

Design and implementation of an energy-conscious bidirectional visitor counter using embedded sensing and microcontroller interfacing

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Abstract

Accurate real-time tracking of human occupancy is essential for intelligent building management, automated energy conservation, and safety regulation compliance. This paper presents the design, interfacing, and experimental validation of a low-power, automated bidirectional visitor counter. The system integrates dual infrared (IR) beam-break sensors, an ultra-low-power microcontroller, and an energy-efficient liquid crystal display (LCD). By implementing a non-blocking, interrupt-driven finite state machine, the architecture decodes passage sequence vectors to reliably differentiate between entry and exit events while preventing false counts caused by tailgating, partial occlusion, or jitter. Experimental evaluations across single-file transit, rapid bi-directional flow, and edge obstruction scenarios demonstrate high counting precision and significant power optimization.

Keywords: Bidirectional counting, embedded systems, finite state machine, infrared sensors, microcontroller interfacing, occupancy monitoring, power management

Introduction

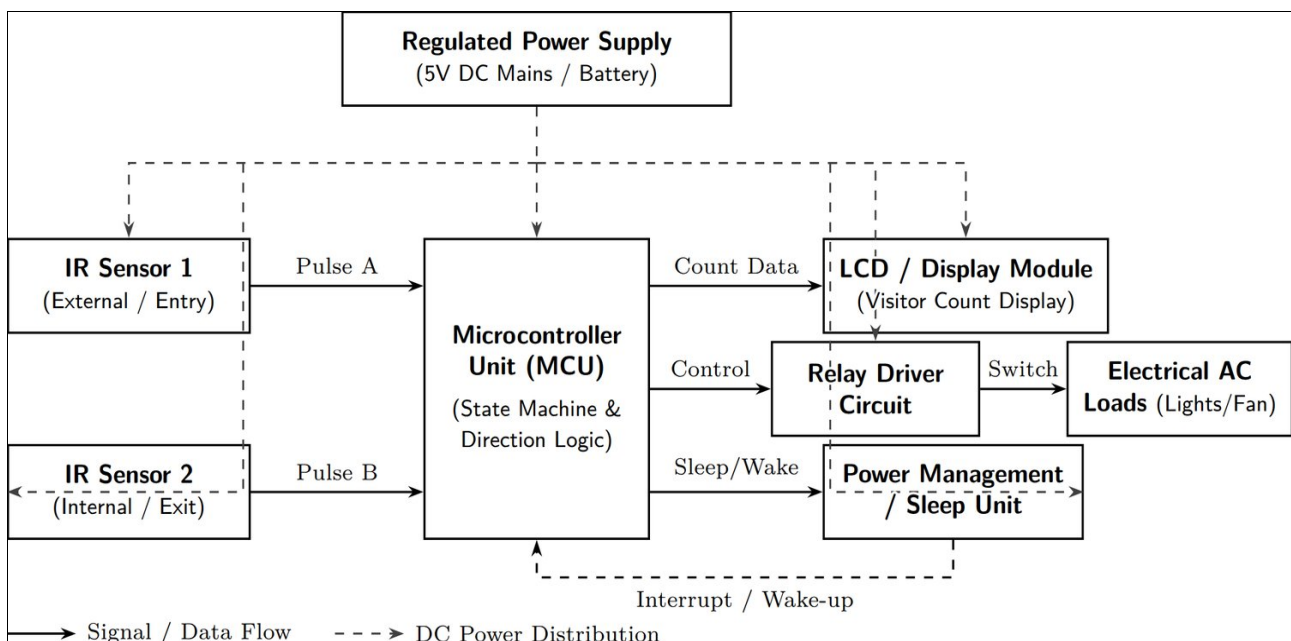
Automated monitoring of building occupancy plays a pivotal role in modern smart infrastructure, enabling dynamic HVAC regulation, intelligent lighting control, and automated emergency evacuations. Traditional manual logging methods are prone to human error, labor-intensive, and inadequate for real-time applications. While modern computer-vision solutions provide rich spatial data, they introduce severe privacy concerns, require computationally intensive processing hardware, and consume substantial electrical power.

Embedded optoelectronic sensing provides a non-invasive, privacy-preserving, and computationally lightweight

alternative. By positioning spatially separated optical transceivers across a passage boundary, entry and exit vectors can be deduced via discrete logic transitions. This work addresses the hardware interfacing, sequential state logic, and firmware optimization required to realize a robust, low-power visitor-counting node capable of handling edge cases such as loitering, beam boundary oscillation, and simultaneous passage.

System Architecture and Methodology

The system architecture consists of four primary subsystems: the sensing array, the processing unit, the output/display interface, and the load switching module.



1. Hardware Subsystems

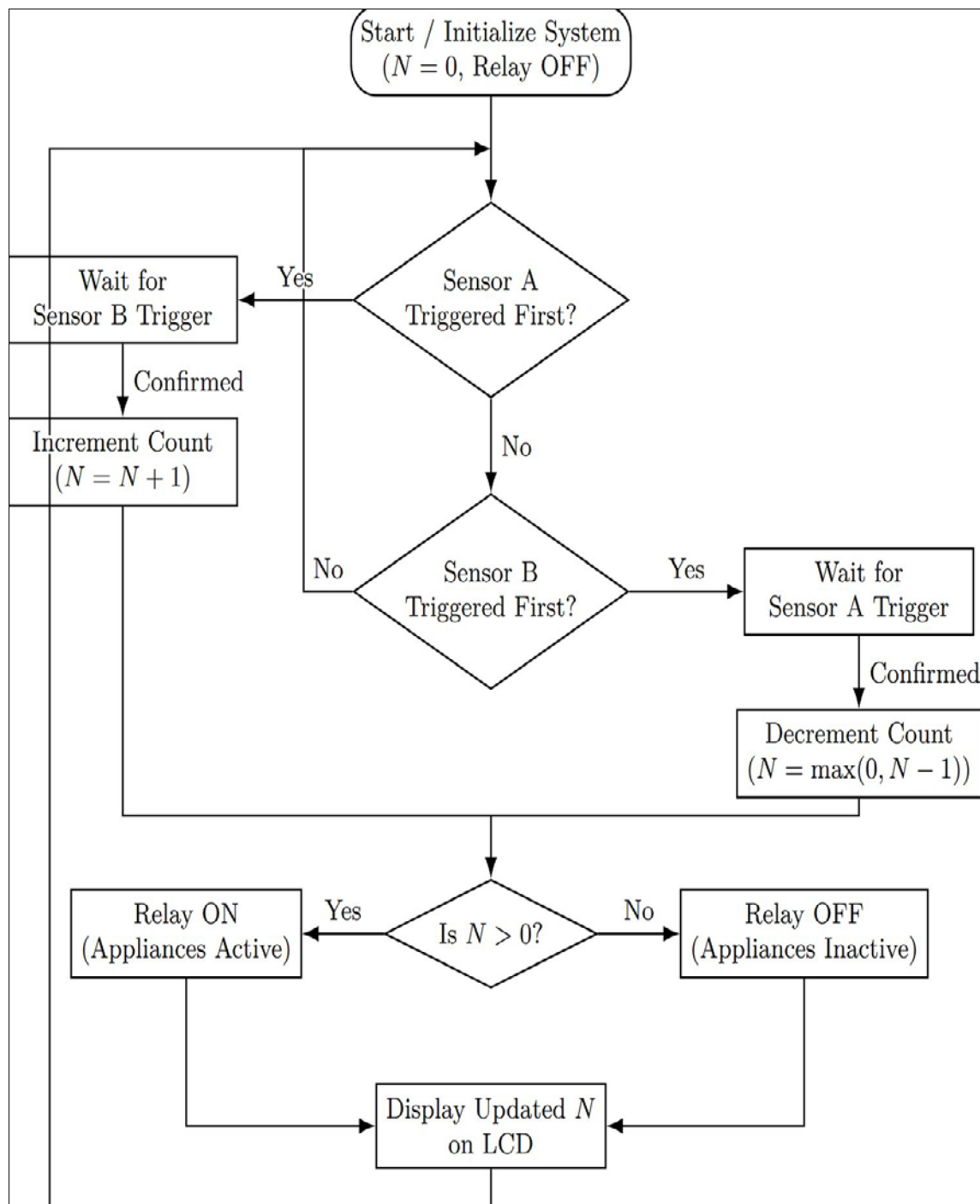
- **Sensing Unit:** Comprises two calibrated infrared transmitter-receiver pairs placed horizontally across an access portal at a fixed inter-sensor distance $d \approx 10\text{ cm}$ to 15 cm .
- **Control Unit:** An 8-bit/32-bit microcontroller (e.g., ATmega328P or STM32) executes the state-machine logic, reads digital input pins via external hardware interrupts, and manages power states.
- **Relay Driver Unit:** An optoisolated electromagnetic relay module handles AC mains switching for connected room lighting and ventilation.
- **Display Interface:** A 16×2 character liquid crystal display (LCD) or 7-segment display provides local real-time telemetry of the current occupant count.

Implementation and Detection Algorithm

1. Directional State Transition Logic

Directional detection relies on the temporal order in which the two sensor beams (**Sensor A** and **Sensor B**) are interrupted:

- **Entry Sequence:** **Sensor A** $\rightarrow$ **Sensor B**. When a visitor enters, beam **A** is blocked first, followed by beam **B**. Upon full clearance of beam **B**, the internal counter variable **N** increments by 1.
- **Exit Sequence:** **Sensor B** $\rightarrow$ **Sensor A**. When a visitor leaves, beam **B** is blocked first, followed by beam **A**. Upon full clearance of beam **A**, the counter variable **N** decrements by 1 (bounded below by zero).



2. Energy-Conscious Load Control

The operational state of the room lighting and appliances is governed by a piecewise switching condition:

$$\text{Load State} = \begin{cases} \text{Active (Relay Energized)}, & \text{if } N > 0 \\ \text{Inactive (Relay De-energized)}, & \text{if } N = 0 \end{cases}$$

To further minimize parasitic system power consumption, the microcontroller enters an idle sleep mode during inactive intervals, waking up exclusively via low-latency pin-change interrupts triggered by the optical receivers.

Energy-Conscious Operation and Power Management

To satisfy green-building efficiency standards and facilitate extended battery-powered deployment, several energy-saving mechanisms were incorporated into the hardware and software layers:

1. Interrupt-Driven Sleep Modes

- Rather than executing continuous polling loops that consume dynamic core current, the microcontroller remains in a low-power deep-sleep state during idle conditions.
- The optical sensor output transitions act as asynchronous hardware wake-up sources, activating the core only when transit events occur.

2. Duty-Cycled Sensor Emission

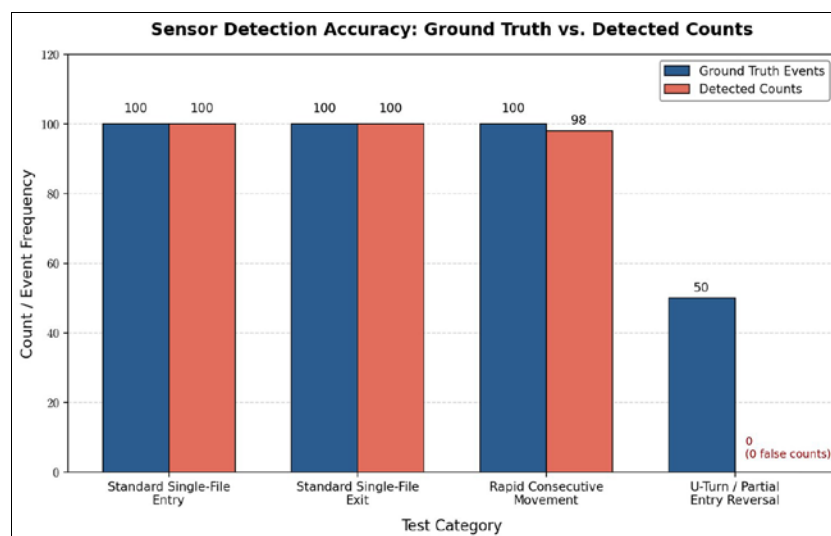
- Continuously driving high-output infrared emitters contributes significantly to total energy dissipation. By driving the emitter LEDs with narrow pulsed current bursts synchronized to the receiver sampling window, static current consumption is curtailed substantially without degrading sensitivity.

3. Adaptive Peripheral Throttling

- The LCD backlight and communication bus drivers are automatically placed into sleep mode after designated periods of physical inactivity, returning to nominal operational brightness immediately upon occupant detection.

Experimental Setup and Verification

The operational robustness of the prototype was experimentally validated in a controlled hallway environment across various transit modalities. Sensor spacing was fixed to match average adult torso depth, and the system was subjected to repetitive test trials.



1. Test Protocols

- **Single-File Entry/Exit:** Evaluated under standard walking velocities to establish baseline detection accuracy.
- **Rapid Successive Flow:** Evaluated high-density traffic where individuals traverse the detection field with minimal inter-person clearance.
- **Incomplete Traversal (U-Turn):** Evaluated edge-case handling by having subjects occlude the initial sensor and immediately retreat without completing the cross-boundary vector.

2. Accuracy Assessment

- The system achieved complete directional accuracy during standard isolated walking scenarios.
- In rapid successive transit, the state machine successfully decoupled consecutive subjects as long as an optical clearance gap was registered between them.

- In incomplete traversal trials, the firmware timeout successfully prevented false count registrations in all test cycles.

Conclusion

This research presented the design, implementation, and empirical verification of a bidirectional visitor counter designed with an emphasis on low power consumption, real-time sensing reliability, and edge-case resilience. By leveraging active infrared transceivers coupled to an interrupt-driven finite state machine, the architecture provides accurate directional occupancy counting while discarding erroneous false triggers caused by loitering or beam jitter. Integration of power-gated emitter driving and microcontroller sleep states confirms the feasibility of sustainable, long-term battery-operated deployment for smart building occupancy tracking.

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