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Bidirectional Visitor Counter System

[1]Arundhati Thakur [2]Amarishi Shrivastava, [3]Gargi Singh Baghel, [4]Aagam Jain, [5]Prof. Sunny Jain
Dept. of ECE, Lakshmi Narain College of Technology, Bhopal (M.P.), India
[1]Thakurarundhati08@gmail.com, [2]amarishishrivastava@gmail.com,
[3]Gargibaghel4008@gmail.com, [4]itsbunny.1802@gmail.com, [5]sunnyj@lnct.ac.in

ABSTRACT
This paper presents the design and implementation of a Bidirectional Visitor Counter System using paired Infrared (IR) sensors and an Arduino UNO microcontroller. The system accurately tracks real-time room occupancy, displays the count on a 16×2 LCD, automates room lighting via a relay module, and triggers a buzzer and LED alert when the preset maximum occupancy is reached. A Finite State Machine (FSM) governs the direction-detection logic by analysing the sequential order in which two sensor beams are interrupted. Prototype testing over 100 trials achieved greater than 95% counting accuracy with zero LCD display errors, validating the system as a cost-effective, reliable, and extensible smart building solution at a total hardware cost under INR 800.
Keywords: Bidirectional Counter, IR Sensor, Arduino UNO, Occupancy Monitoring, Embedded Systems, Smart Building, IoT, Finite State Machine, Real-Time Systems.

INTRODUCTION

The rapid advancement of smart infrastructure and automation technologies has generated significant demand for intelligent, real-time occupancy monitoring systems. Traditional methods—manual headcounts, mechanical turnstiles, or CCTV-based monitoring—are resource-intensive, error-prone, and incapable of providing automated real-time feedback for building resource control.

Automated visitor counters serve a critical role in smart building management. By maintaining accurate occupant counts, such systems enable intelligent control of lighting, HVAC, and emergency evacuation systems. Applications span classrooms, retail stores, hospital wards, libraries, gymnasiums, and public transport hubs.

This paper presents a low-cost Bidirectional Visitor Counter using two IR sensor pairs and an Arduino UNO. The direction-detection challenge is resolved through a dual-sensor sequential detection methodology governed by a Finite State Machine (FSM). Sensor A triggered before Sensor B registers an ENTRY (count++); the reverse registers an EXIT (count−−), floored at zero. A relay automates room lighting based on occupancy, and a buzzer-LED combination alerts when the preset maximum is reached.

The prototype was assembled on a breadboard and subjected to 100 sequential trials, achieving over 95% accuracy, sub-50 ms display latency, and reliable alert triggering—all at under INR 800 (~ USD 10).

LITERATURE REVIEW

Automated people counting has evolved from simple pressure-pad turnstiles to computer-vision systems. IR break-beam sensors became popular for doorway counting due to low cost and immunity to visible-light variation, but single-sensor designs could not detect direction of travel [3].

Dual sequential-sensor architectures solved the directionality problem by analysing beam-interruption order. Mishra and Sharma [3] demonstrated reliable detection under controlled indoor lighting. Arduino-based implementations gained wide academic adoption owing to the open-source ecosystem and ease of integration [1][2].

Kumar [5] formalised the FSM-based approach for directional counting. Agarwal and Verma [4] validated occupancy-driven resource automation—the principle directly implemented in the relay-controlled lighting subsystem of this project.

More recent research explores ultrasonic sensors, PIR arrays, and stereo-camera systems with HOG or deep-learning pedestrian detection for higher-accuracy multi-person counting. IoT-enabled variants stream data to cloud dashboards via MQTT. Despite these advances, IR-based embedded systems remain relevant for cost-sensitive, low-traffic deployments where simplicity and minimal power consumption are priorities.

SYSTEM DESIGN & METHODOLOGY

A. System Architecture

The system comprises two functional subsystems: (1) the Sensing Subsystem—dual IR sensor pairs mounted at the doorway; and (2) the Processing and Output Subsystem—Arduino UNO, 16×2 LCD, relay module, buzzer, and status LED. The block diagram is shown in Fig. 1.

The two IR modules are positioned horizontally at approximately 80 cm height, separated by 5–8 cm along the pedestrian travel axis. This gap ensures sequential—not simultaneous—beam interruptions during normal walking, which is the prerequisite for reliable directional detection.

Fig. 1. Block Diagram of the System

B. Direction Detection Logic

The direction-detection algorithm is implemented as a Finite State Machine within the Arduino main loop, cycling through four states: IDLE, WAIT_B (Sensor A triggered first), WAIT_A (Sensor B triggered first), and TIMEOUT (detection window expired without confirmation).

If Sensor A triggers before Sensor B within a 500–2000 ms window, an ENTRY is logged and the counter increments. If Sensor B triggers first, an EXIT is logged and the counter decrements. The occupancy model is:

$P(t) = P(t-1) + E - X, P(t) \geq 0$

Software debouncing (100 ms suppress window via millis()) eliminates false triggers from partial limb intrusions or sensor noise.

C. Circuit Design

The complete circuit is shown in Fig. 2. IR modules connect to Arduino digital pins D2 and D3. The 16×2 LCD operates in 4-bit mode on pins D4–D9, reducing pin usage versus 8-bit mode. A 10 kΩ potentiometer adjusts LCD contrast. The relay is driven via a transistor on pin D10. The buzzer and LED connect to D11 and D12 respectively, with current-limiting resistors.

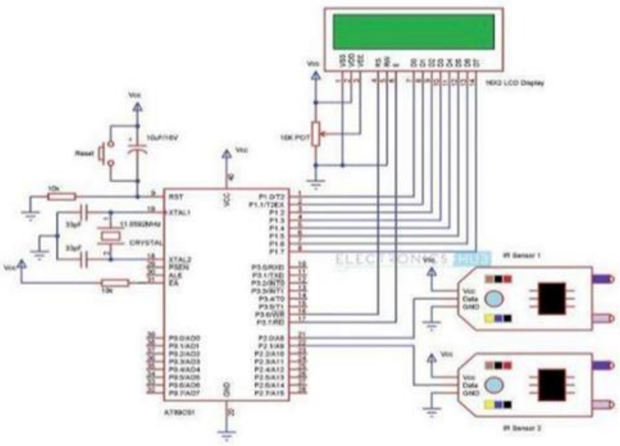

Fig. 2. Circuit Diagram

D. System Flowchart

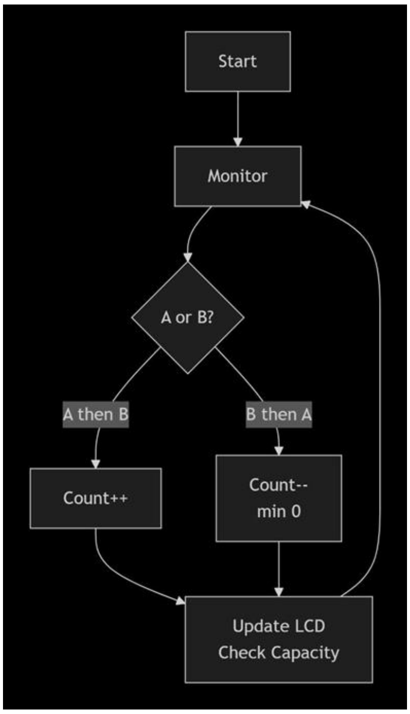

Fig. 3. System Flowchart

The program flow is depicted in Fig. 3: initialise → monitor sensors → FSM state transition → update count → refresh LCD → check capacity → control relay/buzzer/LED → repeat. The loop executes continuously with no blocking delays, ensuring minimal detection latency.

SYSTEM COMPONENTS

A. Arduino UNO

The Arduino UNO (ATmega328P) operates at 16 MHz with 32 KB Flash, 2 KB SRAM, 14 digital I/O pins, and 6 PWM outputs. It serves as the central controller for the FSM, LCD driver, and all actuators. Its 5 V rail powers all peripheral modules directly, simplifying power distribution.

B. IR Sensor Modules (×2)

Each module pairs an IR LED emitter with a phototransistor receiver. The 38 kHz modulated carrier reduces ambient IR interference from incandescent and solar sources. Output is logic HIGH (beam clear) or LOW (beam interrupted). Detection sensitivity is adjustable via an onboard potentiometer, enabling a 2–30 cm detection range.

C. 16×2 LCD Display

The LCD displays two rows of 16 characters each. Line 1 shows the current occupancy count (e.g., "Person: 3"); Line 2 shows the room light status ("Light: ON / OFF"). The module operates in 4-bit parallel mode via the LiquidCrystal library. A 10 kΩ contrast potentiometer ensures readability under varying ambient light.

D. Relay Module

A 5 V single-channel relay switches the room light based on occupancy. An integrated optocoupler provides galvanic isolation between the Arduino control circuit and the high-voltage load circuit. The relay handles loads up to 10 A at 250 V AC.

E. Buzzer & LED

An active piezoelectric buzzer and 5 mm red LED provide audible and visual alerts respectively when occupancy equals or exceeds the configured maximum. Both are protected by 220 Ω current-limiting resistors and share dedicated digital output pins.

IMPLEMENTATION & TESTING

A. Hardware Assembly

The prototype was assembled on a full-size solderless breadboard. The two IR sensor modules were mounted on a doorway frame at 80 cm height, separated by 6 cm along the travel axis—a spacing empirically determined to ensure sequential beam interruption at normal walking speed without cross-triggering.

B. Software Development

Firmware was developed in the Arduino IDE using C/C++. The LiquidCrystal library manages all 4-bit LCD communication. The FSM is implemented as a switch-case structure in the main loop. Non-blocking debouncing uses millis() to avoid delay()-induced latency. The MAX_OCCUPANCY constant is configurable at compile time.

C. Testing Methodology

Testing was conducted in a controlled indoor lab under constant fluorescent lighting. 100 single-person sequential trials were performed—50 entries and 50 exits at natural walking pace. Each result was manually logged. Additional stress tests evaluated: simultaneous two-person passage, brief doorway hesitation, partial limb intrusions, and direct ambient IR exposure from a desk lamp at 15 cm range.

RESULTS & DISCUSSION

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The assembled system during live testing is shown in Figs. 4 and 5, with the LCD displaying "Person: 0 / Light: OFF" in the initial state and updating in real time as persons pass through the sensor frame.

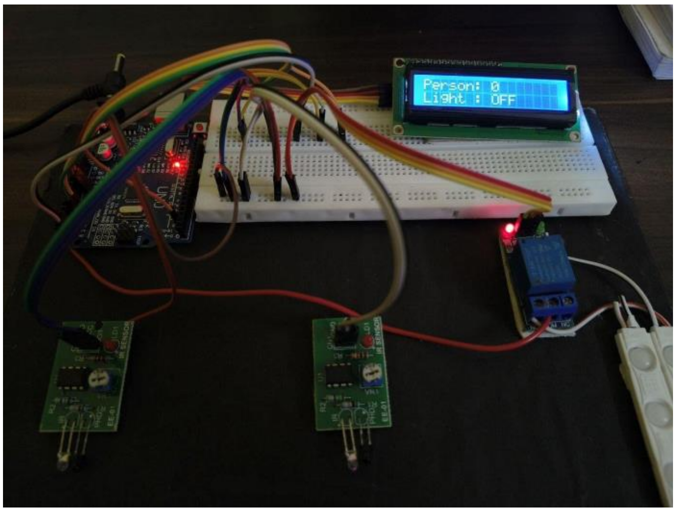

Fig. 4. System in Initial State (Person: 0, Light: OFF)

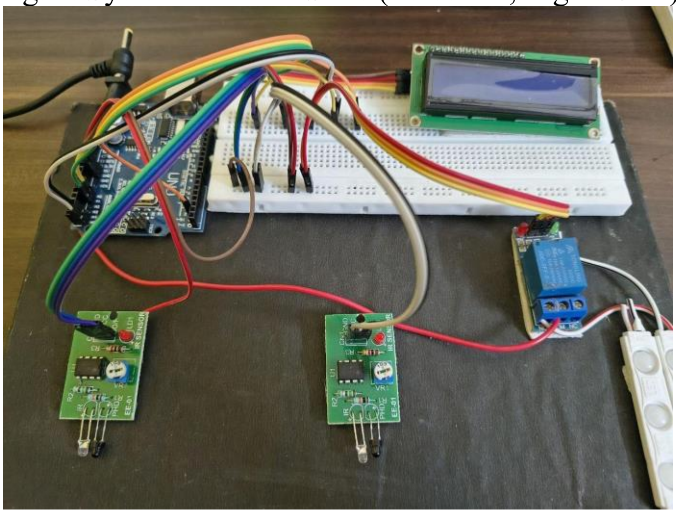

Fig. 5. Breadboard Implementation

A. Counting Accuracy

Over 100 trials, fewer than 5 miscounts were recorded—an accuracy exceeding 95%. Miscounts occurred only when the subject moved significantly slower than walking pace (FSM timeout) or due to minor sensor misalignment from frame vibration. Zero false positives were recorded under artificial lighting.

B. Display Latency

LCD refresh latency from sensor-event detection to updated display was consistently below 50 ms per main loop cycle, providing near-instantaneous occupancy feedback with no perceptible lag.

C. Alert System

The buzzer and LED triggered correctly on every trial in which count equalled the configured maximum (set to 5 for testing). Zero false-positive alerts were recorded. Alerts deactivated correctly after an exit event reduced count below the threshold. The relay switched reliably with no chattering.

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D. Edge Case Testing

Simultaneous two-person passage registered only one entry event—confirming the known IR limitation for high-density scenarios. Partial intrusion tests (hand only) showed 70% suppression via software debouncing. Direct 15 cm IR lamp exposure caused 2 false detections in 20 trials.

E. Cost Analysis

Total hardware cost was under INR 800 (~ USD 10), as itemised in Table I. This positions the system well below commercial occupancy monitors (INR 5,000–50,000), confirming its value for cost-sensitive deployments.

Table I. Bill of materials

Component	**Qty**	**Cost (INR)**
Arduino UNO	1	~350
IR Sensor Modules	2	~80
16×2 LCD Display	1	~80
Relay Module (5V)	1	~50
Buzzer	1	~20
LED + Resistors	1	~10
Breadboard & Wires	1 set	~100
Potentiometer 10kΩ	1	~10
Total		**< 800**

SHORTCOMINGS & LIMITATIONS

Simultaneous passage of two or more persons registers only a single detection event—IR sensing cannot resolve parallel targets on a single axis. Intense ambient IR sources (direct sunlight, halogen lamps) can saturate the phototransistor and cause false triggers despite 38 kHz modulation. The system has no means of distinguishing humans from pets or wheeled objects of sufficient width. Occupancy count is volatile—power loss resets it to zero, with no EEPROM or non-volatile backup implemented. Reliable operation also requires precise mechanical alignment of both sensor pairs; any physical disturbance degrades performance.

FUTURE SCOPE

Integration of an ESP8266 or ESP32 Wi-Fi module would enable cloud-based occupancy dashboards and remote monitoring via MQTT. Replacing IR sensors with ultrasonic or Time-of-Flight (ToF) sensors would improve multi-person detection accuracy. EEPROM-backed count storage would survive power interruptions. Machine learning applied to accumulated historical data could predict peak occupancy hours for proactive HVAC pre-conditioning. RFID or facial recognition could add individual identification alongside aggregate counting. Application domains include smart classrooms, retail footfall analytics, hospital ward management, libraries, gymnasiums, and smart city pedestrian flow monitoring.

CONCLUSION

This paper has presented a complete Bidirectional Visitor Counter System based on dual IR sensor pairs and an Arduino UNO microcontroller. The FSM-based direction-detection algorithm reliably distinguishes entry and exit events through sequential beam-interruption analysis. Prototype evaluation demonstrated greater than 95% counting accuracy, sub-50 ms

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display latency, reliable alert triggering, and stable relay-controlled lighting automation—all at a hardware cost under INR 800.

Inherent limitations of single-axis IR sensing have been candidly documented, and an enhancement roadmap covering IoT connectivity, advanced sensing, and ML analytics has been proposed. The system provides a practical, replicable, and extensible foundation for smart room occupancy management suitable for educational institutions, healthcare facilities, and retail environments.

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