MATERIAL HANDLING SYSTEM

PRIORITY CLAIM

[0001] This application claims priority under 35 U.S.C. §119 to U.S. Provisional Patent Application No. 62/886,602 filed on August 14, 2019. The entire disclosure of U.S. Appl. No. 62/886,602 is hereby incorporated herein by reference.

FIELD OF THE INVENTION

[0002] Embodiments of the present invention generally relate to automated material and article handling systems which can be used in warehouse, storage and/or distribution environments.

BACKGROUND

[0003] Modern material handling systems, such as those used in mail-order warehouses, supply chain distribution centers, and custom-order manufacturing facilities, face significant challenges in responding to requests for inventory articles. In their incipiency, enterprises will generally invest in a level of automation that is at least adequate for current needs. As the scale of an inventory management system expands to accommodate a greater number and variety of articles, however, so too does the cost and complexity of operating it to simultaneously complete the packing, storing, replenishment, and other inventory management tasks for which it is intended.

[0004] Failure to efficiently utilize resources such as space, equipment, and manpower in an inventory management facility results in lower throughput, longer response times, and a growing backlog of unfinished tasks. Greater efficiency may often be achieved, for a time, by incrementally expanding the capacity of the facility's existing automation infrastructure, particularly when that expansion follows a well-conceived plan for growth. Sooner or later, however, a point of diminishing returns is encountered. That is, the achievement of further gains in capacity and/or functionality eventually becomes cost prohibitive as compared to available alternatives, if such gains can be realized at all. When that point of diminishing returns is reached, a facility operator may be forced to abandon pre-existing material handling infrastructure and to replace that infrastructure with a completely new automation platform.

SUMMARY

[0005] The present disclosure provides a number of inventive aspects that relate to material handling and/or storage and retrieval processes.

[0005a] According to an aspect, the present disclosure refers to a method for delivering items to a storage assembly having a plurality of storage locations, comprising the steps of: driving a vehicle along a horizontal surface to a position adjacent a moveable track; operating the vehicle to lift the moveable track; driving the vehicle horizontally to carry the moveable track to a position adjacent the storage assembly; driving the vehicle vertically upwardly along the moveable track to an elevated position; transferring an item between the vehicle and a storage location in the storage assembly while the vehicle is in the elevated position; driving the vehicle vertically down the track after the step of transferring an item.

[0005b] According to another aspect, the present disclosure refers to a material handling system, comprising: a storage assembly having a plurality of elevated storage locations for storing items; a vehicle configured to deliver items to the storage locations and retrieve items from the storage locations, wherein the vehicle comprises: first driving means for driving the vehicle in a horizontal direction; second driving means; and transfer means; a moveable track having an opening configured to receive a portion of the vehicle wherein the moveable track comprises means for engaging the second driving means of the vehicle, wherein the means for engaging cooperates with the second driving means so that driving the second driving means in a first direction is operable to lift the moveable track off the ground and so that driving the second means in a second direction is operable to drive the vehicle vertically upwardly to an elevated position; wherein the vehicle is configured to drive the vehicle along a horizontal surface to a location adjacent the storage assembly; wherein the transfer means is configured to transfer an item between the vehicle and a storage location of the storage assembly while the vehicle is in the elevated position adjacent the storage location.

[0006] According to one example, a method for delivering items to a storage assembly having a plurality of storage locations is provided. The method includes the step of providing a vehicle having a first drive system for driving the vehicle in a horizontal direction and a second drive system. A moveable track is provided having an opening configured to receive a portion of the vehicle. The first drive system is actuated to drive the vehicle along a horizontal surface to a position adjacent the moveable track. The vehicle is aligned with the opening in the moveable track. At least a portion of the vehicle is driven into the opening. The second drive system is actuated to raise the moveable track vertically to lift the moveable track off the ground. The first drive system is actuated to drive the vehicle with the moveable track in a horizontal direction toward the storage assembly. The second drive system is actuated to drive the vehicle

vertically up the moveable track to a position adjacent one of the storage locations. An item is transferred between the vehicle and the one storage location while the vehicle is adjacent the one storage location. Additionally, the second drive system is actuated to drive the vehicle downwardly toward the ground.

[0007] According to another example, a method is provided for delivering items to a storage assembly having a plurality of storage locations. The method includes a plurality of steps, which may include the step of driving a vehicle along a horizontal surface to a position adjacent a moveable track. The method may also include the step of operating the vehicle to lift the moveable track. Optionally, the method includes the step of driving the vehicle horizontally to carry the moveable track to a position adjacent the storage assembly. Additionally, the method may include the step of driving the vehicle vertically upwardly along the moveable track to an elevated position. Further, the method optionally includes the step of transferring an item between the vehicle and a storage location in the storage assembly while the vehicle is in the elevated position. The method may also include the step of driving the vehicle vertically down the track after the step of transferring an item.

[0008] According to another example, a method for delivering items to a storage assembly may include the step of transferring an item from a storage location onto a vehicle, wherein the method comprises the step of driving the vehicle horizontally with the item to deliver the item to a location remote from the one storage location.

[0009] According to yet another example, a method for delivering items to a storage assembly may include a moveable track that comprises a frame configured to receive the vehicle and the method may include the step of driving the vehicle into the frame.

[0010] According to a further example, a method for delivering items to a storage assembly may include the step of positioning a vertical drive of a vehicle in operative engagement with a vertical track of a moveable track.

[0011] According to an additional example, a method for delivering items to a storage assembly may include the step of actuating vertical drive of a vehicle to lower a moveable track after a step of actuating horizontal drive system to drive the vehicle with the moveable track.

[0012] According to another example, a method for delivering items to a storage assembly may include the step of controlling a vehicle to displace a moveable track to releasably connect the moveable track with the storage assembly. Optionally, the step of connecting may comprise releasably connecting the moveable track with the storage assembly to impede displacement of the moveable track relative to the storage assembly along at least one horizontal axis.

[0013] According to a further example, a method for delivering items to a storage assembly may include a moveable track having a connector and the method may include the step of driving a horizontal drive of a vehicle to displace the moveable track vertically to connect the connector of the moveable track with the storage assembly.

[0014] According to an additional example, a method for delivering items to a storage assembly may include the step of controlling a vehicle to disconnect a moveable track from the storage assembly. Optionally, the step of disconnecting comprises vertically displacing the moveable track.

[0015] According to another example, a method for delivering items to a storage assembly may include the step of actuating a vertical drive of a vehicle to raise a moveable track by driving the vertical drive system in a first direction.

[0016] According to a further example, a method for delivering items to a storage assembly may include the step of actuating a vertical drive of a vehicle to drive the vehicle vertically up by driving the vertical drive system in a second direction that is opposite the first direction.

[0017] According to another example, a method for delivering items to a storage assembly may include the step of actuating a vertical drive system of a vehicle to drive the vehicle vertically up while maintaining the orientation of the vehicle relative to the horizon as the vehicle is driven upwardly. Optionally, the step of maintaining the orientation of the vehicle relative to the horizon comprises the step of synchronously driving the vertical drive elements.

[0018] According to another example, a method for delivering items to a storage assembly may include the step of transferring an item between a vehicle and a storage location by actuating a transfer mechanism on the vehicle. Optionally, the step of actuating a transfer mechanism comprises extending a transfer mechanism horizontally toward the one storage location. Optionally, the transfer mechanism may be connected with a horizontal drive system and the step of actuating a transfer mechanism comprises driving the horizontal drive system.

[0019] According to a further example, a method for delivering items to a storage assembly may include the step of actuating a horizontal drive system of a vehicle to drive the vehicle with a moveable track by driving the vehicle horizontally while the moveable track is lifted off the ground. Optionally, the step of driving the vehicle horizontally while the moveable track is lifted off the ground includes the steps of identifying a column of the storage assembly in which the one storage location is located; and aligning the moveable track with the column so that a transfer opening in the moveable track aligns with an opening in the column. Optionally, the step of transferring comprises transferring the item through the transfer opening.

[0020] The present disclosure provides a number of inventive aspects that relate to material handling systems and/or storage and retrieval systems.

[0021] For instance, according to one example, the present disclosure provides a material handling system that includes a storage assembly a vehicle and a moveable track. The storage assembly may have a plurality of elevated storage locations for storing items. The vehicle may be configured to deliver items to the storage locations and retrieve items from the storage locations, wherein the vehicle comprises a first driving assembly for driving the vehicle in a horizontal direction and second driving assembly. The moveable may have an opening configured to receive a portion of the vehicle. Additionally, the moveable track may include an element for engaging the second driving system of the vehicle. The engagement element may cooperate with the second driving system so that driving the second driving system in a first direction is operable to lift the moveable track off the ground and so that driving the second system in a second direction is operable to drive the vehicle vertically upwardly to an elevated position. Optionally, the vehicle is configured to drive the vehicle along a horizontal surface to a location adjacent the storage assembly. Additionally, the vehicle may include a transfer means configured to transfer an item between the vehicle and a storage location of the storage assembly while the vehicle is in the elevated position adjacent the storage location.

[0022] According to another example, the present disclosure provides a material handling system cooperable with a storage assembly having a plurality of storage locations for storing a plurality of items. The system may include a vehicle and a moveable track. The vehicle may include a horizontal drive assembly configured to drive the vehicle horizontally along the ground and a vertical drive assembly configured to drive the vehicle vertically upwardly. The vehicle may also include a transfer mechanism for transferring items between the vehicle and the storage locations. The vehicle may further include a power source for powering the horizontal drive assembly and the vertical drive assembly. The moveable track optionally includes a vertical track cooperable with the vertical drive assembly of the vehicle and a support structure configured to support the vertical track in a vertical orientation. The moveable track may include an opening configured to receive at least a portion of the vehicle. The vertical drive assembly and the vertical track may be configured and positioned so that when the vehicle extends into the opening in the moveable track, the vertical drive assembly engages the vertical track, such that driving the vertical drive in a first direction is operable to raise the moveable track. Optionally, driving the vertical drive assembly in a second direction may be operable to drive the vehicle up the track to an elevated position to facilitate transfer of an item between a storage location and the vehicle. Additionally, the support structure may be configured to support the vehicle when the vehicle is in the elevated position on the vertical track.

[0023] According to a further example, a material handling system may include a vehicle and a moveable track having a support structure that includes a frame forming a column having an opening for receiving the vehicle.

[0024] According to a further example, a material handling system may include a moveable track having a connector for releasably connecting the moveable track with a storage assembly. Optionally, the connector is configured to impede displacement of the moveable track relative to the storage assembly along at least one horizontal axis. Additionally, the connector may be configured so that relative vertical displacement between the moveable frame and the storage assembly connects the connector with the storage assembly. Further, the connector may be configured such that vertical displacement of the connector relative to the storage assembly is operable to disconnect the moveable track from the storage assembly.

[0025] According to a further example, a material handling system may include a vehicle having a vertical drive system for driving the vehicle vertically up a moveable track and the vertical drive assembly may be configured to maintain the orientation of the vehicle relative to the horizon as the vehicle is driven upwardly. Optionally, the moveable track includes a plurality of track

sections extending vertically upwardly and the vertical drive assembly includes a plurality of vertical drive elements interconnected so that operating the vertical drive assembly synchronously drives the vehicle up the track sections to maintain the horizontal orientation of the vehicle.

[0026] According to a further example, a material handling system may include a vehicle having a horizontal drive assembly for driving the vehicle in a horizontal direction and a transfer mechanism. The transfer mechanism may be connected with one of the horizontal drive assembly so that driving the horizontal drive assembly is operable to drive the transfer mechanism away from the vehicle toward a storage location. Optionally, the system includes a clutch for selectively engaging and disengaging the transfer mechanism with the horizontal drive assembly.

[0027] According to another example, a material handling system may include a vehicle having a vertical drive system and a moveable track having a support structure. The vertical drive may project outwardly from the vehicle and the support structure may include gaps configured to align with the vertical drive system to facilitate the vehicle driving into the support structure. Optionally, the moveable track includes a vertical track and the vertical track has an upper section and a lower section each including a plurality of teeth configured to cooperate with the vertical drive assembly. The upper section and lower section may have similar pitch between teeth and the lower section may have gaps between adjacent teeth to provide clearance to facilitate the vertical drive driving through the lower section. Optionally, the vertical drive assembly includes a plurality of spur gears having a tooth pitch and each spur gear is rotatable about an axis. The axes of the spur gear may be substantially parallel. Additionally, the spacing between the teeth of the lower section may provide sufficient clearance for the teeth of the spur gears to pass between the gaps when the spur gears translate horizontally along a line that is parallel to the axis of rotation of the spur gears. Optionally, the spur gears and the vertical track are configured and positioned so that an addendum circle of the spur gears overlaps with the addendum line of the teeth in the track. Additionally, the vertical track may include an upper section and a lower section wherein the upper section has an upper tooth profile having an upper root and an upper dendendum and the lower section has a lower tooth profile having a lower root and a lower dendendum that is greater than the upper dedendum so that the lower root of the teeth extends inwardly away from the vertical drive assembly a greater distance than the upper root.

BRIEF DESCRIPTION OF THE DRAWINGS

[0028] So that the manner in which the above recited features of the present invention can be understood in detail, a more particular description of the invention, briefly summarized above, may be had by reference to embodiments, some of which are illustrated in the appended drawings. It is to be noted, however, that the appended drawings illustrate only typical embodiments of this invention and are therefore not to be considered limiting of its scope, for the invention may admit to other equally effective embodiments.

[0029]

[0030]

[0031] FIG. 1 is a perspective view of a material handling system;

[0032] FIG. 2A is a perspective view of an automated guided of the material handling system illustrated in FIG. 1;

[0033] FIG. 2B is a plan view of the vehicle illustrated in FIG. 2A;

[0034] FIG. 2C is a bottom view of the vehicle illustrated in FIG. 2A;

[0035] FIG. 2D is a front elevation view of the vehicle depicted in FIG. 2A;

[0036] FIG. 2E is a rear elevation view of the vehicle depicted in FIG. 2A;

[0037] FIG. 2F is a side elevation view of the vehicle depicted in FIG. 2A;

[0038] FIG. 2G is a plan view of the vehicle illustrated in FIG. 2A with a portion of a rack of the system illustrated in FIG. 1;

[0039] FIG. 2H is a cross-sectional taken across line II-H in FIG. 2G;

columns 810, each of which includes a plurality of storage locations. The items that are handled by the system may be stored directly in the storage locations. Alternatively, the items may be stored in bins or totes 55 and the storage locations 820 may be configured to store the totes 55 as shown in FIG. 1 and 7-9. Accordingly, it should be understood that unless stated otherwise in the following description, when a tote is mentioned, the term tote is broad enough to include a container for containing one or more items as well as simply being an item that is not necessarily contained in a container. Although the present system is described as using totes, it should be understood that any of a variety of storage mechanisms can be used, such as pallets or similar platforms.

Vehicles

[0076] Figures 2A-2I illustrate details of one of the vehicles 200 that are shown in FIG.1. As noted above, if the system incorporates vehicles, the structure of the vehicle may vary. Accordingly, it should be understood that each of the vehicle's features discussed below are optional features that may be varied or eliminated depending on the application.

[0077] The vehicles 200 may be autonomous systems that include an onboard power supply for driving the vehicle. The vehicles may also include a communication system for wirelessly receiving and transmitting control signals between each vehicle and a control element, such as the central controller 450. In this way, the vehicle may receive control signals regarding the location for retrieving an item and the location to which the vehicle is to deliver the item.

[0078] Referring now to FIGS. 2A to 2I, there is shown an automated guided vehicle 200 constructed in accordance with embodiments of the present disclosure and adapted to perform inventory management tasks in the material handling systems depicted in FIG. 1. Each delivery vehicle may be an automated guided vehicle having a first motorized drive system and a second motorized drive system, as well as an onboard power supply.

[0079] As discussed further below, the vehicle may include a horizontal drive assembly for driving the vehicle 200 in a horizontal direction. The horizontal drive may be configured to drive the vehicle along a track or along an open horizontal surface, such as a floor. For instance, one option for a horizontal drive includes a plurality of rotatable elements, such as wheels or rollers. One or more drive mechanisms may be provided for turning the rotatable elements. Additionally, the rotatable elements may turn from side to side to steer the vehicle.

[0080] The vehicle illustrated in Figures 2A-4E includes a horizontal drive assembly for driving the vehicle 200 in a horizontal direction. The horizontal drive may be configured to drive the vehicle along a track or along an open horizontal surface, such as a floor. For instance, one option for a horizontal drive includes a plurality of rotatable elements, such as wheels or rollers. One or more drive mechanisms may be provided for turning the rotatable elements. Additionally, the rotatable elements may turn from side to side to steer the vehicle.

[0081] As noted above, the vehicle 200 may have any of a variety of steering mechanisms for controlling the direction of travel of the vehicle. For example, an optional steering mechanism is a zero-turn mechanism that can turn the vehicle without substantially moving forwardly. Optionally, the zero-turn mechanism provides a means for turning the vehicle about a vertical axis extending through the vehicle.

[0082] The zero-turn mechanism comprises a linkage that allows the wheels or rollers on one side of the vehicle to rotate at a different speed than the wheels or rollers on the opposing side of the vehicle. Optionally, the linkage allows the wheels or rollers on one side of the vehicle to rotate in different directions than the wheels or rollers on the opposing side of the vehicle. In this way, by varying the speed and/or rotational direction of the wheels on one side of the vehicle relative to the speed and/or rotational direction of the wheels on the opposing side of the vehicle, the zero-turn mechanism changes the direction of travel to steer the vehicle.

[0083] For instance, as illustrated in FIGS. 2A-4E, the vehicle may have a horizontal drive formed of a plurality of rollers 252, 254, 256 that are rotatable around a first axis, such as around an axle. Additionally, each of the rollers 252,254,256 may be constrained to rotation about a single axis. For example, the horizontal drive may include a pair of central rollers 252a,b and first and second sets of outer rollers 254a,b, 256a,b. The first set 254a,b may be positioned forwardly of the central rollers 252a,b while the second set of rollers 256a,b may be positioned rearwardly of the central rollers. Optionally, each set of outer rollers 254a,b and 256a,b may include a pair of rollers on each side of the vehicle as shown in Fig. 2E.

[0084] With particular reference to FIGS. 2C and 2F, the details of the horizontal drive system will be described. However, it should be understood that a variety of elements and configurations can be incorporated to provide a horizontal drive system. Accordingly, the following description is merely one example of a horizontal drive system. As shown in FIG. 2C, vehicle 200 further includes a second drive system which is dimensioned and arranged to propel vehicle 200 upon an underlying support surface -- such as the floor of a warehouse or

apart axles 215 (see FIG. 2F), so that two of the gears are disposed along the forward edge of the vehicle and two of the gears are disposed along the rearward edge of the vehicle.

[0088] Turning now to FIGS. 3A and 3B, FIG. 3A is a forward elevation view of the exemplary automated guided vehicle of FIGS. 2A-2F, taken in cross section across line IIIA-IIIA in FIG. 2A, and FIG. 3B is bottom plan view of the exemplary automated guided vehicle FIGS. 2A-2F. As best seen in FIG. 3A, the first drive system further includes a pair of inner idler pulleys 224a, 224b, and a pair of outer pulleys 222a, 222b that, when driven by respective belts 226a, 226b, cause the geared wheel 220 mounted on the same shaft to rotate and thereby propel the vehicle 200 in a vertical direction within a column (along the drive surfaces of the track). The idler pulleys 224a and 224b rotate freely relative to the axles and maintain the tension of the belts 226a and 226b. Each of the outer pulleys 222a and 222b is fixed relative to the axle 215 onto which it is mounted. The first drive system further includes a pair of counter-rotating gears 228a, 228b which are rotated by first onboard motor 230 (FIG. 3B). So driven, belts 226a and 226b drive pulleys 222a and 222b, respectively and this rotary motion of the pulleys 222a and 222b causes rotation of the geared wheels 200 mounted on a corresponding shaft 215. Accordingly, when the vehicle 200 is moving vertically, the geared wheels 220 carry the weight of the vehicle and any item(s) thereon.

[0089] In the embodiments of FIGS. 3A and 3B, the drive axles 215 are rotatably mounted within housing 232 such that their spacing remains fixed relative to one another. As will be described shortly, the fixed spacing between axles 215 in accordance with some embodiments necessitates an alignment step with the guiding system (e.g., tracks) before entry of a vehicle into the columns which extend between the vertical arrays of storage areas 115 (FIG. 1) and within which the guide system is mounted.

[0090] In alternate embodiments (not shown), elements of the first drive system, as geared wheels 200 and axles 215 may be mounted within housing 232 in a manner that allows them to move inwardly so as to relax any requirement for precise alignment while also eliminating the risk of any damage to either the geared wheels 200 or to the guiding system. In embodiments of the latter type, vehicles intended to carry substantial loads may require motor driven means for temporarily reducing the spacing between axles 215 and thereby accommodate entry of a vehicle 200 into the column(s) between storage areas.

[0091] With continued reference to FIGS. 3A and 3B, it will be seen that first motor 230 is operatively connected with the gears 228a and 228b to drive belts 226a, 226b and rotate both

optionally may be positioned to form rows or aisles 850. For instance, a first rack 800a may be spaced apart from a second rack 820b so that an aisle 850a is formed between the two racks. In particular, the first rack may be substantially parallel to the second rack to form an aisle having a substantially uniform width. Additionally, the system may include a plurality of racks forming a plurality of aisles 850. Although the aisles 850 are illustrated in FIG. 7 as being parallel, it should be understood that if the system incorporates a plurality of racks 800, the racks may be arranged in a variety of configurations and if the system includes a plurality of aisles 850, the aisles need not be parallel.

One of the inventory management tasks assigned to a vehicle 200 may be to retrieve items from the storage locations 800. This task can be viewed as a series of sub-tasks which include exiting the current or starting location of the vehicle, traversing a path which takes the vehicle between the starting location to an intermediate destination adjacent a point of entry into the array of storage locations and, at the intermediate destination, aligning the vehicle 200 with the point of entry. As a further sub-task of the retrieval task, the aligned vehicle enters the array and maintains its alignment until it reaches the column within which the vehicle is positioned, is operated to climb, according to yet another sub-task, until it reaches a target one of the storage areas 820. As further sub-tasks of the retrieval process, a transfer mechanism of the vehicle is operated to retrieve an item, descend within the column until the vehicle rests upon a support surface, and then exit the array of storage location. As a final sub-task of the retrieval operation, the vehicle 200 proceeds along a path to an output station 500, where an operator can retrieve the item from the vehicle.

[00167] Optionally, the system includes an automated element for storing and retrieving totes from the storage locations. One such automated element is an autonomous vehicle. For example, as discussed further below, the automated element may include a plurality of autonomous vehicles 200. Additionally, the automated vehicles 200 may be configured to transport the totes 55 to workstations 500. At the workstation 500, one or more items may be removed from a tote on one of the vehicles 200. In one embodiment, a human operator may remove an item from the vehicle. However, it should be understood that an automated mechanism may remove the item from the vehicle. Accordingly, it should be understood that the operator that handles items at the workstation(s) 500 may be a human operator or an automated mechanism or a combination of the two.

[00168] The system 10 and/or various components of the system may be controller by a central controller 450, such as a microcomputer. The central computer may receive signals from

various elements, such as sensors and control various aspects of the system based on signals received from the various components. The central controller may also store data regarding the location of various items to be retrieved from the system. Additionally, the central controller may include data regarding the identification of items to be retrieved, such as a number of items to fill customer orders, as well as the quantify of such items. In this way, the central controller may control and coordinate the operation of various elements to schedule the retrieval and processing of a variety of items from the storage locations.

[00169] Figure 7 is a plan view depicting a part of an inventory management system 800, which may form part of the system shown in FIG. 1 and utilizes autonomous vehicles 200 to transfer containers 55 of inventory items back and forth between a picking area and a vertical array of storage locations 820. The system may incorporate a plurality of vehicles 200 and the array of storage locations 820 as elements of an automated storage and retrieval system (AS/RS). The vehicles 200 may be configured in the same manner as the vehicles 200 described above. However, it should be understood that the vehicles may have modifications for different tasks within the system if desired.

[00170] In any event, and turning now to FIGS. 1 and 7-13, a system for storage and retrieval of items within an array of storage locations 820 will now be described in detail. Turning first to FIG. 1 and 7, a plurality of automated guided vehicles 200a to 200f are depicted being operated within or about a rack structure 800. As in previously described embodiments, the vehicles perform various item replenishment and/or item retrieval tasks and in this instance, some of those tasks involve retrieving containers from or returning the containers (or totes) to storage locations 820.

[00171] As discussed above, the system may include a plurality of racks that are spaced apart to form one or more aisles 850. Optionally, a track 840 may be positioned along one or more of the racks. For instance, the track may be fixedly connected to the racks 800. Additionally, the track may be configured to guide vehicles vertically so that the vehicles may be conveyed up and down the column to the storage locations in the column. Additionally, it may be desirable to position a first track along a rack on one side of the aisle, such as along rack 800a and a second track along a rack on the opposite side of the aisle, such as along rack 800b. The vehicles 200 may be configured so that the vehicle travels in the aisle 850a traveling with one side of the vehicle travelling vertically along a track 840a on rack 800a while simultaneously a second side of the vehicle travels vertically along a track 840b on rack 800b.

[00179] Figure 10 illustrates vehicle 200b moving along path 860 that is parallel to the aisle and vehicle 200c moving along path 860' that is parallel to path 860. Preferably path 860' has a centerline that is spaced apart from the posts 815 adjacent the aisle by a distance that is greater than half the length "L" of the vehicle 200 (see FIG. 2B). Similarly, preferably path 860 has a centerline that is spaced apart from the posts at the rearward edge of the column remote from the aisle 850 by a distance that is greater than half the length of the vehicle.

[00180] Optionally, the paths 860, 860' under the rack that are parallel to the aisle may be spaced apart to provide a gap to allow a first vehicle travelling along path 860 to pass a second vehicle positioned along path 860', such as a vehicle travelling in an opposite direction along path 860'. For instance, path 860 may be spaced apart from path 860' by a distance greater than the width "W2" of vehicle 200 (see FIG. 2B).

[00181] Additionally, as discussed above, the vehicles may change direction by rotating about a vertical axis of rotation that passes through the vehicle. In particular, the axis of rotation may pass through the center of the vehicle. The columns 810 preferably have a depth sufficient to facilitate the vehicle rotating about the axis of rotation while the vehicle is positioned in the column under the rack. Specifically, each of path 860, 860' is preferably spaced apart from the posts 815 a distance greater than the distance from the axis of rotation to each of the corners of the vehicle.

[00182] When the vehicle turns under the rack 800, the vehicle may turn in any of a variety of angles. Optionally, the vehicle may turn in increments of 90 degrees. In particular, optionally, the vehicle turns either 90 degrees or 270 degrees after exiting the aisle so that the vehicle travels parallel to the aisle under the rack after climbing the track in the aisle.

[00183] Figure 9 is a side elevation view depicting the rack structure 800 that includes a plurality of columns 810a-810f populated within a number of containers or totes, including totes T_a, T_b, T_c and T_d. A plurality of vehicles operating to perform various item replenishment and/or item retrieval tasks as part of the inventory management system. Vehicle 200a is shown having entered the leftward most drive column 810a. In this regard, and with reference now to FIG. 10, it will be seen that the structure 800 may incorporate an array of parallel guide rails, as rails R1 and R2, which define a gap g_G between them. The gap is dimensioned and arranged to receive corresponding alignment structures on the vehicles to enable entry, exit and reorientation of the vehicles without damage to each other and the rack structure as discussed further below.

[00184] Optionally, the system may also include one or more guides 880 to guide or align the vehicles as they travel. For instance, referring to FIGs. 2E and 10, the guide 880 may include a channel or groove and the vehicle may include a corresponding guide element 235 that cooperates with the guide 880 to control movement of the vehicle 200. One example of a guide element is a follower 235. The follower may be any element configured to engage with or cooperate with the guide 880. In the present instance, the vehicle 200 includes a central follower 233 that includes a rotatable element such as a bearing that rotates about a vertical axis. Optionally, the follower 233 includes a shaft so that the follower projects away from a surface of the vehicle, such as downwardly from a lower surface of the vehicle. The central follower 233 engages the channel in the guide 880 to constrain horizontal movement of the vehicle.

[00185] Optionally, the vehicle may also include one or more lateral guide member 235. The lateral guide members 235 may cooperate with an outer surface of the guide 880 to constrain movement of the vehicle. For instance, guides 880 may comprises circular guides having a circumferential surface for guiding the rotation of the vehicles. The vehicle may have a pair of lateral guide members 235 spaced apart from one another a distance equal to the diameter of the circumferential surface of the guide. In this way, the lateral guides 235 engage the circumferential surface of the guide to constrain the vehicle to rotational motion.

[00186] Referring to FIG. 10, optionally the guide 880 includes a plurality of intersecting guideways. For instance, guide 880 may include a first guideway 882 in the form of a groove or channel having walls spaced apart a distance substantially similarly to the width of central follower 233 of the vehicle. The first guideway 882 may be oriented so that it extends parallel to pathway 860. Additionally, guide 880 may have a second guideway 884 in the form of a groove or channel have walls spaced apart a distance substantially similar to the width of the follower 233 of vehicle 200. The second guideway 884 may be oriented so that it extends transverse pathway 860. In the present instance, guideway 884 extends substantially perpendicular to pathway 860. In this way, the first and second guideways 8828, 884 of guide 880 extend in a linear direction that is preferably parallel or perpendicular to the aisle 850.

[00187] Guide 880 may optionally include a non-linear guideway. For instance, the perimeter of the guide may form a non-linear guide surface identified as 886 in FIG. 10. Specifically, the guide may have a substantially circular profile forming a circumferential bearing surface. The diameter of the circular profile may have a diameter corresponding to the distance between lateral guides 235 of the vehicle 200 (see FIG. 2D).

the lower section is greatest and the spacing between adjacent teeth at the upper part of the lower section is at a minimum and the clearance gradually decreases from the maximum to the minimum.

[00200] Optionally, the posts 815 may have a variable width to facilitate the vertical drive passing through the opening between the posts 815. For instance, as described above, posts 815 may have a first width so that the edge E3 of the post extends beyond the root of the teeth of the track. Additionally, the lower portion 816a,b of the post 815 may have a reduced width relative to the upper portion of the post. Specifically, the post may have a reduced width so that the edge of the post terminates below the root of the tooth. In this way, the lower portion of the post has a width that is narrower than the upper portion of the post. Similarly, the distance between lower post 816a and lower post 816b is greater than the distance between edge E2 and edge E3. Additionally, the opening to the column between lower portion 816a and 816b is greater than the widest width W2 of the vehicle.

[00201] Configured as described above, the vertical drive 220 may optionally be configured to pass through openings in the track so that the vertical drive is aligned with the track. After the vertical drive is aligned with the track, the vertical drive is positioned to cooperate with the track to raise the track and/or to climb the track as described further above.

[00202] As noted above, a central controller 450 may provide control signals for controlling the vehicles 200. For instance, the central controller may control the operation of a vehicle to follow a path through the rack to retrieve a tote 55 from a storage location 820 in one of the columns 810 in the rack 800. The vehicle may follow a path along the ground to align the width of the vehicle with a path that extends through an opening between two vertical posts 815 of the rack 800. The vehicle may travel along the path crossing through a plurality of columns in the rack. Optionally, the central controller may provide signals to control a second vehicle so that the second vehicle travels along a second path parallel to the first path and under the same rack as the first vehicle so that the second vehicle passes the first vehicle under the rack.

[00203] After the vehicle passes through a plurality of columns under the rack, the vehicle reaches the column in the rack the select storage location is located. The central controller provides signals to stop the forward progress of the vehicle along the path. The central controller provides signals to turn the vehicle under the rack to align the vehicle with an opening in the column. After turning, the vehicle advances along a path parallel to the depth of the column so that the vehicle passes through the opening in the column and into the aisle.