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Multi-function rack systems and methods

Abstract

A location determination system for a material handling vehicle operating near a charging node. The system may include a power receptor configured to receive power from the charging node and provide current to the material handling vehicle. The system may include a sensor electrically coupled to the power receptor and configured to measure the current provided by the power receptor, and a controller configured to determine a current profile based on the measured current and determine a distance of the power receptor to the charging node based on the current profile. The system may determine the distance of the material handling vehicle from the charging node and may determine the location of the material handling vehicle based on a predetermined location of the charging node. The system may comprise multiple power receptors each with a current profile and may determine a speed and/or direction based on the multiple current profiles.

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Background/Summary

CROSS-REFERENCES TO RELATED APPLICATIONS (1) This application is based on, claims priority to, and incorporates herein by reference in its entirety U.S. Provisional Patent Application No. 63/301,228 filed Jan. 20, 2022, and entitled “MULTI-FUNCTION RACK SYSTEMS AND METHODS.”

BACKGROUND
(1) Battery powered material handling vehicles require periodic recharging of their batteries. Recharging generally requires either removing a depleted battery from a material handling vehicle, installing a charged battery into the material handling vehicle, and recharging the depleted battery, or parking the material handling vehicle and recharging the depleted battery. In both cases, warehouse assets (e.g., batteries and/or material handling vehicles) are unable to be used for regular periods of time, as it may take hours to recharge batteries. Excessive downtime caused by recharging batteries can negatively affect the productivity and/or profitability of the material handling vehicle and the warehouse the material handling vehicle operates in. Furthermore, substantially and/or fully depleting batteries (e.g., 80% to 100% depth of discharge) can prematurely shorten the lifespan of batteries.
(2) Additionally, there are several difficulties in tracking and/or remotely piloting material handling vehicles in a warehouse. Certain tracking approaches that use wire-guided material handling vehicles require technicians to install guidance wires on paths where a material handling vehicle is piloted. Similarly, approaches that use markers such as optical markers and/or RFID tags require the markers to be installed on paths where the material handling vehicle travels.
(3) In addition, for certain types of vehicles there are training requirements imposed by various government agencies, laws, rules and regulations. For example, OSHA imposes a duty on employers to train and supervise operators of various types of material handling vehicles. Recertification every three years is also required. In certain instances, refresher training in relevant topics shall be provided to the operator when required. In all instances, the operator remains in control of the material handling vehicle during performance of any actions. Further, a warehouse manager remains in control of the fleet of material handling vehicles within the warehouse environment. The training of operators and supervision to be provided by warehouse managers requires among other things proper operational practices including among other things that an operator remain in control of the material handling vehicle, pay attention to the operating environment, and always look in the direction of travel.
BRIEF SUMMARY
(4) The present disclosure relates generally to multi-function rack systems and methods for use with material handling vehicles. For example, a multi-function rack can be used with material handling vehicles such as forklifts in warehouses and/or other storage facilities. The term “multi-function rack” may refer to a rack arrangement that provides at least one functional aspect in addition to providing storage capabilities (e.g., supporting loads). For example, a multi-function rack may provide storage capabilities as well as provide location tracking and/or power delivery for

material handling vehicles.
(5) According to some aspects of the present disclosure, a location determination system for a material handling vehicle operating near a charging node is provided. The system can include a power receptor configured to receive electric power from the charging node and provide a current to the material handling vehicle, wherein the current is based on the received electric power, a sensor electrically coupled to the power receptor and configured to measure the current provided by the power receptor, and a controller communicatively coupled to the sensor and configured to determine a current profile based on the measured current and determine a distance of the power receptor to the charging node based on the current profile.
(6) According to some aspects of the present disclosure, a power delivery system for receiving power from a charging node is provided. The system can include a material handling vehicle, comprising a power receptor coupled to the material handling vehicle and configured to receive electric power wirelessly from the charging node and provide a current to the material handling vehicle, wherein the current is based on the received electric power, a sensor electrically coupled to the power receptor and configured to measure the current provided by the power receptor, and a controller electrically coupled to the sensor and configured to determine a current profile based on the measured current, wherein the current profile comprises time-varying current measurements, and determine a location of the material handling vehicle based on the current profile.
(7) According to some aspects of the present disclosure, a method for determining a location of a material handling vehicle is provided. The method can include receiving, via a wireless power receptor, electric power from a charging node, providing, via the wireless power receptor, a current to the material handling vehicle based on the received electric power, measuring the current provided by the wireless power receptor at a plurality of times, determining a current profile based on the plurality of measured currents, and determining a distance of the power receptor to the charging node based on the current profile.
(8) The foregoing and other aspects and advantages of the disclosure will appear from the following description. In the description, reference is made to the accompanying drawings which form a part hereof, and in which there is shown by way of illustration a preferred configuration of the disclosure. Such configuration does not necessarily represent the full scope of the disclosure, however, and reference is made therefore to the claims and herein for interpreting the scope of the disclosure.

Description

BRIEF DESCRIPTION OF DRAWINGS
(1) The invention will be better understood and features, aspects and advantages other than those set forth above will become apparent when consideration is given to the following detailed description thereof. Such detailed description makes reference to the following drawings.
(2) FIG. **1** illustrates a multi-function rack, in accordance with an embodiment;
(3) FIG. **2** schematically represents a material handling vehicle and a multi-function rack, in accordance with an embodiment;
(4) FIG. **3**A graphically represents a first distance-varying current, in accordance with an embodiment;
(5) FIG. **3**B graphically represents a second distance-varying current, in accordance with an embodiment;
(6) FIG. **4** illustrates a method for locating a material handling vehicle, in accordance with an embodiment; and
(7) FIG. **5** illustrates an example controller, in accordance with an embodiment.
(8) Corresponding reference characters indicate corresponding parts throughout several views.

Although the drawings represent embodiments of the present disclosure, the drawings are not necessarily to scale and certain features may be exaggerated in order to better illustrate and explain the embodiments of the present disclosure.

DETAILED DESCRIPTION

(9) Before any aspects of the present disclosure are explained in detail, it is to be understood that the present disclosure is not limited in its application to the details of construction and the arrangement of components set forth in the following description or illustrated in the following drawings. The present disclosure is capable of other non-limiting examples and of being practiced or of being carried out in various ways. Also, it is to be understood that the phraseology and terminology used herein is for the purpose of description and should not be regarded as limiting. The use of “including,” “comprising,” or “having” and variations thereof herein is meant to encompass the items listed thereafter and equivalents thereof as well as additional items. Likewise, “at least one of A, B, and C,” and the like, is meant to indicate A, or B, or C, or any combination of A, B, and/or C. Unless specified or limited otherwise, the terms “mounted,” “secured,” “connected,” “supported,” and “coupled” and variations thereof are used broadly and encompass both direct and indirect mountings, connections, supports, and couplings. Further, “connected” and “coupled” are not restricted to physical or mechanical connections or couplings.

(10) It is also to be understood that any reference to an element herein using a designation such as “first,” “second,” and so forth does not limit the quantity or order of those elements, unless such limitation is explicitly stated. Rather, these designations may be used herein as a convenient method of distinguishing between two or more elements or instances of an element. Thus, a reference to first and second elements does not mean that only two elements may be employed there or that the first element must precede the second element in some manner.

(11) The following discussion is presented to enable a person skilled in the art to make and use aspects of the present disclosure. Various modifications to the illustrated configurations will be readily apparent to those skilled in the art, and the generic principles herein can be applied to other configurations and applications without departing from aspects of the present disclosure. Thus, aspects of the present disclosure are not intended to be limited to configurations shown, but are to be accorded the widest scope consistent with the principles and features disclosed herein. The following detailed description is to be read with reference to the figures, in which like elements in different figures have like reference numerals. The figures, which are not necessarily to scale, depict selected configurations and are not intended to limit the scope of the present disclosure. Skilled artisans will recognize the non-limiting examples provided herein have many useful alternatives and fall within the scope of the present disclosure.

(12) It should be appreciated that material handling vehicles are designed in a variety of classes and configurations to perform a variety of tasks. It will be apparent to those of skill in the art that the present disclosure is not limited to any specific material handling vehicle, and can also be provided with various other types of material handling vehicle classes and configurations, including for example, lift trucks, forklift trucks, reach trucks, SWING REACH® vehicles, turret trucks, side loader trucks, counterbalanced lift trucks, pallet stacker trucks, order pickers, transtackers, tow tractors, and man-up trucks, and can be commonly found in warehouses, factories, shipping yards, and, generally, wherever pallets, large packages, and/or loads of goods can be required to be transported from place to place. The various systems and methods disclosed herein are suitable for any of operator controlled, pedestrian controlled, remotely controlled, and autonomously controlled material handling vehicles. Further, the present disclosure is not limited to material handling vehicles applications. Rather, the present disclosure may be provided for other types of vehicles, such as automobiles, buses, trains, tractor-trailers, farm vehicles, factory vehicles, and the like.

(13) Generally, the present disclosure provides systems and methods for power delivery and location determination, for example using a multi-function rack, that in some embodiments is configured to supplement material handling vehicles with energy, for example providing electrical

energy to charge a battery or power a motor of the material handling vehicle. In some embodiments, the multi-function rack may provide a portion of the power required by the material handling vehicle, and the remaining power may be supplied by a battery onboard the material handling vehicle. While such systems are discussed primarily with respect to material handling vehicles and storage racking, it should be appreciated that the various aspects of the disclosure can be applied to other vehicles and environments as well.

(14) FIG. **1** shows an exemplary multi-function rack system **100**. The multi-function rack system **100** may be used, for example, in a warehouse. The multi-function rack system **100** may comprise a storage rack **102**. In some embodiments, the rack system **100** can include one or more charging nodes **104**. For example, the rack system **100** can include a first charging node **104**A, a second charging node **104**B, and a third charging node **104**C. The charging nodes **104**A-C can be positioned at a predetermined height above a base of the storage rack **102**. The predetermined height can be selected based on the rack **102** and/or type of a material handling vehicle **108** in the warehouse. For example, the predetermined height may be determined based on the height (e.g., above a ground surface) of a power receiver on the material handling vehicle **108**. In some embodiments, the charging nodes **104**A-C can be coupled to the first level or higher of the storage rack **102**, which may allow the material handling vehicle **108** to charge without affecting with the lowest rack level.

(15) The charging nodes **104**A-C can be spaced apart at regular intervals along the rack system **100**. In some embodiments, the distance between the charging nodes **104**A-C can be determined based on the power requirements of material handling vehicles. For example, in applications with relatively higher power requirements, the charging nodes **104**A-C can be placed closer together (e.g., one foot apart) than in applications with relatively lower power requirements (e.g., three feet apart). Closer spacing of charging nodes **104**A-C and/or an otherwise increased number of charging nodes **104** can provide more frequent opportunities for the material handling vehicle **108** to receive power as it moves along the multi-function rack system **100**. In some embodiments, a charging node may comprise a continuous charging pad **112**. The continuous charging pad **112** can be any length, up to (for example) the full length of the storage rack. In some exemplary embodiments, the continuous charging pad **112** may extend along the majority and/or entire length of a section of the rack system **100**. For example, the continuous charging pad **112** can be approximately twelve feet long for a storage rack **102** having twelve foot wide sections.

(16) The charging nodes **104**, **112** may comprise any suitable system and/or method for providing electric power. The charging nodes **104**, **112** can transmit electric power to the material handling vehicle **108** in order to power the material handling vehicle **108** (e.g., a motor), and/or to charge a battery **110** included in the material handling vehicle **108**. In some embodiments, the charging nodes **104**, **112** can be wireless power transmitters, for example inductive (e.g., coil-based) or capacitive wireless power transmitters. In some embodiments, the charging nodes **104**A-C, **112** can be a contact-based power transmitter. For example, the charging nodes **104**, **112** can include an electrically conductive surface that supplies a current to a contactor arm (e.g., arms **114** referring briefly to FIG. **2**) electrically coupled to the material handling vehicle **108**. The contactor arm **114** can include an arm that extends from the material handling vehicle **108** to the electrically conductive surface, and a distal end of the arm may include a conductive surface configured to contact the electrically conductive surface and receive the current from the charging node **104**A-C, **112**.

(17) In some embodiments, the rack system **100** can include a number of sensors that can detect the presence and/or location of the material handling vehicle **108**. In some embodiments, the rack system **100** can include a first sensor **116**A, a second sensor **116**B, a third sensor **116**C, a fourth sensor **116**D, a fifth sensor **116**E, and/or a sixth sensor **116**F. In some embodiments, the sensors **116** can include at least one proximity sensor (e.g., an inductive sensor, an optical sensor, etc.) that can detect the presence of the material handling vehicle **108** in an aisle near any of the sensors **116**A-F.

In some embodiments, the first sensor **116**A, the second sensor **116**B, and the third sensor **116**C can be positioned above a corresponding charging nodes **104**A-C. For example, the first sensor **116**A can be positioned above the first charging node **104**A, the second sensor **116**B can be positioned above the second charging node **104**B, and/or the third sensor **116**C can be positioned above the third charging node **104**C.

(18) The multifunction rack system **100** may be configured to communicate with a warehouse management system **120**. For example, the warehouse management system **120** may communicate with (e.g., wired or wirelessly) or otherwise control the charging nodes **104**A-C, continuous charging pad **112**, sensors **116**A-F, or the like. The warehouse management system **120** may perform functions such as routing of material handling vehicles, charging control, vehicle location determination, zone monitoring, and the like. In some embodiments, a warehouse management system **120** can turn the charging nodes **104**A-C and/or the continuous charging pad **112** on and off based on information from the sensors **116**A-F (e.g., information indicating presence of the material handling vehicle **108**). In some embodiments, the warehouse management system **120** can turn on the respective charging node **104**A-C and/or the continuous charging pad **112** closest to the sensor(s) **116**A-F that detected the material handling vehicle **108**. In some embodiments, the warehouse management system **120** can turn on all charging nodes **104**A-C and/or the continuous charging pad **112** if any of the sensor(s) **116**A-F detect the material handling vehicle **108**. In some embodiments, the charging nodes **104**A-C and/or the continuous charging pad **112** can be left on continuously and the sensors **116**A-F may not be required. In some embodiments, the warehouse management system **120** may use information on demand to adjust the voltage, current, and/or add or remove capacity onto the network of charging nodes **104**, for example to monitor and limit current draw to avoid exceeding power delivery capacity or other predetermined limits.

(19) Referring now to FIG. **2**, a top-down view of the material handling vehicle **108** and an exemplary multi-function rack system **212** is shown. In some embodiments, the material handling vehicle **108** and/or the multi-function rack system **212** may be configured to communicate with the warehouse management system **120**. For example, the controller **208** of the material handling vehicle may communicate with the warehouse management system **120**.

(20) The material handling vehicle **108** can include one or more power receptors **204** and a battery **110**. In some embodiments, the material handling vehicle **108** can include a first power receptor **204**A, a second power receptor **204**B, a third power receptor **204**C, and/or a fourth power receptor **204**D. In some embodiments, the power receptors **204**A-D can be positioned at a front right corner of the material handling vehicle **108**, a rear right corner of the material handling vehicle **108**, a front left corner of the material handling vehicle **108**, and a rear left corner of the material handling vehicle **108**, respectively. In some embodiments, the material handling vehicle **108** may include a single power receptor **204** on each side of the material handling vehicle **108**. In some such embodiments, each power receptor **204** can extend along the majority and/or the entirety of each side of the material handling vehicle **108**.

(21) The power receptors **204** may comprise any suitable system and/or method for receiving electric power. The power receptors may be configured to receive electric power and to provide the electric power for use by the material handling vehicle **108**. In some embodiments, the received electric power may be used to charge a battery **110**, and/or power a motor **230** or other functions of the material handling vehicle. In some embodiments, the power receptors **204**A-D can be wireless power receivers, for example inductive (e.g., coils) or capacitive wireless power receivers that can receive wireless power from the multi-function rack **212**. In some embodiments, each of the power receptors **204**A-D can include a contactor arm **114** that extends from the material handling vehicle **108** and is configured to electrically couple with (e.g., via contacting) a conductive surface included on the multi-function rack **212**, for example one of the charging nodes **104**A-C and/or the continuous charging pad **112**. A distal end of each contactor arm **114** may include a conductive surface that receives the current from the electrically conductive surface of the charging node **220**

included in the multi-function rack **212**.

(22) The number and location of the charging nodes **220** and power receptors **204** may be chosen based on the configuration and amperage requirements of the material handling vehicle(s) **108** that operate near the multi-function rack **212**. For example, a smaller material handling vehicle **108** may require less power transfer, and so fewer charging nodes **220** and/or fewer power receptors **204** may be required. A smaller material handling vehicle **108** may include a power receptor **204** at each corner of the material handling vehicle **108**. For further example, a larger or higher current material handling vehicle **108** may include a power receptor **204** strip along substantially all of one or more sides of the material handling vehicle **108**.

(23) Referring briefly to FIG. **5**, various components of the material handling vehicle **108**, the multi-function rack **212**, and/or the warehouse management system **120** may be implemented on one or more controllers **500**. Referring back to FIG. **2**, in some embodiments, the material handling vehicle **108** can include a controller **208** communicatively coupled to the one or more power receptors **204**A-D, the battery **110**, a motor **230** (e.g., a traction motor for moving the vehicle) and/or an electrical sensor **206** (e.g., a current sensor). Communicative coupling may comprise electrical coupling. In some embodiments, the electrical sensor **206** may be communicatively coupled with a controller other than the controller **208** of the material handling vehicle **108**, for example a controller of the multi-function rack **212** and/or the warehouse management system **120**, described below.

(24) The electrical sensor **206** may be coupled with one or more power receptors **204**A-D (such coupling not shown in FIG. **2**). Each power receptor may have its own electrical sensor **206**. As will be described in greater detail below, the electrical sensor **206** and the controller **208** can work together to determine a distance of the material handling vehicle **108** from the multi-function rack **212** and/or the location of the material handling vehicle **108** within the operating environment of the multi-function rack system **212** (e.g., location within a warehouse). In some embodiments, the controller **208** may include a battery management unit to control and monitor charging of the battery **110**, state of charge, perform battery protection functions, and the like.

(25) Referring again to FIG. **5**, a controller **500**, such as controller **208**, may be configured to send and/or receive information (e.g., including instructions, data, values, signals, or the like) to/from the various components of the material handling vehicle **108**, the multi-function rack **212**, and/or the warehouse management system **120**. The controller **500** may comprise processing circuitry **510**, for example, a processor, DSP, CPU, APU, GPU, microcontroller, application-specific integrated circuit, programmable gate array, and the like, any other digital and/or analog components, as well as combinations of the foregoing (whether distributed, networked, locally connected, or the like), and may further comprise inputs and outputs for receiving and providing control instructions, control signals, drive signals, power signals, sensor signals (e.g., current or voltage sensor output), digital signals, analog signals, and the like. All such computing devices and environments are intended to fall within the meaning of the term “controller,” “control unit,” “processor,” “processing device,” or “processing circuitry” as used herein unless a different meaning is explicitly provided or otherwise clear from the context. In some examples, the controller **500** may comprise one or more such processor devices.

(26) The controller **500** may comprise processing circuitry **510** configured to execute operating routine(s) **530** stored in a memory **520**. The controller **500** may directly include the memory **520** (e.g., local memory) or may be otherwise communicatively coupled to the memory **520** (e.g., a remote server). The memory **520** may include any suitable volatile memory, non-volatile memory, storage, any other suitable type of storage medium, or any suitable combination thereof. For example, the memory **520** may include RAM, ROM, EEPROM, one or more flash drives, one or more hard disks, one or more solid state drives, one or more optical drives, etc. In some embodiments, the memory **520** may have encoded thereon a computer program (e.g., operating routine) for controlling operation of the controller **500**, material handling vehicle **108**, the multi-

function rack **212**, the warehouse management system **120**, and the like. In some embodiments, the various components of the material handling vehicle **108**, the multi-function rack **212**, and/or the warehouse management system **120** may be implemented entirely as software (e.g., operating routine), entirely as hardware, or any suitable combination thereof. In some embodiments, the operating routine(s) **530** may comprise firmware.
(27) Referring again to FIG. **2**, in some embodiments, the multi-function rack **212** can include a first section (or side) **212**A and a second section (or side) **212**B, for example a left side and a right side of an aisle through which the material handling vehicle **108** can travel. In some embodiments, the multi-function rack **212** can include the rack system **100** in FIG. **1**. The multi-function rack **212** can include a number of charging nodes **220**A-D, which may be the same or substantially similar to the charging nodes **104**A-C and/or **112** in FIG. **1**. As will be described below, the charging nodes **220**A-D can be used to identify the position of the material handling vehicle **108**.
(28) In some embodiments, the charging nodes **220**A-D can be spaced at a sufficiently short distance to provide constant power to the material handling vehicle **108**. In some embodiments, the charging nodes **220**A-D can be spaced apart by approximately a foot, by approximately a meter, by approximately two meters, or the like. If the charging nodes **220**A-D are spaced together closely, there may always be at least one power receptor **204**A-D receiving power from at least one of the charging nodes **220**A-D. In some embodiments where the material handling vehicle **108** includes a single (e.g., long or strip-like) power receptor **204** on each side of the material handling vehicle, the power receptors **204** may each interface with multiple charging nodes **220**A-D simultaneously. The controller **208**, for example via the battery management unit, can monitor and control the current applied to the material handling vehicle **108** (e.g., motor **230**) and/or battery **110** from the multiple charging nodes **220**A-D.
(29) In some embodiments, the charging nodes **220**A-D can communicatively couple with the power receptors **204**A-D. The communicative coupling may be one way (in either direction) or two way. In some embodiments, the charging nodes **220**A-D may communicate with the power receptors **204**A-D using a communication protocol, for example a power line communication (PLC) type protocol, communication over wireless power transfer, and the like. For example, a modulated carrier frequency can be added to the current, voltage, or electromagnetic signals transmitted by one or more of the charging nodes **220**A-D to transmit instructions to one or more of the power receptors **204**A-D. In some embodiments, one or more charging nodes **220**A-D and/or one or more power receptors **204**A-D may include wireless transmitters and/or receivers, for example configured to send and/or receive wireless data. In some embodiments, the material handling vehicle **108** may be configured to communicate, for example by a separate transceiver or by the power receptors **204**A-D, using the same wireless communication standard(s) as the charging nodes **220**A-D. In some embodiments, the charging nodes **220**A-D may implement millimeter wave (e.g., 60 GHz) wireless transmission, and one or more charging nodes **220**A-D may act as anchor points. For example, the charging node **220**, with a known location, may be used as the anchor and range may be determined based on time of flight. In this way, instructions (e.g., movement commands), location information (e.g., determined by the material handling vehicle **108**), and the like can be transmitted via the multi-function rack **212** using the communication protocol.
(30) Referring now to FIG. **2**, as well as FIG. **3**A, an exemplary graph of a distance-varying current at a power receptor (e.g., one of power receptors **204**A-D) is shown. More specifically, the power receptor **204**A-D can be a wireless power receptor (e.g., an inductive charging coil). The current at the power receptor **204**A-D can be the current flowing in inductive charging coils of the respective power receptor **204**A-D, induced by an inductive charging coil of a charging node (e.g., one of charging nodes **220**A-D). In other words, when the charging coils of the power receptor **204** and charging node **220** are sufficiently close, they may inductively couple and thereby allow a current to be generated in the coil of the power receptor **204**. An inductive coupling amount may vary

based on the distance between the power receptor **204** and the charging node **220**, for example increasing or decreasing as the material handling vehicle **108** moves closer or further away from the charging node **220** in any direction along the two-dimensional plane parallel to the ground surface on which the material handling vehicle **108** operates (e.g., movement along a path parallel to or perpendicular to the direction of the multi-function rack **212**).
(31) The current at the one or more power receptors **204**A-D can be measured, for example by a current sensor **206** communicatively coupled to the controller **208** and/or power receptors **204**A-D. Based on the measured current, the location of the material handling vehicle along the length of, as well as the lateral distance to, the multi-function rack **212** can be estimated, as will be described below. In some embodiments, the current may be measured at the one or more charging nodes **220**A-D, for example by a coupled current sensor.
(32) The current of the power receptor **204** (which may be referred to herein as the "coupled current") may vary based on the proximity of the power receptor **204**A-D to various charging nodes **220**A-D. For example, the coupled current may peak and/or plateau at a location A corresponding to a first charging node **220** (e.g., the first charging node **220**A) and a location B corresponding to a second charging node **220** (e.g., the second charging node **220**B). As the material handling vehicle moves past the first charging node (e.g., on a path parallel to the length of the multi-function rack **212**), the power receptor **204** (e.g., the first power receptor **204**A), may receive power from the first charging node, and the coupled current may increase, peak, and then decrease. The coupled current may increase as the material handling vehicle **108** continues past the second charging node and the power receptor **204** (e.g., the first power receptor **204**A) receives power from the second charging node.
(33) Additionally, the current may also vary as the material handling vehicle **108** moves laterally closer to or further away from the charging nodes **220**A-D. In some embodiments, the lateral distance between the material handling vehicle and the multi-function rack **212** can be estimated based on the measured amperage at a peak in the measured current (i.e., a maximum in the current profile described below). As a power receptor **204** moves closer to one of the charging nodes **220**A-D, the measured amperage value will increase. By comparing the measured amperage at a peak in the current profile to a predetermined lateral profile, the lateral distance of the power receptor **204**, and thus the material handling vehicle **108**, can be determined (e.g., by the vehicle controller **208** or another controller **500**). The lateral profile may be determined, for example, by measuring amperage values at multiple lateral distances at the point of closest approach between the power receptor **204** and charging node **220**. In some embodiments, the material handling vehicle **108** can be kept within a certain acceptable distance of the multi-function rack **212** by defining an acceptable range of amperage, for example measured at a peak in the measured current. In some embodiments, based on such measured amperage, control instructions (e.g., steering, motor) may be given to the material handling vehicle to maintain it in the acceptable range, to move it to an optimal distance, or the like. If such measured amperage is outside the acceptable range, then instructions can be given to the material handling vehicle **108** to steer or otherwise control it back into the acceptable range.
(34) Alternatively, or additionally, if charging nodes **220**A-D are present on both sides of an aisle, and power receptors **204**A-D are present on both sides of the material handling vehicle **108**, the relative distance between (i) a first side of the material handling vehicle **108** to a first side of the multi-function rack **212**A and (ii) a second side of the material handling vehicle **108** to a second side of the multi-function rack **212**B can be determined based on the relative strength of the maximum measured amperage on each side. If the total width of the aisle between the first and second sides of the multi-function rack **212** is known, then the absolute lateral distances on each side may be determined.
(35) In some embodiments, the current may be measured with respect to time (i.e., a time-varying current) and then converted to distance or may be measured with respect to distance (i.e., a

distance-varying current) and then converted to time. The conversion may be based on the speed of the material handling vehicle **108** and/or other relevant telemetry relating to the vehicle movement. The resulting measurement of the changing current as the material handling vehicle **108** moves along an aisle (with respect to distance or time) may be referred to as a “current profile.” In some embodiments, the controller **208** (or another communicatively coupled controller **500**) may determine a change in position per unit of time (for example, based on the curve or slope of the current profile), which the controller **208** can then use to calculate speed and acceleration of the material handling vehicle **108**. In some embodiments, the current profile may be determined by electrical measurement of the charging node **220** instead of and/or in addition to the electrical measurement of the power receptor **204**.

(36) In some embodiments, the points of the current profile where the respective power receptor **204** is closest to the charging node **220** may result in a reduced ability to resolve position. More specifically, these locations, where the current profile is at a peak, allow a larger variation in position for a smaller change in the coupling current (i.e., the slope is shallow or zero). Similarly, the locations where the charging node **220** is receiving little or no coupling current also result in reduced spatial resolution (similarly having a shallow or no slope, or there being no signal to resolve). Thus, a current profile can also be configured to indicate the effectiveness of inductive coupling between a power receptor **204** and a charging node **220**.

(37) Referring to FIGS. **3**A and **3**B, in some embodiments, multiple power receptors **204** may be interleaved (e.g., strategically offset from one another) to help resolve such areas of reduced spatial resolution. The spacing of such multiple power receptors **204** depends on many factors, such as number of power receptors **204** present on the material handling vehicle **108**, the number and spacing of the charging nodes **220**, the power transferred by the charging nodes **220**, inductive coil size, whether charging nodes are present on one or multiple sides of the material handling vehicle **108**, and the like. For example, FIG. **3**B represents the current profile of a second power receptor (e.g., the second power receptor **204**B) that is offset in position from the first power receptor **204**A. When the current profile of the first power receptor **204**A is zero (e.g., after it is out of range of charging node **220**A), the second power receptor **204**B can have a varying current profile as it moves by the first charging node **220**A, the peak of which is labeled as “Location A′”. Likewise, the current profile of the second power receptor **204**B can have a maximum as it moves by the second charging node **220**B, which is labeled as “Location B′”. Therefore, the controller **208** may still resolve the location of the material handling vehicle **108**.

(38) In some embodiments, the multiple power receptors **204** may be offset at other than a 180 degree phase offset to increase the controller's **108** ability to resolve location. For example, if the second power receptor **204**B is positioned on the material handling vehicle **108** such that its current profile is at a maximum (e.g., caused by the first charging node **220**A) when the current profile of the first power receptor **204**A is at a minimum (e.g., no longer in range of a charging node **220**), then location resolution may remain reduced as the slopes of both current profiles are shallow or zero. If the multiple power receptors **204** are placed such that the current profile of the second power receptor **204**B is not at a maximum or minimum when the current profile of the first power receptor **204**A is at a maximum or minimum, then increased location resolution can be possible. Further, offsetting by other than 180 degrees can help resolve ambiguity in the direction of travel. By interleaving power receptors **204** as described above, a more continuous location resolution can be achieved.

(39) In some embodiments, the material handling vehicle **108** may use odometry to determine a relative location of the material handling vehicle **108** within an operating environment (e.g., warehouse, aisle, or the like) based on information such as vehicle control, speed, tire diameter, heading direction, and/or other known factors. Such odometry may not be exact, and accuracy may be reduced by sensor inaccuracies, tire wear, gear wear, and so on. The vehicle location, as determined for example by odometry, may be interpolated (e.g., by the vehicle controller **208** or

another communicatively coupled controller **500**) with location as determined according to the current profile(s) (as described above) to determine a more accurate location. The material handling vehicle **108** may, for example via the controller **208**, complement the odometry with the positional information determined by the distance-varying (or time-varying) current measurement. For example, the material handling vehicle **108** may know the predetermined location of all charging nodes **220**, and the varying current measurement can be used (e.g., by the controller **208**) to determine proximity to a charging node **220**. The material handling vehicle **108** may, for example, determine a point of closest approach to a given charging node **220**, which can be compared with and used to correct the location determined by the vehicle odometry.

(40) In some implementations, devices or systems disclosed herein can be utilized or configured for operation using methods embodying aspects of the invention. Correspondingly, description herein of particular features, capabilities, or intended purposes of a device or system is generally intended to inherently include disclosure of a method of using such features for the intended purposes, a method implementing such capabilities, and a method of configuring disclosed (or otherwise known) components to support these purposes or capabilities. Similarly, unless otherwise indicated or limited, discussion herein of any method of manufacturing or using a particular device or system, including configuring the device or system for operation, is intended to inherently include disclosure, as embodiments of the invention, of the utilized features and implemented capabilities of such device or system.

(41) Correspondingly, some embodiments of the present disclosure can include a method for determining a location of a material handling vehicle. Referring to FIG. **4**, a non-limiting example of method for location determination **400** is illustrated. The location determination method **400** may be implemented, for example in the vehicle controller **208** or another coupled controller **500**, as operating routines **530** stored in memory **520** (e.g., as software) and executable by a processor **510**. The location determination method **400** may comprise measuring current values **410** from one or more power receptors **204**, determining one or more current profiles **420** based on the measured current values, determining a location **430** of the material handling vehicle **108** based on the current profile(s), and outputting the location **440** of the material handling vehicle **108**. In some embodiments, the location determination method **400** may be implemented on the warehouse management system **120**.

(42) At step **410**, a current value from one or more power receptors **204** may be measured. A current value may be measured, for example, by a current sensor **206**. Each current value can be an amperage sensed at a power receptor **204** at a given point in time. In some embodiments, at step **410**, multiple current values can be measured at discrete timepoints, and for one or more power receptors (e.g., power receptors **204**A-D). At step **420**, one or more current profiles may be determined, for example by the controller **208** or the warehouse management system **120**, based on the measured current values from step **410**. In some embodiments, a current profile may be determined for each of a plurality of power receptors (e.g., power receptors **204**A-D). In some embodiments, the current values may be normalized by automatic gain controls or other known methods, to allow unit dimensional analysis to be computed.

(43) At step **430**, a location of the material handling vehicle **108** may be determined based on the one or more current profile(s) In some embodiments, determining the location **430** may comprise determining a speed and direction of the material handling vehicle **108**. In some embodiments, the location determination method **400** can determine the location of the material handling vehicle between two charging nodes **220** included in the multi-function rack **212**. As described above, the amperage at a given power receptor **220** may increase as the power receptor is moved closer to a first charging node (e.g., charging node **220**A), decrease as the power receptor is moved away from the first charging node, and increase again as the power receptor approaches a second charging node (e.g., charging node **220**B). In some embodiments, the location determination method **400** can determine whether or not the current values for a previous set of time points have been decreasing,

increasing, or staying about the same. For example, if the current values have been decreasing, the location determination method **400** can determine that the material handling vehicle **108** is moving away from the first charging node **220**A; if the current values have been increasing, the location determination method **400** can determine that the material handling vehicle **108** is approaching the second charging node **220**B; and if the current values have stayed about the same, the location determination method **400** can determine that the material handling vehicle **108** is located near the first charging node **220**A.

(44) In some embodiments, determining the location **430** of the material handling vehicle **108** may comprise determining a direction of travel and/or a speed of the material handling vehicle **108** based upon the plurality of current values (i.e., the current profile(s)). The speed can be determined by comparing how much the current values change between timepoints, with larger changes indicating higher speeds. The direction of travel can indicate if the material handling vehicle is moving parallel to the multi-function rack **212** or not. For example, in some embodiments, it can be determined that the truck is moving away from the multi-function rack if the current values sensed at all power receptors **204** on the same vehicle side are all decreasing. As further described above, with appropriate arrangement of power receptors **204**, the direction of travel along the multi-function rack (e.g., forward or reverse down the aisle) may also be determined.

(45) In some embodiments, where a single power receptor **204** is used (e.g., per vehicle side), the current profile of the single power receptor **204** can be used to estimate its position relative to a charging node **220**. For example, the inverse function of the current profile can indicate relative distance to a charging node **220**. With a single power receptor **204**, the direction and absolute location of the material handling vehicle **108** may be resolved in combination with other inputs, such as vehicle speed, steer angle, and the like. For clarity, the current profile may provide the relative distance of the power receptor **204** to the charging node **220**. This can then be translated to the relative distance and/or location of the material handling vehicle **108** since the location of the power receptor **204** on the material handling vehicle **108** will be predetermined. The location of a power receptor **204**, and likewise a material handling vehicle **108**, relative to a given charging node **220** may be referred to herein as the “local position” or “offset” from the given charging node **220**.

(46) In some embodiments, where multiple power receptors **204** are used (e.g., per vehicle side), the multiple current profiles can be used in a manner similar to analog or sinusoidal encoders. As the current profiles move through phases of high coupling (i.e., a maximum of the current profile) to low coupling (i.e., a minimum of the current profile), the position of the power receptors **204** (and thus the material handling vehicle **108**) relative to a charging node (i.e., the offset) can be calculated. In some embodiments, direction (e.g., forward or backward along the multi-function rack **212**) and speed can be resolved directly from the multiple current profiles and may not require additional inputs such as vehicle speed, steer angle, or the like.

(47) In some embodiments, methods for analog encoders, such as sinusoidal encoders, may be used to determine location (e.g., local position), speed, and direction based on the multiple current profiles. For example, if two power receptors **204**A, **204**B are located on a first side of a material handling vehicle **108** such that their resulting current profiles are about or otherwise effectively 90 degrees out of phase when moving past a given charging node **220** along an intended path of travel for the material handling vehicle **108**, then one of the current profiles (“A”) can be treated as a sine signal and the other current profile (“B”) can be treated as a cosine signal. The intended path of travel may include, for example the material handling vehicle **108** moving forward or reverse down an aisle, parallel to the direction of the multi-function rack **212**. Signal processing may be performed on the signals to determine speed and direction, for example based on a quadrature encoding scheme. In some embodiments, the signals may be digitized (before or after signal processing). The phase of the signals may be determined by arctan (A/B), which can indicate the location with respect to the given charging node **220**. The resolution of location may depend on the interpolation function used. For example, a standard 1024 interpolation function may determine

1024 discrete locations for every period of charging node **220** placement.

(48) It will be recognized that the same methods may be used, for example, if the multiple power receptors **204**A, **204**C are located on opposite sides of the material handling vehicle **108** and a charging node **220** exists on each side of the aisle (e.g., charging node **220**C on multi-function rack **212**A, and charging node **220**B on multi-function rack **212**B). In some embodiments, the charging nodes **220**B, **220**C may be arranged at the same distance along the racks **212**A, **212**B (e.g., directly across the aisle from each other), and the power receptors **204**A, **204**C may be offset from each other (e.g., to create an effective 90 degree phase) such that they are not aligned across the material handling vehicle **108**. In other embodiments, the power receptors **204**A, **204**C may be arranged at the same locations on each side of the material handling vehicle **108** (e.g., directly across the vehicle from each other), and the charging nodes **220**B, **220**C may be offset from each other (e.g., to create a 90 degree phase) such that they are not aligned across the aisle. In this way, the respective sine- and cosine-related signals may still be obtained by power receptors **204**A, **204**C on opposite sides of the material handling vehicle **108**.

(49) Typical radio location systems, such as UWB, and other location services used in warehouses, may have a typical resolution on the order of one meter due to technology limitations. In an exemplary embodiment according to the present description, having charging nodes **220** spaced at two meter intervals and using 1024 interpolation, location accuracy may be on the order of about two millimeters (2000 mm/1024). Advantageously, systems and methods according to the present description may have improved location resolution, while also providing power supplementation to a material handling vehicle.

(50) The methods described above may determine the local position of the power receptors **204** and/or material handling vehicle **108** with respect to a charging node **220**. Determining the location of the material handling vehicle **430** may further comprise determining the absolute position of the material handling vehicle within an operating environment (e.g., a warehouse). The absolute location of the material handling vehicle **108** may be determined by combining the determined local position with the absolute position of the respective charging node **220**. In some embodiments, the absolute position of each charging node **220** may be predetermined and stored (e.g., in a memory **520**) for use by the location determination method **400**. In some embodiments, each charging node **220** may have a unique identifier. The unique identifier may be transmitted to the material handling vehicle **108**, for example by the respective charging node **220** using a communication protocol. The material handling vehicle **108** may then look up the absolute position of the respective charging node **220** in memory and determine the absolute position of the material handling vehicle **108** by combining the looked up value with the determined local position.

(51) In some embodiments, the warehouse management system **120** may know which charging node **220** is active, for example based on sensors **116**, changes in electrical measurements of the charging node **220** (e.g., measured by an electrical sensor coupled to the charging node **220**), communication received by the charging node **220** from the material handling vehicle **108** (e.g., from a power receptor **204** using a communication protocol), or the like. In some embodiments, the warehouse management system **120** may transmit the respective charging node identifier and/or absolute position of the respective charging node to the material handling vehicle **108**, using any suitable communication method. The material handling vehicle **108** may then determine its absolute position as discussed above. In some embodiments, the material handling vehicle **108** may communicate its local position to the warehouse management system **120**, using any suitable communication method. The warehouse management system **120** may then determine the absolute position of the material handling vehicle **108** as discussed above. Thus, the local position of the material handling vehicle **108** and the absolute position of the respective charging node **220** can be communicated to any suitable computation system (e.g., a controller **500**) to determine the absolute position of the material handling vehicle **108**.

(52) At step **440**, the location determination process **400** can output the determined location of the

material handling vehicle. In some embodiments, at step **440**, the location determination process **400** may output the determined speed, direction of travel, and/or lateral distance to racking. In some embodiments, this information may be output, e.g., by the material handling vehicle **108**, to the warehouse management system **120** using any suitable communication methods. In some embodiments, this information may be output by the warehouse management system **120** to the material handling vehicle **108**. In some embodiments, outputting **440** the determined location information may comprise storing it in memory, for example memory **520** of a controller **500**.

(53) In some embodiments, the warehouse management system **120** and/or the material handling vehicle **108** (e.g., via controller **208**) can generate commands to pilot the material handling vehicle **108** based on the absolute location, speed, and/or direction of travel. For example, the warehouse management system **120** can generate a command to keep traveling along the multi-function rack **212** if the material handling vehicle has not passed enough charging nodes and/or a charging node with a particular identifier to make it to a prescribed destination. As another example, the warehouse management system **120** can generate a command to speed up or slow down the material handling vehicle based on the calculated speed. As yet another example, the warehouse management system **120** can generate a command to steer right or left to cause the material handling vehicle to move closer to the multi-function rack if the direction of travel indicates that material handling vehicle is moving parallel to the multi-function rack. For further example, the warehouse management system **120** can generate a command to stop the material handling vehicle **108** at the appropriate bay or rack so that an operator of the material handling vehicle **108** does not overshoot or undershoot the correct bay or rack, thus increasing efficiency.

(54) Using aspects of the disclosure, a multi-function rack that efficiently locates and provides power to a material handling vehicle can be accomplished. The multi-function rack can allow material handling vehicles to operate continuously without stopping to recharge truck batteries, as well as replace some functionality of wire guidance systems. The multi-function rack can reduce or eliminate the need for remote charging systems and battery rooms. Additionally, when combined with newer battery technology such as lithium ion batteries (LIB), the multi-function rack could provide the ability to utilize a smaller amp-hour battery, thereby reducing initial capital outlay for a warehouse. Furthermore, smaller battery space requirements can allow for a reduced truck envelope, and thus potentially allow for more efficient warehouse design.

(55) In addition, for certain types of vehicles there are training requirements imposed by various government agencies, laws, rules and regulations. For example, OSHA imposes a duty on employers to train and supervise operators of various types of material handling vehicles. Recertification every three years is also required. In certain instances, refresher training in relevant topics shall be provided to the operator when required. In all instances, the operator remains in control of the material handling vehicle during performance of any actions. Further, a warehouse manager remains in control of the fleet of material handling vehicles within the warehouse environment. The training of operators and supervision to be provided by warehouse managers requires among other things proper operational practices including among other things that an operator remain in control of the material handling vehicle, pay attention to the operating environment, and always look in the direction of travel.

(56) While various spatial and directional terms, such as top, bottom, lower, mid, lateral, horizontal, vertical, front, and the like may be used to describe examples of the present disclosure, it is understood that such terms are merely used with respect to the orientations shown in the drawings. The orientations may be inverted, rotated, or otherwise changed, such that an upper portion is a lower portion, and vice versa, horizontal becomes vertical, and the like.

(57) Within this specification embodiments have been described in a way which enables a clear and concise specification to be written, but it is intended and will be appreciated that embodiments may be variously combined or separated without parting from the invention. For example, it will be appreciated that all preferred features described herein are applicable to all aspects of the invention

described herein.
(58) Thus, while the invention has been described in connection with particular embodiments and examples, the invention is not necessarily so limited, and that numerous other embodiments, examples, uses, modifications and departures from the embodiments, examples and uses are intended to be encompassed by the claims attached hereto. The entire disclosure of each patent and publication cited herein is incorporated by reference, as if each such patent or publication were individually incorporated by reference herein.
(59) Various features and advantages of the invention are set forth in the following claims.

Claims

1. A location determination system for a material handling vehicle operating near a charging node, comprising: a power receptor configured to: receive electric power from the charging node; and provide a current to the material handling vehicle, wherein the current is based on the received electric power; a sensor electrically coupled to the power receptor and configured to measure the current provided by the power receptor; and a controller communicatively coupled to the sensor and configured to: determine a current profile based on the measured current; and determine a distance of the power receptor to the charging node based on the current profile.
2. The location determination system of claim 1, wherein the current profile comprises distance-varying current measurements.
3. The location determination system of claim 1, wherein the power receptor is a wireless power receptor.
4. The location determination system of claim 1, comprising a plurality of power receptors, and wherein the controller is configured to determine: a first current profile for a first power receptor of the plurality of power receptors; and a second current profile for a second power receptor of the plurality of power receptors.
5. The location determination system of claim 4, wherein the controller is further configured to determine, based on the first current profile and the second current profile, at least one selected from the group of a direction of the power receptor with respect to the charging node and a speed of the power receptor with respect to the charging node.
6. The location determination system of claim 5, wherein the first power receptor and the second power receptor are arranged on the material handling vehicle to cause the current profile of the first power receptor to be offset by a phase of about 90 degrees from the current profile of the second power receptor when the material handling vehicle moves by the charging node in an intended path of travel.
7. The location determination system of claim 1, wherein the power receptor is electrically coupled to at least one selected from the group of a battery of the material handling vehicle and a motor of the material handling vehicle.
8. The location determination of claim 1, wherein the controller is further configured to: determine a distance of the material handling vehicle from the charging node based on the determined distance of the power receptor from the charging node; and determine a location of the material handling vehicle based a predetermined location of the charging node and the determined distance of the material handling vehicle from the charging node.
9. A power delivery system for receiving power from a charging node, comprising: a material handling vehicle, comprising: a power receptor coupled to the material handling vehicle and configured to: receive electric power wirelessly from the charging node; and provide a current to the material handling vehicle, wherein the current is based on the received electric power; a sensor electrically coupled to the power receptor and configured to measure the current provided by the power receptor; and a controller electrically coupled to the sensor and configured to: determine a current profile based on the measured current, wherein the current profile comprises distance-

varying current measurements; and determine a location of the material handling vehicle based on the current profile.

10. The power delivery system of claim 9, wherein: the material handling vehicle comprises a plurality of power receptors; and the controller is configured to determine: a first current profile for a first power receptor of the plurality of power receptors; and a second current profile for a second power receptor of the plurality of power receptors.

11. The power delivery system of claim 10, wherein the controller is further configured to determine, based on the first current profile and the second current profile, at least one selected from the group of a direction of the material handling vehicle with respect to the charging node and a speed of the material handling vehicle with respect to the charging node.

12. The power delivery system of claim 11, wherein the first power receptor and the second power receptor are arranged on the material handling vehicle to cause the current profile of the first power receptor to be offset by a phase of about 90 degrees from the current profile of the second power receptor when the material handling vehicle moves by the charging node in an intended path of travel.

13. The power delivery system of claim 9, wherein the power receptor is electrically coupled to at least one selected from the group of a battery of the material handling vehicle and a motor of the material handling vehicle.

14. The power delivery system of claim 9, wherein determining the location of the material handling vehicle comprises: determining a distance of the power receptor to the charging node; and receiving a predetermined location of the charging node from a memory communicatively coupled to the controller.

15. A method for determining a location of a material handling vehicle, comprising: receiving, via a wireless power receptor, electric power from a charging node; providing, via the wireless power receptor, a current to the material handling vehicle based on the received electric power; measuring the current provided by the wireless power receptor at a plurality of times; determining a current profile based on the plurality of measured currents; and determining a distance of the power receptor to the charging node based on the current profile.

16. The method of claim 15, wherein the material handling vehicle comprises a plurality of power receptors, and wherein determining the current profile comprises: determining a first current profile for a first power receptor of the plurality of power receptors; and determining a second current profile for a second power receptor of the plurality of power receptors.

17. The method of claim 16, further comprising: determining, based on the first current profile and the second current profile, at least one selected from the group of a direction of the power receptor with respect to the charging node and a speed of the power receptor with respect to the charging node.

18. The method of claim 15, wherein providing power to the material handling vehicle comprises providing power to at least one selected from the group of a battery of the material handling vehicle and a motor of the material handling vehicle.

19. The method of claim 15, further comprising: determining a distance of the material handling vehicle from the charging node based on the determined distance of the power receptor from the charging node; and determining a location of the material handling vehicle based a predetermined location of the charging node and the determined distance of the material handling vehicle from the charging node.

20. The method of claim 19, wherein determining a distance of the material handling from the charging node comprises determining at least one selected from the group of a speed of the material handling vehicle and a steering angle of the material handling vehicle.