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Sequenced Mobile Racking Aisle Closing with Energy Limitation

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Abstract

This disclosure describes a mobile racking system configured to manage the kinetic energy of closing aisles, addressing the fundamental hazard of personnel entrapment. The system employs a specific aisle opening sequence and movement control strategy to limit the maximum kinetic energy achievable by any closing aisle section. This approach complements presence detection arrangements, which may have inherent coverage gaps, by ensuring that even in the event of an undetected presence, the potential impact energy remains below a predetermined threshold. The system also incorporates a manual release mechanism to facilitate egress from a partially or fully closed aisle.

1. Technical Field

[0001] The present disclosure relates to mobile storage systems, specifically to mobile racking systems used in industrial warehouses and distribution centers. More particularly, it concerns safety arrangements and operational sequences for controlling the movement of mobile racking units to mitigate hazards associated with closing aisles.

2. Technical Context

[0002] Mobile racking systems comprise a series of movable rack bases that travel on rails, allowing aisles to be opened or closed as required for access. While efficient in terms of space utilization, the movement of large, heavy racking units presents inherent safety challenges. A primary concern is the potential for personnel to be present within an aisle as it closes, leading to entrapment or injury. Traditional safety measures often include presence detection systems, such as light curtains or laser scanners, intended to halt movement if an object is detected. However, such systems can have coverage gaps due to racking structure geometry, stored goods, or environmental factors. Furthermore, a failure in a detection system or a rapid unexpected movement can still lead to hazardous situations. The problem addressed by this disclosure is that reliance solely on presence detection may be insufficient to prevent harm, necessitating additional mechanisms to manage the energy involved in aisle closure.

3. System Overview

[0003] The disclosed system manages the movement of mobile racking units (20) to bound the kinetic energy of any closing aisle, thereby reducing the potential severity of an impact. This is achieved through a combination of controlled movement sequencing, speed regulation, and active monitoring of rack positions. A central control unit (10) orchestrates the movement of individual mobile racking units (20), each equipped with a dedicated drive module (12) and position sensor (14). Presence sensors (16) are integrated to detect obstructions, but the primary safety enhancement derives from limiting the potential energy of a closing aisle through a defined opening sequence (FIG. 3). The system ensures that only a single aisle closure with limited kinetic energy is possible at any given moment, and incorporates a manual release (18) for personnel egress.

4. Components

[0004] The system comprises several interconnected components as depicted in FIG. 1:

[0005]

- **Control Unit (10):** This central processing unit manages all movement commands, monitors sensor inputs, and implements the aisle sequencing logic. It typically includes a programmable logic controller (PLC) or an industrial computer with safety-rated inputs and outputs. The control unit (10) processes requests to open aisles, determines which mobile racking units (20) need to move, and issues commands to their respective drive modules (12). It also receives feedback from position sensors (14) and presence sensors (16).
- **Drive Module (12):** Each mobile racking unit (20) is equipped with at least one drive module (12), which typically consists of an electric motor, a gearbox, and a drive wheel (24). The drive module (12) receives speed and direction commands from the control unit (10) and provides operational status back to the control unit (10). The motor can be a variable-frequency drive (VFD) controlled induction motor or a servo motor, allowing precise speed and acceleration control.
- **Position Sensor (14):** Mounted on each mobile racking unit (20) or within the racking structure, position sensors (14) provide real-time location data to the control unit (10). Common types include rotary encoders on drive wheels (24), linear encoders along the rails, or laser distance sensors. These sensors enable the control unit (10) to accurately determine the width of open aisles and the proximity of adjacent units.
- **Presence Sensor (16):** These sensors are deployed to detect the presence of objects or personnel within the path of a moving rack or within an open aisle. Examples include light curtains, laser scanners, ultrasonic sensors, or pressure mats. As shown in FIG. 2, they are typically mounted on the leading edges of mobile racking units (20) or strategically placed to cover aisle entrances and interiors. The signals from presence sensors (16) are fed to the control unit (10) to initiate movement halts.
- **Manual Release (18):** A mechanism accessible from within an aisle, designed to allow personnel to stop rack movement or open a closed aisle. This typically consists of emergency stop buttons, pull cords, or dedicated release levers located at various points within the racking system. Activation of a manual release (18) sends a signal directly to the control unit (10), triggering an immediate stop or a controlled opening sequence.
- **Mobile Racking Unit (20):** This refers to the entire movable assembly, comprising a base carriage (20) with wheels (24) that run on floor rails, and mounted racking structure (22) for storing goods. Each unit (20) is driven by its own drive module (12).

5. Operation

[0006] The operation of the system involves a sequence of steps from aisle request to movement completion, with specific safety interlocks.

[0007] **Start-Up and Initialization:** Upon power-up, the control unit (10) performs a self-diagnostic check of its internal hardware and software. It then initializes all connected components, querying position sensors (14) to determine the current location of all mobile racking units (20). This establishes a known initial state for the entire system. Any discrepancies or sensor faults detected during initialization will prevent system operation and trigger a fault condition.

[0008] **Aisle Opening Request (Normal Operation):**

[0009]

- **Request Input (30):** A user initiates an aisle opening by selecting a desired aisle via a control panel.
- **Aisle Selection and Validation:** The control unit (10) receives the request and identifies the target aisle. It verifies that the requested aisle is valid and accessible.
- **Adjacent Aisle Check (32):** The control unit (10) checks the status of all aisles adjacent to the requested aisle. This is a critical step for energy bounding. The system is designed to ensure that only one aisle can be actively closing at any given time, or that the closing movement is limited to a single mobile racking unit (20) moving a predetermined, small distance.
- **Movement Plan Generation (34):** Based on the current positions and the requested aisle, the control unit (10) calculates the required movement for each mobile racking unit (20). To open an aisle, one or more units must move away from each other. To close an aisle, units move towards each other.
- **Energy Bounding Logic:** The control unit (10) applies a rule that limits the number of mobile racking units (20) that can move simultaneously in a closing direction. Typically, only one unit (20) is permitted to close an aisle at a given time. If multiple units are required to move to open an aisle, the sequence is designed such that only one unit (20) is responsible for reducing an existing aisle gap, while others move to create a new gap. The maximum speed of any closing unit (20) is also limited to a design figure, for example, 0.1 to 0.2 meters per second. This speed, combined with the mass of the mobile racking unit (20) (e.g., 5,000 kg to 50,000 kg), ensures the kinetic energy (0.5 *mass* velocity^2) remains below a specified safety threshold (e.g., approximately 150 Joules to 500 Joules).
- **Drive Activation (36):** The control unit (10) issues commands to the relevant drive modules (12) to begin movement.
- **Movement Monitoring (38):** During movement, the control unit (10) continuously monitors feedback from position sensors (14) and presence sensors (16).
- **Position Monitoring:** Ensures units move to the correct position and at the commanded speed.
- **Presence Detection:** If a presence sensor (16) detects an obstruction, the control unit (10) immediately halts all movement and signals an alarm.
- **Completion (40):** Once all mobile racking units (20) have reached their target positions, the control unit (10) confirms the aisle is open, deactivates the drive modules (12), and signals that the operation is complete.

[0010] **Fault or Interruption:**

[0011]

- **Sensor Fault:** If a position sensor (14) or presence sensor (16) reports an anomaly or failure, the control unit (10) triggers a safety stop, halting all movement.
- **Drive Fault:** A fault reported by a drive module (12) (e.g., overcurrent, motor overload) will also lead to an immediate system stop.

- **Emergency Stop:** Activation of any emergency stop button connected to the control unit (10) will override all other commands and immediately de-energize drive modules (12).
- **Manual Release (18) Activation:** If a manual release (18) is activated from within an aisle, the control unit (10) immediately halts any closing movement and, depending on configuration, may initiate a slow, controlled opening of the affected aisle to provide egress space.

6. Example Embodiments

[0012] **Embodiment 1** In this embodiment, the system strictly enforces that only one mobile racking unit (20) can be in motion at any given time if that motion contributes to closing an aisle. When an aisle opening is requested, the control unit (10) first identifies the mobile racking unit (20) that needs to move to open the aisle. If this movement would cause another aisle to simultaneously narrow or close, the system will not permit the movement until the adjacent aisle is confirmed to be fully open and safe, or until an explicit two-step sequence is initiated. The movement speed is limited to 0.15 meters per second, and the system is designed for a maximum rack mass of 30,000 kg, resulting in a maximum kinetic energy of approximately 337.5 Joules.

[0013] **Embodiment 2** This embodiment utilizes a segmented movement strategy for aisles. To open a central aisle, the system may allow two adjacent mobile racking units (20) to move simultaneously, but only if they are both moving outwards to create an opening. If one unit (20) needs to move inwards to allow the other to move outwards, the inward movement is executed first, stopping when it reaches its limit, then the outward movement commences. The kinetic energy bounding is achieved by limiting the maximum speed of any closing movement to 0.1 meters per second, irrespective of the rack's mass, which can range up to 50,000 kg. This provides a maximum kinetic energy of approximately 250 Joules.

[0014] **Embodiment 3** This embodiment integrates advanced position prediction and dynamic speed control. The control unit (10) monitors not only the current position but also the predicted future position of all mobile racking units (20) based on their commanded velocity and acceleration profiles. If the predicted path of one unit (20) intersects with the closing path of another unit (20) or if it predicts an unsafe closing rate, the system dynamically adjusts the speed or sequence of movements. For instance, a unit (20) nearing an end stop might accelerate more slowly than one in the middle of a long travel. The energy bound is maintained by ensuring that the calculated kinetic energy of any closing rack, considering its instantaneous speed and mass, never exceeds a design limit of 400 Joules. This may allow for slightly higher speeds (e.g., up to 0.2 meters per second for lighter racks) or slower speeds for heavier racks.

7. Alternative Configurations

[0015]

- **Distributed Control:** Instead of a single central control unit (10), a distributed control architecture could be employed where each mobile racking unit (20) has its own local controller. These local controllers would communicate with a master supervisor over a network, with the master supervisor enforcing the global sequencing and energy bounding rules.
- **Redundant Presence Sensing:** The presence detection arrangement (16) could incorporate redundant sensor types (e.g., both light curtains and laser scanners) operating

in parallel, with logic requiring both systems to be clear before movement is permitted. This also includes multiple sensors in different zones along the aisle to minimize coverage gaps.

- **Hydraulic Drives:** While electric motors are common, hydraulic drive systems could be used for the drive modules (12), offering high torque and precise speed control. The energy bounding principles would still apply through controlled flow rates and pressure.

8. Parameter Variations

Parameter	Range	Effect of Increasing Value	Effect of Decreasing Value
Max Closing Speed	0.05 to 0.25 m/s	Higher throughput, increased kinetic energy upon impact.	Lower throughput, reduced kinetic energy upon impact.
Rack Mass	5,000 to 100,000 kg	Requires higher drive torque, increased kinetic energy.	Easier to move, reduced kinetic energy.
Aisle Width	0.8 to 3.0 m	Greater travel distance for opening/closing.	Shorter travel distance, potentially faster access.
Presence Sensor Density	1 to 4 sensors per rack face	Improved detection coverage, reduced blind spots.	Increased potential for coverage gaps, reduced safety.
Control Unit Cycle Time	10 to 100 ms	Faster response to inputs and faults.	Slower response, increased reaction time.
Manual Release Activation Force	5 to 50 N	Easier activation, higher chance of accidental trigger.	Harder activation, requires more deliberate action.

9. Additional Implementations

[0017]

- **Pre-emptive Warning System:** Prior to any rack movement, an audible alarm and flashing lights could activate for a pre-set duration (e.g., 5 seconds) to warn personnel in the vicinity. This is particularly useful in areas with high noise levels or limited visibility.
- **Zoned Movement Control:** For very long mobile racking systems, the system could be divided into independent movement zones. A request to open an aisle in one zone would not necessarily lock out all movement in a distant zone, provided the energy bounding rules are maintained independently within each zone. This allows for parallel operations in different areas of a large warehouse.
- **Integrated Obstacle Mapping:** The presence sensors (16) could be advanced laser scanners capable of mapping the aisle space in 3D. This data could be used by the control unit (10) to identify not just the presence of an object, but also its size and location, allowing for more intelligent decisions, such as distinguishing between a pallet intrusion and a human presence.
- **Wireless Manual Release:** The manual release (18) could be implemented using wireless technology, allowing for portable or wearable activation devices for personnel working within the aisles. Such devices would transmit signals to local receivers connected to the control unit (10).

10. Figures

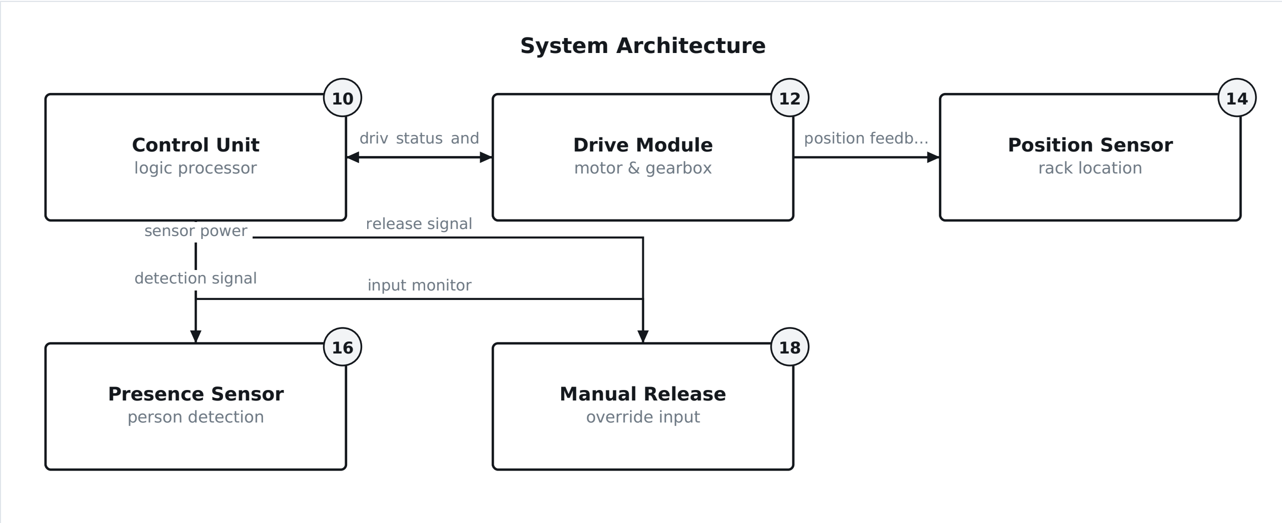

FIG. 1 A block diagram illustrating the main components of the mobile racking control system. PNG

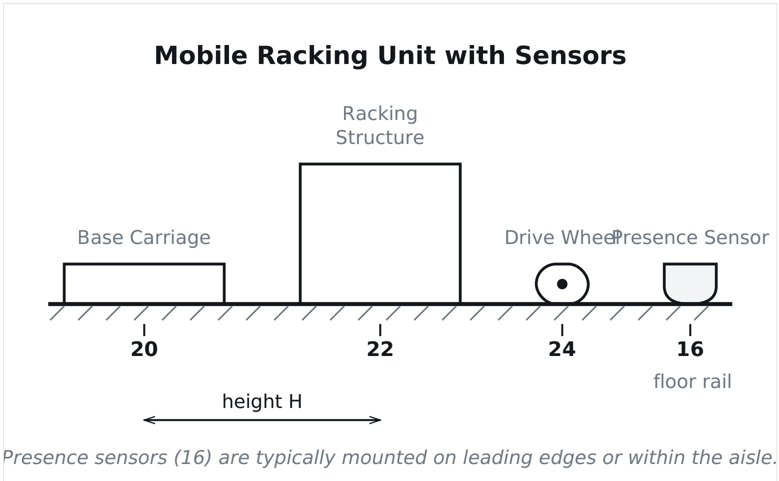

FIG. 2 An elevation view of a mobile racking unit showing typical sensor mounting locations. PNG

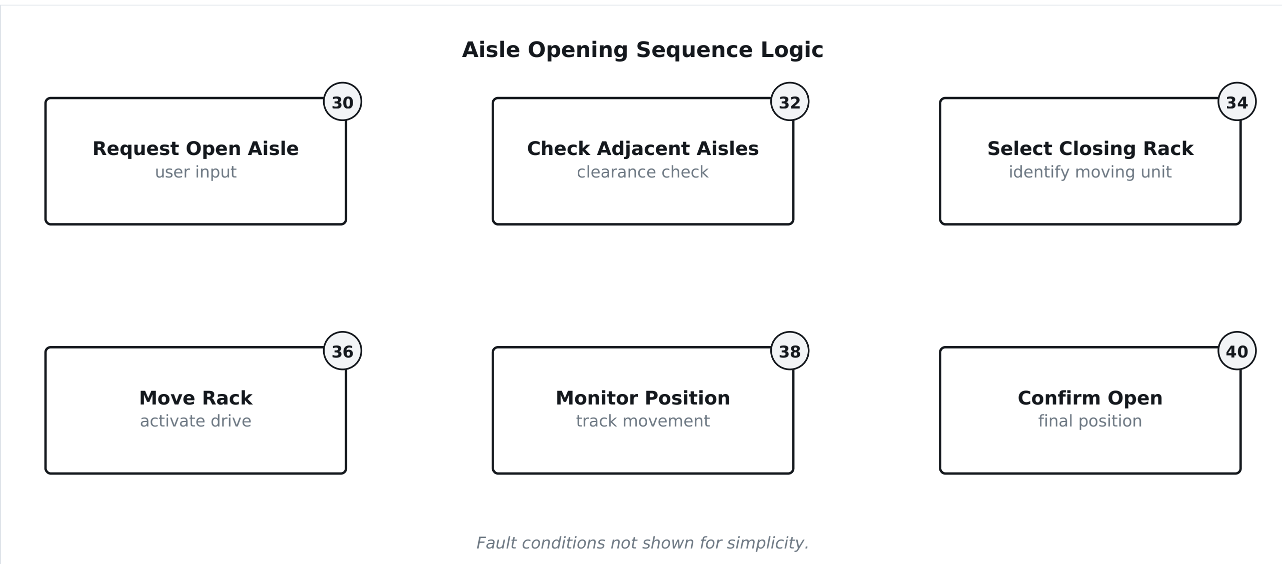

FIG. 3 A simplified state machine diagram illustrating the logic for aisle movement requests. PNG

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