, the database **218**, and the artificial intelligence module **220**, and provides output, such as commands to the fork actuator **210**, backplate actuator **212**, and the mast actuator **214**.

[0042] In an embodiment, the sensor module **118** includes a plurality of sensors including, at least an IMU **204**, a LiDAR system **206**, and/or at least one camera **120**.

[0043] In an embodiment, the IMU **204** combines a plurality of sensors (e.g., accelerometer, gyroscope, magnetometer, pressure sensor . . .) to provide data regarding the orientation, acceleration, and angular velocity of the autonomous forklift **100**. More specifically, an accelerometer of the IMU **204** may measure linear acceleration to determine changes in velocity and direction. Further, a gyroscope of the IMU **204** may measure rotational movements and the magnetometer detects the Earth's magnetic field and to determine orientation information as well as the angle of tilt of the autonomous forklift **100**.

[0044] In an embodiment, the IMU **204** can be communicatively coupled to the drive wheels **106** and/or the load-handling assembly **104** and can receive signals therefrom. The IMU **204** can collect, for example, information related to speed, velocity, orientation, angular rates, direction, gravitational forces, wheel rotation, and the like, of the drive wheels **106**.

[0045] Furthermore, the IMU **204** can collect, for example, information related to the weight or load carried, lateral and vertical adjustments of each fork, tilt of the fork assembly **114**, and the like.

[0046] In an embodiment, the camera **120** may be a stereoscopic camera (also known as a stereo or 3D camera), a time-of-flight (ToF) camera or sensor, line scan or area scan camera, a CCD camera, a CMOS camera, or any other suitable camera used in robotics. The camera **120** may capture images in monochrome or in color. Physically, the camera **120** may be located on the front side of the autonomous forklift **100**, such as on the backplate **302** shown in FIG. **3**, to be able to capture the position of the fork assembly **114**, as well as the surrounding environment that faces the forward movement direction of the autonomous forklift **110**. Additionally, there may be one or more cameras disposed on the autonomous forklift **100**, such as a camera array and/or multiple cameras located at various locations on the autonomous forklift **100**, such as to provide a 360-degree field of view around the autonomous forklift **100**. In an embodiment, the camera **120** captures image data and video data.

[0047] In an embodiment, the LiDAR system **206** is mounted on the carriage **300** shown in FIG. **3**. The LiDAR system **206** can provide distance estimation of obstacles and objects, as well as facilitate object recognition by the perception module **208**.

[0048] The use of the IMU **204**, the LiDAR system **206**, and the camera **120** in the sensor module **118** is exemplary, and are not intended to be a limiting. The sensor module **118** can include various other sensing or detecting devices as described herein.

[0049] In an embodiment, the perception module **208** receives visual data from the sensor module **118** that is collected as the autonomous forklift **100** traverses an environment. The visual data can include, for example, a collection of low- and high-resolution video frames and/or images, including but not limited to one or more (e.g., monocular or stereo) color or grayscale light intensity images, 3D depth images, and derived images such as 2D or 3D traversability maps, or sets of features recognized within the visual data.

[0050] The perception module **208** performs object recognition on the visual data and determines if obstacles are present in the visual data. If an obstacle is detected in the visual data, the perception module **208** classifies each obstacle, such as, for example, as a human, a pallet, a wall, a vehicle, a trailer, and the like.

[0051] In an embodiment, the perception module **208** determines dimensions of objects, such as a pallet, as well as dimensions of obstacles which may need to be cleared by the autonomous forklift **100** when loading/picking, carrying, or unloading/placing the pallet.

[0052] In an embodiment, the planning module **216** generates a plan for placing or inserting the pallet carried by the autonomous forklift **100** based on the dimensions of the pallet as well as the dimensions of any detected obstacles.

[0053] In an embodiment, the database **218** is configured to store various data, receive queries from the controller **202**, and return data to the controller **202** in response to the queries. The database **106** can store visual data collected by the sensor module **118**, data processed by the perception module **208**, data collected from the drive wheels **106**, data collected from the fork actuator **210** and the backplate actuator **212**, and/or relevant information generated by the planning module **216**.

[0054] For example, the database **218** can store data collected by the sensors module **118** related to motion, navigation, speed, and trajectory of the autonomous forklift, as well as detected obstacles, collision avoidance maneuvers undertaken, and work performed such as picking and placing operations of pallets.

[0055] In an embodiment, the data in the database **218** is stored with an identifier related to at least one of a carried pallet, the autonomous forklift, a loading location, a placement location and/or any combination thereof. In addition, the data in the database **218** can be stored with timestamps.

[0056] This data may be stored locally within a database on the autonomous forklift **100**, and can be transmitted to the controller **202**, which can process the data, and further transmit data from the sensor module **118**, planning module **216**, and other sensors on the autonomous forklift **100**, to the database **218** for storage and subsequent retrieval.

[0057] In another embodiment, all or portion of the data can be stored remotely on a remote database which is accessible by the controller **202**.

[0058] In an embodiment, the artificial intelligence module **220** is communicatively coupled to the controller **202** and/or the database **218**. The artificial intelligence module **220** can analyze data collected and generated over time by the sensor module **118**, the perception module **208**, the fork actuator **210**, the backplate actuator **212**, the planning module **216**, and/or the drive wheels **106**. This analysis by the artificial intelligence module **220** allows the controller **202** to process the future data more efficiently, quickly generate commands, and improve the efficacy and accuracy of the side-shift adjustment system **200**.

[0059] For example, the artificial intelligence module **220** can analyze historical side-shift operations for a particular trailer and use the historical data to suggest a side-shift adjustment plan for a current picking or placement operation, or a subsequent picking or placement operation.

[0060] FIG. **3** is a diagram of a side-shift assembly **122**, according to an embodiment of the present invention. In an embodiment, the side-shift assembly **122** includes a carriage **300**. The carriage **300** can be mounted on the mast **116** and is configured to be adjusted vertically relative to the vehicle body **102**.

[0061] In an embodiment, a backplate **302** is moveably mounted on the carriage **300**. The backplate **302** can move in two directions laterally along a horizontal plane relative to the carriage **300**. In an embodiment, the backplate **302** is mounted to the carriage **300** via at least one rail, where the mounting allows lateral movement of the backplate **302** along the rail. In an embodiment, the backplate actuator **212** (not depicted in FIG. **3**) provides driving force to move the backplate **302** along the rail.

[0062] In an embodiment, the fork assembly **104** includes a right fork **304** and left fork **306**, which are both moveably mounted on the backplate **302**. In an embodiment, each fork **304**, **306** can independently move in two directions laterally along a horizontal plane relative to the backplate **302**. In an embodiment, each fork **304**, **306** is mounted to the backplate **302** via a respective rail, where the mounting allows lateral movement of each fork **304**, **306** along its respective rail. The fork actuator **210** (not depicted in FIG. **3**) provides driving force to move each fork **304**, **306** along the rail.

[0063] In another embodiment, each fork **304**, **306** is mounted on a single rail. In yet another embodiment, the backplate actuator **212** and the fork actuator **210** can be a single actuator that provides driving force to the backplate **302** and each of the forks **304**, **306**.

[0064] In an embodiment, the forks **304**, **306** have a rounded distal end, which prevents damaging or stabbing of soft obstacles or objects loaded on pallets.

[0065] In an embodiment, each fork **304**, **306** is coupled to an independent fork actuator. In another embodiment, a single fork actuator is coupled to both forks **304**, **306**. Each fork **304**, **306** can be independently moved such that the fork **304** can be positioned while the fork **306** remains stationary, and vice versa. Furthermore, each fork **304**, **306** can be independently moved to different degrees, such that the fork **304** can be moved laterally a greater distance than fork **306**, and vice versa.

[0066] Thus, the side-shift assembly **122** of the present invention utilizes a combination of backplate **302** and fork **304**, **306** positioning to yield an increased range of lateral range of motion suitable for extended shift applications, such as loading and unloading pallets near the tail of a trailer and other shipping containers. In an embodiment, the backplate **302** can be adjusted laterally relative to the carriage **300**, while one or more forks **304**, **306** can be independently adjusted laterally relative to the backplate **302**. The side-shift assembly **122** facilitates picking pallets narrower than the width of the backplate **302**, as well as placing pallets in confined spaces.

[0067] Furthermore, the side-shift assembly **122** allows for the picking of various sized pallets, in addition to standard GMA pallets, such as varying sized stringer pallets and European pallets which can have dimensions of 31.5"×47.2". The side-shift assembly **122** supports the transporting of a wide range of pallet types, as the independent adjustment of the backplate **302** and forks **304**, **306** provides variable spacing to accommodate the picking of different sized pallets.

[0068] In an embodiment, each fork **304**, **306** includes a respective fork sensor **308** mounted at a distal end of each fork **304**, **306**. The fork sensor **308** is preferably mounted at an outer edge of each fork **304**, **306**. In an embodiment, the fork sensor **308** comprises a robotic vision system that includes a stereo depth camera and a high-resolution camera, such as an OAK-D camera manufactured by Luxonic Inc. In an embodiment, the fork sensor **308** includes multiple robotic vision systems, cameras, and/or sensors which are stacked on top of one another about the outer edge of each fork **304**, **306**.

[0069] FIG. **4** is a diagram of an adjusted side-shift assembly **122**, according to an embodiment of the present invention. As shown in FIG. **4**, the backplate **302** has been shifted toward the left along the axis **400** relative to a centerline **402** of the backplate **302**, and relative to the carriage **300**. In addition, the left fork **306** has been shifted toward the left along the axis **410** relative to a centerline **408** of the left fork, and relative to the backplate **302**. The right fork **304** remains at its centerline **406** and has not been adjusted along its axis **404**. The laterally adjusted backplate **302** and left fork **306** shown in FIG. **4** is merely exemplary, and numerous combinations of adjustments of the backplate **302** and forks **304**, **306** can be achieved by the present invention.

[0070] The side-shift assembly **122** allows for independent lateral adjustment of the backplate **302** relative to the carriage **300** and further allows for independent lateral adjustment of each fork **304**, **306** relative to one another, as well as to the backplate **302** and the carriage **300**.

[0071] FIG. **5** is a flowchart illustrating the steps of operation of the side-shift adjustment system **200** during a pallet picking maneuver, according to an embodiment of the present invention. At step **500**, the autonomous forklift **100** navigates to a target location where a pallet is located.

[0072] At step **502**, the perception module **208** determines the width of the target location. In an embodiment, the target location can be, for example, a trailer which the pallet is located in. The perception module **208** determines the width of the target location by using at least one of the sensor module **118** and the sensors **308** on the forks **304**, **306**. Furthermore, the perception module **208** determines a lateral clearance between the autonomous forklift **100** and the width of the target location, which can account for obstacles such as side walls, barriers, posts, and the like.

[0073] Next, at step **504**, the perception module **208** determines the width of the pallet using at least one of the sensor module **118** and the fork sensors **308**.

[0074] At step **506**, the controller **202** utilizes the detected width of the target location, the lateral clearance, and the width of the pallet to navigate the autonomous forklift **100** to an approach pose, where the approach pose is a safe minimum distance within the lateral clearance where the autonomous forklift **100** can safely adjust the side-shift assembly **122** as needed to complete the pallet picking operation.

[0075] At step **508**, the controller **202** determines if the side-shift assembly **122** requires adjustment to safely pick the pallet. If the backplate **302** and/or forks **304**, **306** are at an insertion pose (i.e., the side-shift assembly **122** is optimally positioned to safely pick the pallet), then the process continues to step **510** where the controller **202** manipulates the drive wheels **106** such that the forks **304**, **306** are inserted into the pallet, thereby picking the pallet from the target location.

[0076] However, if at step **508**, the controller **202** determines that the side-shift assembly **122** requires adjustment to perform the pallet picking operation, then at step **512**, the controller **202** adjusts the backplate **302**, the right fork **304**, and/or the left fork **306** to the required insertion pose. As described herein, the backplate **302**, the right fork **304**, and the left fork **306** can each be independently manipulated to achieve the required insertion pose.

[0077] At step **514**, as the side-shift assembly **122** is being adjusted, the perception module **208** determines if the side-shift assembly **122** is approaching a lateral obstacle, such as wall or post of the trailer door, for example. In an embodiment, the perception module **208** utilizes the fork sensors **308** to determine if either fork **304**, **306** is approaching a lateral obstacle as the backplate **302** and/or forks **304**, **306** are being adjusted.

[0078] In an embodiment, the backplate **302** also includes backplate sensors (not depicted) on its lateral sides. The perception module **308** can also utilize the backplate sensors to determine if the backplate is approaching a lateral obstacle as it is being adjusted.

[0079] In yet another embodiment, the forks **304**, **306** and/or the backplate **302** can include at least one bump sensor on, for example, the distal and/or lateral edges or sides. When the bump sensor contacts a lateral obstacle, the controller **202** receives a signal indicating lateral resistance.

[0080] If a lateral obstacle is detected at step **514**, then the process continues step **516** where the controller **202** determines if the side-shift assembly **122** is at the required insertion pose. If the side-shift assembly **122** is not at the required insertion pose, then a fault is generated at step **518**, and a human operator may be notified and prompted to intervene so that the autonomous forklift **100** can be safely maneuvered to the required insertion pose.

[0081] If, however, the side-shift assembly **122** is at the required insertion pose at step **516**, then the process continues to step **510** where the controller **202** manipulates the drive wheels **106** such that the forks **304**, **306** are inserted into the pallet, thereby picking the pallet from the target location.

[0082] If a lateral obstacle is not detected however at step **514**, then the process continues to step **520** where the controller **202** determines if the side-shift assembly **122** is at the required insertion pose. If the controller **202** determines that the side-shift assembly **122** is not at the required insertion pose, then the process returns to step **512** where the side-shift assembly **122** continues to be adjusted.

[0083] If, however, the side-shift assembly **122** is at the required insertion pose at step **520**, then the process continues to step **510** where the controller **202** manipulates the drive wheels **106** such that the forks **304**, **306** are inserted into the pallet, thereby picking the pallet from the target location.

[0084] FIG. **6** is a flowchart illustrating the steps of operation of the side-shift adjustment system **200** during a pallet placing maneuver, according to an embodiment of the present invention. At step **600**, the autonomous forklift **100** navigates to a target location where a pallet is to be placed.

[0085] At step **602**, the perception module **208** determines the width of the target location. In an embodiment, the target location can be, for example, a trailer which the pallet is to be placed. The perception module **208** determines the width of the target location by using at least one of the sensor module **118** and the sensors **308** on the forks **304**, **306**. Furthermore, the perception module **208** determines a lateral clearance between the autonomous forklift **100** and the width of the target location, which can account for obstacles such as side walls, barriers, posts, and the like.

[0086] At step **604**, the controller **202** utilizes the detected width of the target location, the lateral clearance, and the width of the pallet to navigate the autonomous forklift **100** to an approach pose, where the approach pose is a safe minimum distance within the lateral clearance where the autonomous forklift **100** can safely adjust the side-shift assembly **122** as needed to complete the pallet placing operation.

[0087] At step **606**, the controller **202** determines if the side-shift assembly **122** requires adjustment to safely place the pallet. If the backplate **302** and/or forks **304**, **306** are at a placement pose (i.e., the side-shift assembly **122** is optimally positioned to safely place the pallet), then the process continues to step **608** where the controller **202** manipulates the drive wheels **106** such that the forks **304**, **306** are removed from the pallet, thereby placing the pallet at the target location.

[0088] However, if at step **606**, the controller **202** determines that the side-shift assembly **122** requires adjustment to perform the pallet placement operation, then at step **610**, the controller **202** adjusts the backplate **302**, the right fork **304**, and/or the left fork **306** to the required placement pose. As described herein, the backplate **302**, the right fork **304**, and the left fork **306** can each be independently manipulated. Thus, the side-shift assembly **122** can independently adjust the backplate **302**, the right fork **304**, and/or the left fork **306** while supporting a load, such as a pallet.

[0089] At step **612**, as the side-shift assembly **122** is being adjusted, the perception module **208** determines if the side-shift assembly **122** is approaching a lateral obstacle, such as wall or post of the trailer door, for example. In an embodiment, the perception module **208** utilizes the fork sensors **308** to determine if either fork **304**, **306** is approaching a lateral obstacle as the backplate **302** and/or forks **304**, **306** are being adjusted.

[0090] In an embodiment, the backplate **302** also includes backplate sensors (not depicted) on its lateral sides. The perception module **308** utilizes the backplate sensors to determine if the backplate is approaching a lateral obstacle as it is being adjusted.

[0091] In yet another embodiment, the forks **304**, **306** and/or the backplate **302** can include at least one bump sensor on, for example, the distal and/or lateral edges or sides. When the bump sensor contacts a lateral obstacle, the controller **202** receives a signal indicating lateral resistance.

[0092] If a lateral obstacle is detected at step **612**, then the process continues step **614** where the controller **202** determines if the side-shift assembly **122** is at the required placement pose. If the side-shift assembly **122** is not at the required placement pose, then a fault is generated at step **616**, and a human operator may be notified and prompted to intervene so that the autonomous forklift **100** can be safely maneuvered to the required placement pose.

[0093] If, however, the side-shift assembly **122** is at the required placement pose at step **614**, then the process continues to step **608** where the controller **202** manipulates the drive wheels **106** such that the forks **304**, **306** are removed from the pallet, thereby placing the pallet at the target location.

[0094] If a lateral obstacle is not detected however at step **612**, then the process continues to step **618** where the controller **202** determines if the side-shift assembly **122** is at the required placement pose. If the controller **202** determines that the side-shift assembly **122** is not at the required placement pose, then the process returns to step **610** where the side-shift assembly **122** continues to be adjusted.

[0095] If, however, the side-shift assembly **122** is at the required placement pose at step **618**, then the process continues to step **608** where the controller **202** manipulates the drive wheels **106** such that the forks **304**, **306** are removed from the pallet, thereby placing the pallet at the target location.

[0096] While the principles of the disclosure have been illustrated in relation to the exemplary embodiments shown herein, the principles of the disclosure are not limited thereto and include any modification, variation, or permutation thereof.

1. A side-shift assembly for a forklift, comprising:

a carriage mounted on the forklift;

a backplate mounted on the carriage, the backplate capable of lateral adjustment relative to the carriage; and

a fork assembly mounted on the backplate, wherein the fork assembly includes a first fork and a second fork, each of the first fork and the second fork capable of independent lateral adjustment relative to the backplate.

2. The side-shift assembly of claim **1**, wherein the first fork and the second fork are mounted on a rail coupled to the backplate.

3. The side-shift assembly of claim **1**, further comprising a backplate actuator coupled to the backplate, the backplate actuator configured to provide driving force to adjust the backplate.

4. The side-shift assembly of claim **1**, further comprising a fork actuator coupled to the first fork and the second fork, the fork actuator configured to provide driving force to independently adjust the first fork and the second fork.

5. The side-shift assembly of claim **1**, further comprising a first fork actuator coupled to the first fork, the first fork actuator configured to provide driving force to adjust the first fork, and a second fork actuator coupled to the second fork, the second fork actuator configured to provide driving force to adjust the second fork.

6. The side-shift assembly of claim **1**, wherein each of the first fork and the second fork are capable of being independently adjusted laterally relative to one another.

7. The side-shift assembly of claim **1**, wherein the backplate, the first fork, and the second fork are capable of being independent adjusted laterally relative to one another.

8. A side-shift assembly for a forklift, comprising:

a carriage mounted on the forklift;

a backplate coupled to the carriage, the backplate capable of lateral adjustment relative to the carriage;

a backplate actuator coupled to the backplate, the backplate actuator configured to provide driving force to adjust the backplate;

a fork assembly mounted on the backplate, wherein the fork assembly includes a first fork and a second fork, each of the first fork and the second fork capable of independent lateral adjustment relative to the backplate;

a fork actuator coupled to the first fork and the second fork, the fork actuator configured to provide driving force to independently adjust the first fork and the second fork; and

a controller communicatively coupled to the backplate actuator and the fork actuator.

9. The side-shift assembly of claim **8**, wherein the first fork and the second fork are mounted on a rail coupled to the backplate.

10. The side-shift assembly of claim **8**, wherein the first fork is mounted on a first rail coupled to the backplate, and the second fork is mounted on a second rail coupled to the backplate.

11. The side-shift assembly of claim **8**, wherein the fork actuator is selected from a group consisting of an electric actuator, a hydraulic actuator, a pneumatic actuator, a mechanical actuator, and an electromagnetic actuator.

12. The side-shift assembly of claim **8**, further comprising a sensor module mounted on at least one of the first fork and the second fork.

13. The side-shift assembly of claim **8**, further comprising a sensor module mounted on the carriage.

14. The side-shift assembly of claim **8**, wherein each of the first fork and the second fork are capable of being independently adjusted laterally relative to one another.

15. A side-shift assembly for a forklift, comprising:

a carriage mounted on the forklift;

a backplate coupled to the carriage, the backplate capable of lateral adjustment relative to the carriage;

a backplate actuator coupled to the backplate, the backplate actuator configured to provide driving force to adjust the backplate;

a fork assembly mounted on the backplate, wherein the fork assembly includes a first fork and a second fork, each of the first fork and the second fork capable of independent lateral adjustment relative to the backplate, and each of the first fork and the second fork capable of independent lateral adjustment relative to one another;

a fork actuator coupled to the first fork and the second fork, the fork actuator configured to provide driving force to independently adjust the first fork and the second fork; and

a controller communicatively coupled to the backplate actuator and the fork actuator.

16. The side-shift assembly of claim **15**, wherein the first fork and the second fork are mounted on a rail coupled to the backplate.

17. The side-shift assembly of claim **15**, wherein the first fork is mounted on a first rail coupled to the backplate, and the second fork is mounted on a second rail coupled to the backplate.

18. The side-shift assembly of claim **15**, wherein the fork actuator is selected from a group consisting of an electric actuator, a hydraulic actuator, a pneumatic actuator, a mechanical actuator, and an electromagnetic actuator.

19. The side-shift assembly of claim **15**, wherein the backplate actuator is selected from a group consisting of an electric actuator, a hydraulic actuator, a pneumatic actuator, a mechanical actuator, and an electromagnetic actuator.

20. The side-shift assembly of claim **15**, further comprising a sensor module mounted on the carriage.

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