processes of a specific apparatus, such as a special purpose computer or a similar special purpose electronic computing device. In the context of this specification, therefore, a special purpose computer or a similar special purpose electronic computing device is capable of manipulating or transforming signals, typically represented as physical electronic or magnetic quantities within memories, registers, or other information storage devices, transmission devices, or display devices of the special purpose computer or similar special purpose electronic computing device.

[0060] Reference will now be made in detail to exemplary embodiments of the present invention, examples of which are illustrated in the accompanying drawings. Wherever possible, the same reference numbers will be used throughout the drawings to refer to the same or like parts.

[0061] Referring now to the figures in general and to FIGS. 1A-1B specifically, a material handling apparatus is designated generally 10. The apparatus 10 is configured to sort items into separate groupings and to retrieve the items once a grouping is completed. The apparatus 10 optionally includes a sortation system 50 for sorting items to a plurality of locations, such as a plurality of bins 45. The apparatus also includes a retrieval system 300 for automatically retrieving a bin from a storage location 80 of the sortation system once items have been sorted to the bin. Optionally, the retrieval system 300 may also be configured to replace the full bin with an empty bin at the storage location. Additionally, the retrieval system 300 may be configured to convey the full bin to a workstation or conveyor system so that the full bin can be further processed, such as by being prepared for shipment.

[0062] The apparatus 10 may be incorporated into an overall warehouse automation system 5, which may include one or more systems 10 for sorting and retrieving items. The system 5 may include an input conveyor system 30 for feeing bins 45 to each apparatus 10. For instance, the input conveyor may convey bins ~~full~~ of items to be sorted to an input station of the sortation system 50. Additionally, the system 5 may include an output conveyor 32 for conveying bins away from the sortation systems after the bins have been filled with sorted items. In particular, each sortation apparatus 10 may include a retrieval system 300 that can transfer bins 45 from the sortation system

extend across the other half of the track. As shown in Fig. 9E, the drive surface 120 may be formed on an inner wall of the track and the opposing outer wall may be a generally flat surface parallel to the guide surface 122 of the inner wall.

[0088] As described above, the track may include a plurality of vertical legs 112 extending between the horizontal upper and lower rails 114, 116. An intersection may be formed at each section of the track at which one of the vertical legs intersects one of the horizontal legs. For instance, each intersection may include a pivotable gate 125 having a smooth curved inner race and a flat outer race that has drive surfaces that correspond to the drive surfaces 120 of the track. The gate 125 may pivot between a first position and a second position. In the first position, the gate 125 may be closed so that the straight outer race of the gate is aligned with the straight outer branch of the intersection. In the second position, the gate 125 may be open so that the curved inner race of the gate is aligned with the curved branch of the intersection.

[0089] A central controller 20 is configured to control operation of the gates 125 in response to the locations of each vehicle 200 and the path along which each vehicle is to travel. Specifically, the central controller is configured to provide signals for each gate to actuate the gate to either the open or closed position.

Sortation Vehicles

[0090] As noted above, the system may include any of a variety of sortation elements. One exemplary system described herein utilizes one or more sortation vehicles 200. Referring to Figs. 10-11, the details of the sortation vehicle 200 will be described in greater detail. Each sortation vehicle 200 may be a semi-autonomous vehicle having an onboard drive system, including an onboard power supply. Each vehicle optionally includes a mechanism for loading and unloading items for delivery. An exemplary vehicle is illustrated and described in U.S. Pat. No. 7,861,844, the entire disclosure of which is incorporated herein by reference.

[0091] As discussed further below in detail, the vehicle includes a mechanism for driving the vehicle 200 along the track 100. The drive mechanism may include any of a variety of elements. In the present instance, the drive mechanism includes a plurality of wheels 220 that engage the track 100.

[0092] Additionally, the vehicle 200 optionally incorporates a mechanism for loading an

present instance, the power supply is made up of one or more ultracapacitors.

[00101] The central controller 20 may control operation of the sortation vehicles 200 to direct the vehicles to an appropriate bin 45. Specifically, the central controller is configured to receive data from a variety of sensors along the track and on the vehicles in addition to data received regarding the appropriate bin to which an item is to be delivered. Based on the data received by the central controller, the central controller directs the vehicle to the appropriate bin. At the appropriate bin 45, the vehicle discharges an item into the bin. The central controller may provide a variety of control signals to control the vehicle. For instance, the central controller may provide control signals to actuate the gates to direct the path that the vehicle follows. Additionally, the central controller may provide signals to selectively advance the vehicle based on the location of other vehicle in the system.

RETRIEVAL VEHICLES

[00102] Figures 12-15 illustrate details of one of a retrieval vehicle 310 that can be incorporated into the retrieval system 300. As noted above, if the system incorporates vehicles, the structure of the vehicle may vary. Accordingly, it should be understood that each of the features of the vehicle 310 that are discussed below are optional features that may be varied or eliminated depending on the application.

[00103] The retrieval vehicles 3100 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 20. 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.

[00104] The vehicle illustrated in Figure 12 includes a horizontal drive assembly 320 for driving the retrieval vehicle 310 in a horizontal direction. The horizontal drive 320 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.

[00105] Alternatively, as illustrated in Figures 13-15, the vehicle may have a horizontal drive 320 formed of a plurality of rollers 322, 323, 324 that are rotatable around a first axis, such as around an axle. Additionally, the rollers 322, 323, 324 may be constrained to rotation about a single axis. For example, in the embodiment illustrated in Figs. 13-15, the horizontal drive 320 includes a pair of central rollers 324 and first and second sets of outer rollers 322, 323. The first set 322 is positioned forwardly of the central rollers while the second set of rollers 323 is positioned rearwardly of the central rollers 324. The outer rollers 322, 323 may include rollers spaced apart along the length of a horizontal axle so that each set of outer rollers includes a first roller 3232 on one side of the vehicle and a second roller 3232 on an opposite side of the vehicle as shown in Fig. 14. Additionally, as shown in Fig. 14, each set of outer rollers may include a pair of rollers 323 on each side of the vehicle.

[00106] As noted above, the retrieval vehicle 310 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.

[00107] 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.

[00108] Optionally, the system may also include one or more guides to guide or align the vehicles as they travel. For instance, the guide may include a channel or groove and the vehicle may include a corresponding guide element that cooperates with the guide to control movement of the retrieval vehicle 310. One example of a guide

vehicle or to transfer a bin off of the vehicle. Additionally or alternatively, the transfer mechanism may include one or more displaceable pins 352 and a drive element for displacing the pins 352. For instance, optionally, the transfer mechanism 350 includes two drive elements in the form of endless carriers such as a drive belt or as shown drive chains 354. Optionally, each pin 352 projects or extends inwardly toward the longitudinal center line of the vehicle. The transfer mechanism is preferable configured to cooperate one of the bins to releasably engage the bin. For example, in the present instance, the pins 352 are configured to mate with a recess on the bin so that the transfer mechanism can engage the bin. Flowever, it should be recognized that the transfer mechanism may include any of a variety of elements for engaging items to be transferred onto of off of the vehicle.

[00117] The vehicle includes one or more drive elements for driving the transfer mechanism. Optionally, the vehicle includes one or more motors that drive the transfer mechanism 350. For instance, one or more motors of the vehicle drive system may drive the chains 354 to selectively move the chains and pins 352 toward or away from storage locations, such as one of the bins 45 in the sortation system 50.

[00118] As the vehicle approaches a storage location to retrieve a bin, the chains may drive the displaceable pins 352 toward the storage location so that the pins underlie a groove or notch in the bottom of the bin. The vehicle travels a small distance upward until the pins 352 are disposed with the groove or notch of the bin. The chain 354 then reverses so that the pins 352 move away from the storage location. Since the pins engage the bin within the notch, when the pins move away from the storage location, the pins pull the bin onto a surface of the vehicle. In this way, the transfer mechanism 350 is operable to retrieve items from a storage location. Similarly, to transfer an item to a storage location 80, the chains 354 of the transfer mechanism 350 drives the pins 352 toward the storage location until the item is in the storage location. The vehicle then moves downwardly to disengage the pins from the bin, thereby releasing the bin.

[00119] The retrieval vehicle 310 may include a separate drive element for driving the transfer mechanism 350. Alternatively, the transfer mechanism may be interconnected with one of the horizontal or vertical drive elements of the vehicle. Specifically, the transfer

vehicles may be conveyed up and down the track to retrieve a full bin. The track may be formed as one or move columns 400 positioned adjacent the storage locations. For instance, the retrieval track may include one or more columns 400 of vertical tracks 420 configured to cooperate with the retrieval vehicles 310 so that the retrieval vehicles can ascend to the storage locations 80 of the sortation system 50.

[00127] As shown in Figs. 2-5 and 16-20, the retrieval system 300 may include a moveable track 400 configured to guide the retrieval vehicles 310 to retrieve a full bin 45. Since the bins may be located in a plurality of vertically spaced apart storage locations, the moveable track 400 may be formed as a vertical track so that the retrieval vehicles can ascend the track. Optionally, the track includes a plurality of tracks forming a column and the vehicle is configured to drive vertically within the column to retrieve a full bin. Additionally, the column may be configured so that the vehicle may raise and lower the track while the vehicle is positioned within the column 400 as discussed further below.

[00128] Referring to Figs. 16-21 , a moveable retrieval column configured to cooperate with the retrieval vehicles 310 is designated generally 400. The retrieval column 400 may be a lift such as an elevator that includes a powered element for lifting the retrieval vehicle. Alternatively, the structure may include a guide or track configured to cooperate with the vehicle to raise the vehicle without an externally powered mechanism. For instance, the retrieval column 400 may include a track 420 configured to cooperate with the vertical drive 340 of the retrieval vehicle. The vehicles may drive up the track 420 to lift the vehicle to the desired storage location in the sortation system.

[00129] The retrieval column 400 may be moveable so that the structure can be moved to different storage locations or columns of the sortation storage racks 60, 62. Further still, optionally, the retrieval column 400 is configured to cooperate with the retrieval vehicle 310 so that the vehicle can lift the retrieval column vertically and convey the retrieval column horizontally along a path toward a storage location, such as along a path toward one of the columns of the sortation racks 760, 762. In this way, the vehicle may be configured to move the track vertically or horizontally to a desired location and then climb the track to retrieve a full bin.

[00130] Referring to Figs.16-21, the moveable retrieval column 400 will now be described in greater detail. The retrieval column 400 includes a plurality of track elements for guiding the retrieval vehicle. Additionally, the retrieval column may include an optional transfer assembly that is separate from the vehicle. The optional transfer assembly is operable to engage a bin 45 in one of the storage locations 80 and transfer the bin onto the vehicle. The retrieval column may also include a storage mechanism for storing one or more bins while the retrieval vehicle retrieves a full bin or delivers an empty bin to an empty storage location.

[00131] The moveable track includes a support structure forming a vertical column. The column includes a plurality of spaced apart vertical posts 410a,b,c,d. The posts are generally parallel to one another and spaced apart to form a column having a length and width corresponding to the length and width of the vehicle. In particular, the vertical posts are spaced apart so that post 410a and 410b form an opening at least as wide as the width of the vehicle. Post 410c is parallel to post 410a and spaced apart from post 410a a distance at least as long as the approximate length of the vehicle. Post 41 Od is parallel to post 410b and 410c and together with post 410c forms an opening that forms a discharge opening for transferring items between the vehicle and a storage location. The moveable column 400 may include a plurality of horizontal rails 412 interconnecting the posts 410a-d and or cross brackets connecting the posts to form a free-standing structure.

[00132] The moveable column 400 may also include a structure that cooperates with the vertical drive 34220 of the vehicle so that the vehicle can climb upwardly. For instance, the moveable column may include one or more track elements configured to cooperate with the vehicle to allow the vehicle to climb upwardly. Optionally, the track elements may include a plurality of teeth vertically spaced apart along the track. The track may have teeth spaced at a uniform pitch to cooperate with the climbing gears 220 of the vehicle. Although the track 420 is described as having a plurality of teeth, it should be understood that the track can be any of a variety of structures configured to permit the vehicle to climb upwardly. Accordingly, the term track may mean any guide

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

[00140] Configured as described above, the vertical drive 340 may optionally be configured to pass through openings in the track 420 of the retrieval column 400 so that the vertical drive 320 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 retrieval column 400 and/or to climb the retrieval column as described further above.

[00141] Optionally, the moveable track 400 may incorporate one or more connector or retainer 440 that releasably connects the moveable track with the sortation system 50. Optionally, the sortation system 50 may include a mating connector 150 that matingly engages the connector 440 on the moveable rack. The connectors 150, 440 may be any of a variety of mechanical connectors. In the present instance, the connectors 150 may be configured as a hanger to cooperate with connector 440 are configured so that relative vertical displacement of the column relative to the sortation system connects the two connectors. Optionally, relative vertical displacement of the column relative to the sortation system in the reverse direction releases the two connectors.

[00142] Referring to Figs. 2-5 and 33-35, the details of a releasable connector or retainer 440 will be discussed in greater detail. The retainer 440 is configured to cooperate with an upper connector 150 on the sortation system 50 to align the retrieval column 400 relative to the sortation system 50. The retainer 440 optionally includes one or more pins that fit into recesses or grooves of the upper connector 150. For example, the upper connector 150 may include a first v-groove 152 for aligning the retrieval frame in a first direction and a second v-groove 154 for aligning the retrieval frame in a second direction that is orthogonal to the first direction. As shown in FIGS. 3~~4~~6-3~~5~~7, the v-grooves may have a rounded root so that the grooves form more of a u-shape. Either way, the upper connector 150 comprises grooves having converging tapered walls that guide the retainer 440 into a particular location.

[00143] In this way, one or more connectors optionally interconnect the retrieval column 400 with the sortation system to impede lateral displacement of the retrieval column relative to rack 70, 72 of the sortation system. It should be noted that the

impede movement of the bin off of the shelf. In this way, the stop prevents the bin from inadvertently falling off the front edge of the shelf.

[00164] The stop 84 is displaceable between a raised position and a lowered position. In the raised position the stop engages the bin to impede movement of the bin relative to the shelf. In the lowered position the bin is free to move along the shelf.

[00165] The stop may be a simple lever, however in the present instance, the stop 84 is a compound mechanism having an actuator arm connected with the stop 84. The actuator arm 90 is pivotable about a pivot axis and has a first end 92 configured to engage the transfer head to actuate the stop 84. The actuator arm 90 has a second end 94 having a flange configured to engage the stop 84. The stop 84 may be a pivotable arm that extends across the width of the shelf 82. The stop 84 may have an extension that projects downwardly forming a first engagement surface 87 and a second engagement surface 88. Additionally, the stop may pivot about pivot axis 95. Further, a plurality of biasing elements may bias the stop toward the raised position.

[00166] Referring to Figs. 38 and 40A-40C, the operation of the stop will be described. As the transfer head 470 is displaced toward the extended position, an actuation surface, such as the face of the transfer head 472, engages the actuation arm 90 of the stop. The transfer head 470 displaces the actuation arms from a first position shown in Fig. 40C to a second position shown in Fig. 40A. As the actuator arm is displaced from the first to the second position, the second end of the actuator arm engages the first~~second~~ engagement surface 8~~7~~8 of the stop arm 84 to drive the stop into the lowered position as shown in FIG. 40A. Once the stop is lowered, the transfer head 470 pulls the bin onto the vehicle 310 as discussed above. As the transfer head 470 moves away from the storage location, the face of the transfer head disengages the actuator arm 90. Biasing elements bias the actuator arm toward the first position, so that the second end of the actuator arm engages the second~~first~~ engagement surface or flange 8~~8~~7 of the stop to drive the stop as shown in FIG. 40B into the raised position as shown in FIG. 40C.

[00167] In this way, in addition to extending to engage a bin in the storage location, the transfer head is operable to actuate a stop to release the bin from the storage location.

[00168] It may be desirable to retrieve a plurality of full bins and store the bins in the retrieval column and then deliver all of the full bins at once by driving the column to an input/output station. Accordingly, referring to Figs. 5 and 41 -43C, the system may include a bin retainer 600 for retaining bins in the retrieval column. Specifically, the bin retainer may include a plurality of paddles or fingers 610, 612 displaceable between a retracted position and an extended position. In the retracted position the paddles are retracted out of engagement with the bins. In the extended position as shown in Fig. 5 the paddles form a ledge under the lip or flange that extends outwardly from the top rim of the bin. In this way, the paddles hold the bin up in the column so that the vehicle can retrieve a bin, raise the bin up in the column so that the bin retainer retains the bin. Then the vehicle can lower down to release the bin so that the vehicle can retrieve another bin.

[00169] The bin retainer 600 includes a pair of sides 605 and 606 on opposite sides of the column 400 as shown in Figs. 41. The first and second sides 605, 606 are substantially mirrors of one another. The first side is illustrated in Fig, 42. As shown in Fig, 42, a connecting arm 615 connects the first paddle 610 with the second paddle. Additionally, a drive arm 618 connected the first paddle 610 with an actuator 620. The actuator 620 includes a recess or pocket for engagement with an actuator 540 on the transfer head 470.

[00170] Referring to Figs. 43A-43C, the bin retainer actuator 540 includes a pivotable arm 542 having a roller on a distal end 544 that ~~enages~~engages the bin retainer actuator 620. The actuator ~~540~~ arm 542 also includes follower roller 546 configured to follow a surface profile to extend and retract the arm. Specifically, as shown in Figs. 43A-C, the follower 546 follows a cam surface 550 having a retracted surface 552, an extended surface 554, an angled extension surface 556 and an angled retraction surface 558. As the transfer head 470 is displaced from the retracted position to the extended position, the bin retainer actuator 540 is actuated to extend the arm outwardly to actuate the paddles to rotate the paddles 610, 612 from the retracted position to the extended position.