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Dynamic Muting Window for Conveyor Light Curtain Safety

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Abstract

This disclosure describes a system for dynamically adjusting the muting window of a light curtain based on conveyor speed. The arrangement addresses the limitations of fixed muting windows, which can either create unsafe conditions by allowing personnel access behind slow-moving objects or cause nuisance trips with fast-moving or irregular objects. By deriving the muting sequence and time window from the measured speed of the conveyed object, the system ensures that the muting period precisely accommodates the object's passage while minimizing the risk of unauthorized access or premature re-activation of the safety function.

1. Technical Field

[0001] The present disclosure relates to industrial safety systems, specifically to arrangements for temporary suppression of electro-sensitive protective equipment, such as light curtains, in the presence of authorized objects. More particularly, it concerns dynamic muting systems that adapt to variable operational conditions, such as conveyor speed.

2. Technical Context

[0002] In automated material handling systems, light curtains (18) are commonly employed to prevent personnel access to hazardous zones while allowing materials to pass through. When an authorized object, such as a pallet or container, must pass through the light curtain's protective field, the safety function of the light curtain (18) must be temporarily suspended, a process known as muting. Conventional muting systems often rely on fixed time windows or simple sequential sensor activation. These fixed windows present challenges: if the muting window is too short, slow-moving objects may cause nuisance trips, interrupting operations. Conversely, if the window is too long, it can create a hazardous condition where a person might enter the protected zone behind a slow-moving object before the light curtain (18) reactivates, or the system might allow prolonged access if the object unexpectedly stops within the protected zone. The requirement for dynamic adjustment of the muting window based on real-time operational parameters, such as conveyor (12) speed, addresses these safety and operational efficiency conflicts.

3. System Overview

[0003] The system provides a dynamic muting function for a light curtain (18) based on the measured speed of objects conveyed through a protected zone. A safety controller (20) receives input from a conveyor speed sensor (14), a series of object presence sensors (16), and the light curtain (18) itself, as shown in FIG. 1. The safety controller (20) processes these

inputs to calculate and manage a muting window that is precisely tailored to the object's passage. This ensures that the light curtain (18) is muted only for the necessary duration and immediately reactivates once the object has cleared the protective field. The system includes provisions for early termination of the muting sequence and robust fault reactions in case of sequence violation or object stalling. The conveyor drive (10) may be controlled or monitored by the safety controller (20) to ensure safe operation.

4. Components

[0004] The primary components of the system are:

[0005]

- **Conveyor Drive (10):** This unit provides the motive force for the conveyor belt (12), typically an electric motor coupled with a gearbox. It is configured to receive commands from the safety controller (20), such as stop commands.
- **Conveyor Belt (12):** The moving surface that transports objects through the protected zone. Its speed is a critical parameter for the muting logic.
- **Speed Sensor (14):** A device that measures the linear velocity of the conveyor belt (12) or the objects on it. This can be an encoder mounted on a conveyor roller, a laser Doppler velocimeter, or a wheel encoder in contact with the belt or object. The sensor (14) provides a continuous or pulsed signal representing the current speed to the safety controller (20).
- **Muting Sensors (16):** A set of at least two, and typically four, object presence detectors (16A, 16B) positioned in sequence along the conveyor path, before and/or within the light curtain (18) zone. These are commonly proximity sensors, photo-electric sensors (through-beam, retro-reflective, or diffuse), or ultrasonic sensors. They detect the presence and passage of an object, providing sequential signals to the safety controller (20). As depicted in FIG. 2, two sensors (16A, 16B) are shown for illustrative purposes, positioned relative to the light curtain's protective field.
- **Light Curtain (18):** An electro-sensitive protective equipment (ESPE) consisting of an emitter (18A) and a receiver (18B) that create a protective field of infrared light beams. Interruption of one or more beams typically triggers a safety stop. The light curtain (18) includes muting inputs that, when activated by the safety controller (20), temporarily suspend its safety function.
- **Safety Controller (20):** A programmable electronic safety system that executes the muting logic. It receives inputs from the speed sensor (14) and muting sensors (16), controls the muting inputs of the light curtain (18), and manages fault conditions. The safety controller (20) is certified for safety-related applications.

5. Operation

[0006] The system's operation involves several phases: idle, object approach, muting, object passage, and fault reaction.

[0007] **Idle State:** In the idle state, no object is approaching the light curtain (18). The light curtain (18) is active, providing full safety protection. All muting sensors (16) are clear, and the safety controller (20) monitors the conveyor speed (14) and sensor (16) states.

[0008] **Object Approach and Muting Initiation:** As an object on the conveyor belt (12) approaches the protected zone, it first interrupts a primary muting sensor (16A). The safety controller (20) registers this event. The conveyor speed sensor (14) continuously provides the

current speed of the conveyor belt (12) to the safety controller (20). Upon detection by sensor (16A), the safety controller (20) begins to monitor for the subsequent activation of other muting sensors (16B). Once the object has activated a defined sequence of muting sensors (e.g., 16A then 16B), and provided that the conveyor speed (as measured by 14) is within acceptable operational limits, the safety controller (20) calculates the expected time duration for the object to pass through the light curtain (18). This calculation uses the known physical dimensions of the object (or a standard object length) and the measured conveyor speed. Based on this calculated duration, a dynamic muting window is established. The safety controller (20) then activates the muting inputs on the light curtain (18), temporarily suspending its safety function.

[0009] **Object Passage and Muting Termination:** During muting, the object passes through the light curtain (18) protective field. The light curtain (18) remains muted for the calculated duration. As the object exits the protective zone, it clears the final muting sensor (e.g., 16B), or the calculated muting time window expires. The safety controller (20) then deactivates the muting inputs, reactivating the light curtain (18) safety function.

[0010] **Early Muting Termination Conditions:** To enhance safety, the muting period can be terminated early under specific conditions:

[0011]

- **Object Clears Final Sensor:** If the object clears the last muting sensor (e.g., 16B) before the calculated muting time window expires, the safety controller (20) immediately deactivates muting.
- **Unforeseen Sensor Interruption:** If any muting sensor (16A, 16B) that should be active during the passage of the object unexpectedly becomes clear, or a sensor outside the expected sequence is interrupted, muting is immediately terminated.
- **Light Curtain Interruption:** If the light curtain (18) protective field is interrupted by an object other than the authorized material, for instance, a person entering from the side, while muting is active, the system immediately terminates muting and initiates a safety stop. This requires the light curtain (18) to have a diagnostic output that indicates an "unexpected" interruption during muting.

[0012] **Fault Reaction:** The system is designed with robust fault reactions to address deviations from the expected sequence or conditions:

[0013]

- **Sequence Violation:** If the muting sensors (16) are activated in an incorrect order (e.g., 16B before 16A), or if an object remains detected by a sensor (16) for longer than a predefined maximum stationary time (indicating a stalled object), the muting process is aborted, and the conveyor drive (10) is stopped. The light curtain (18) remains active or immediately reactivates.
- **Speed Deviation:** If the measured conveyor speed (14) falls outside the configured operational range during an object's passage through the muting zone, or if the speed changes significantly during the muting window, the muting is immediately terminated, and a safety stop is initiated.
- **Sensor Failure:** A failure of any muting sensor (16) or the speed sensor (14) will prevent muting from initiating or cause an immediate termination of muting and a safety stop. The safety controller (20) monitors the health of these sensors.

- **Light Curtain Fault:** Any internal fault detected by the light curtain (18) itself will cause it to revert to its safe state (active, non-muted) and signal a fault to the safety controller (20), which then initiates a system stop.

6. Example Embodiments

[0014] **Embodiment 1: Single Object with Fixed Length** In this embodiment, the system is configured for handling objects of a uniform, known length. The safety controller (20) uses the measured conveyor speed (from 14) and the pre-programmed object length to calculate the exact time duration required for the object to clear the light curtain (18). Two muting sensors (16A, 16B) are used. Sensor (16A) is located upstream of the light curtain (18) to initiate the muting sequence. Sensor (16B) is located downstream of the light curtain (18) to detect the object's exit. The muting duration is calculated as (Object Length + Distance between Light Curtain Center and Sensor 16B) / Conveyor Speed. Muting is terminated when the calculated time expires or when sensor (16B) clears, whichever occurs first. A third sensor, within the light curtain (18) zone, may be used for additional validation of object presence during muting.

[0015] **Embodiment 2: Multiple Objects with Variable Lengths** This configuration employs four muting sensors (16), two on each side of the light curtain (18), forming an "X" or "L" pattern. The safety controller (20) uses the activation sequence and timing of these four sensors to dynamically determine the length of each individual object as it approaches the light curtain (18). For example, by measuring the time difference between specific sensor activations and combining it with the measured conveyor speed (14), the controller (20) estimates the object's length. This estimated length is then used in conjunction with the conveyor speed (14) to calculate the precise muting window for that specific object. This embodiment is suitable for lines handling a mix of pallet sizes or containers.

[0016] **Embodiment 3: Predictive Muting with Deceleration Monitoring** This embodiment integrates advanced monitoring of the conveyor drive (10) performance. In addition to the speed sensor (14) and muting sensors (16), the safety controller (20) monitors the conveyor drive's (10) motor current or torque to detect incipient stalling or unexpected deceleration of the object. If the system predicts that an object will stop within the protected zone, or if significant deceleration is detected that would extend the muting period beyond a safe threshold, the muting sequence is immediately aborted, and a safety stop is initiated. This provides an additional layer of protection against unexpected object behavior.

7. Alternative Configurations

[0017]

- **Sensor Type Substitution:** The muting sensors (16) can be implemented using vision systems or laser scanners instead of discrete proximity or photoelectric sensors. A vision system could identify the object type and dimensions, providing more precise data for length calculation. A laser scanner could detect the object's profile and speed without direct contact.
- **Speed Measurement Redundancy:** Two independent speed sensors (14) could be used, with their readings cross-checked by the safety controller (20) for consistency. Discrepancy between the readings would trigger a fault.

- **Muting Sensor Redundancy:** Each muting sensor (16) could consist of two redundant detectors, with both required to be active or inactive for a valid signal. This enhances fault tolerance against single sensor failures.
- **Interlocked Gates:** Instead of, or in addition to, a light curtain (18), interlocked safety gates or barriers could be used, with their unlocking sequence controlled by the dynamic muting logic. The gate would only unlock for the calculated duration of the object's passage.

8. Parameter Variations

Parameter	Realistic Range	Effect of Moving Towards Lower End	Effect of Moving Towards Upper End
Conveyor Speed	0.1 to 2.5 m/s	Shorter objects may be processed, longer muting windows for given length, increased risk of nuisance trips on fixed windows.	Faster throughput, shorter muting windows, reduced risk of personnel access behind objects.
Object Length	0.3 to 3.0 m	Shorter muting durations, higher throughput for short objects.	Longer muting durations, reduced throughput, increased potential for exposure if not dynamically managed.
Sensor Spacing (d1, d2, d3)	0.1 to 1.0 m	More precise object detection, but smaller tolerance for object variations.	Reduced precision in object length or speed estimation, wider detection zones.
Light Curtain Width (L)	0.3 to 2.0 m	Smaller objects fit, less area to protect, potentially faster passage.	Larger objects fit, more area to protect, longer muting durations.
Response Time (System)	5 to 50 milliseconds	Faster reaction to faults, reduced safety distance requirements.	Slower fault reaction, increased safety distance requirements.
Safety Controller Processing Delay	1 to 10 milliseconds	More accurate real-time calculations for muting window.	Increased latency in muting window adjustment, potential for over- or under-muting.

9. Additional Implementations

[0019]

- **Integration with Production Control System:** The safety controller (20) can interface with a higher-level production control system to receive information about upcoming object types or dimensions. This allows for predictive adjustment of the muting logic even before the object reaches the initial muting sensors (16).
- **Personnel Detection During Muting:** Auxiliary personnel detection systems, such as radar or LIDAR sensors, could be deployed in the vicinity of the light curtain (18) during muting. If a person is detected during an active muting phase, the system would immediately terminate muting and initiate a safety stop, even if the light curtain (18) itself is muted.
- **Self-Learning Object Profiles:** The safety controller (20) could incorporate machine learning algorithms to 'learn' the typical dimensions and speeds of various objects passing through the system. Over time, this could improve the accuracy of muting window calculations and adapt to subtle variations in object presentation or conveyor (12) behavior. This would involve storing and analyzing sensor activation patterns over many cycles.

10. Figures

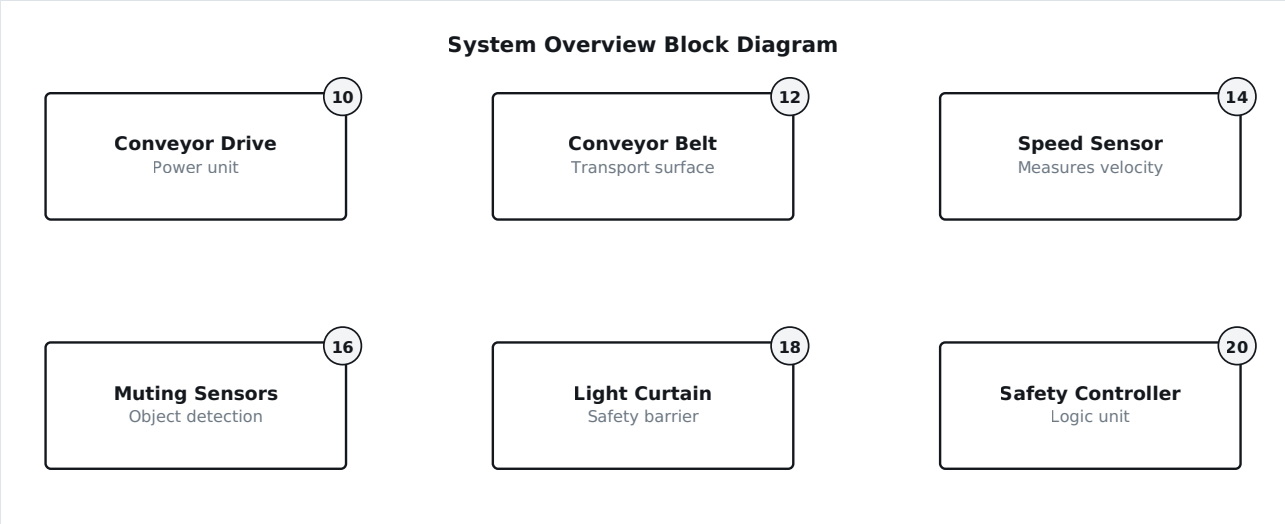

FIG. 1 A block diagram illustrating the main components and their interconnections in the dynamic muting system. PNG

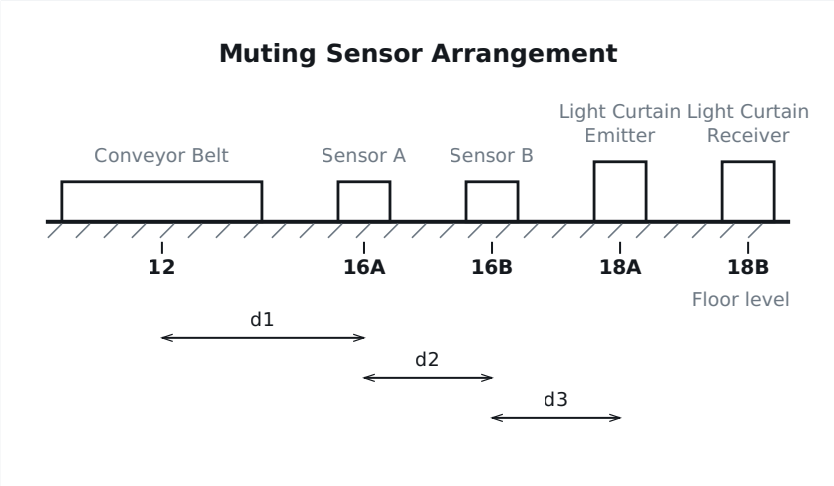

FIG. 2 An elevation view showing the arrangement of muting sensors relative to the light curtain and conveyor path. PNG

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