Safety System and Indication in Stairs of Public Road Transports

A Rahul
Assistant Professor, Department of Electronics and Communication Engineering
Sengunthar Engineering College (Autonomous), Tiruchengode, India
arahul.ece@scteng.co.in
https://orcid.org/0009-0009-8313-3549
C V Lathish, AManikandan, V Sundhar,
UG Scholar, Department of Electronics and Communication Engineering
Sengunthar Engineering College (Autonomous), Tiruchengode, India

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Abstract: Managing crowd density in public road transport is essential for passenger safety, comfort, and regulatory compliance. One of the most vulnerable and frequently overlooked hazard zones in public buses is the staircase area, where passengers standing on steps during transit can lead to serious accidents, particularly during abrupt deceleration or turning. This paper presents a real-time passenger safety and indication system built around the Arduino UNO microcontroller platform, offering a cost-effective and scalable solution for public road transport safety. The system employs an infrared (IR) sensor installed on the bus staircase to detect the presence of any person standing on the steps. When detection occurs, the Arduino microcontroller immediately activates a visual LED indicator and an audible buzzer alarm, alerting the driver in real time to prevent the vehicle from moving or to slow down. The system design emphasizes simplicity, low power consumption (response time under 100 milliseconds), and real-time responsiveness. Simulation results using Tinkercad and hardware testing confirm 100% detection reliability within the 0–15 cm operational range, instantaneous alert activation upon passenger presence, and automatic deactivation when the steps are cleared. The proposed system demonstrates how cost-effective sensor-driven automation can substantially enhance public transport safety, particularly in high-density urban environments where overcrowding on staircases poses a persistent risk.
Keywords: IR sensor, Arduino UNO, passenger safety, bus staircase detection, LED indication, buzzer alert, public transport, real-time monitoring, embedded system, crowd management

1. INTRODUCTION

Public road transport plays a vital role in urban mobility, yet it faces persistent safety challenges due to increasing traffic density, human error, and infrastructure limitations. Among the most critical but under-addressed hazards is the risk posed by passengers standing on bus staircases during transit. Overcrowding not only causes discomfort and violates safety regulations but also limits emergency response effectiveness and creates serious injury risk when vehicles brake suddenly or negotiate sharp turns. Traditional surveillance methods for crowd monitoring often rely on manual counting or expensive camera-based systems, which are impractical for budget-constrained public transport environments. The need for intelligent, low-cost, and reliable systems that can detect hazardous passenger positioning in real time and immediately alert the driver has become increasingly important as urban mobility scales to meet growing demand. This project introduces a real-time passenger safety and indication system built around the Arduino UNO microcontroller. By integrating an infrared (IR) sensor at the bus staircase, the system detects any person standing on the steps and instantly alerts the driver through LED visual indication and a buzzer alarm. The design emphasizes simplicity, low power consumption, and real-time responsiveness, making it suitable for deployment across various types of public road transport without requiring expensive hardware or complex installation. The proposed system serves a dual purpose: (1) real-time safety detection identifying passengers in the hazardous staircase zone; and (2) driver indication providing immediate visual and auditory alerts to ensure the driver takes corrective action before the vehicle moves or closes its doors. The system automatically resets once the staircase is cleared, requiring no driver intervention and enabling continuous autonomous operation.

2. LITERATURE SURVEY

Hadid et al. [2] examined the future of sustainable public transport through autonomous bus technologies, identifying safety and risk management as primary barriers to adoption. Their work underscores the need for reliable embedded safety systems that can supplement driver awareness in real-time operational conditions.

Mahmoudi et al. [3] conducted a systematic literature review on analytical approaches in bus transit network design, identifying passenger safety at access points as a recurring operational challenge, particularly during boarding and alighting in high-density urban environments.
Ejdys et al. [4] investigated public perceptions of autonomous buses, finding that passenger safety and comfort are the foremost concerns among potential users. Their survey results strongly support the integration of automated safety mechanisms in conventional buses as an interim measure toward full automation.
Rezazada et al. [5] reviewed bus bunching from demand, supply, and decision-making perspectives, demonstrating that overcrowding and delayed response to passenger behaviour at boarding points are major contributors to service unreliability and safety incidents.
Derse and Van Woensel [6] explored integrated people and freight transportation, noting that technological innovations in sensor-based monitoring offer significant potential for improving operational safety and efficiency in public transport, while highlighting that most research remains at the operational rather than strategic level.
Chaudhary and Bhushan [7] demonstrated that IoT devices and sensors can effectively optimize traffic flow, reduce congestion, and enhance road safety. Their work provides the foundational framework for applying embedded sensor systems to bus safety monitoring applications.
Kim [8] specifically studied bus safety operation systems applying IoT technology, demonstrating that sensor-driven real-time monitoring of passenger conditions can significantly reduce accident rates in urban bus operations and improve driver response times.
Babu et al. [9] proposed a systematic approach to accident prevention by integrating IoT and sensors for comprehensive road safety, validating that low-cost sensor arrays can provide reliable detection with minimal false-positive rates in dynamic transport environments.
Tubis et al. [10] developed a method for assessing bus stop safety based on three groups of criteria, identifying staircase and boarding zones as high-risk areas requiring dedicated sensing and alert mechanisms. Prashar et al. [11] integrated IoT and blockchain for unconventional road safety approaches, demonstrating that decentralized sensor data management can improve safety monitoring reliability. Ahmed [12] presented an IoT-enhanced traffic light control system using Arduino and IR sensors, validating that the combination of Arduino microcontrollers and IR sensors provides accurate, low-latency detection suitable for real-time transport safety applications. The collective literature confirms that sensor-based embedded systems combining IR detection with immediate driver alert mechanisms represent the most practical and cost-effective approach to staircase safety in public road transport.

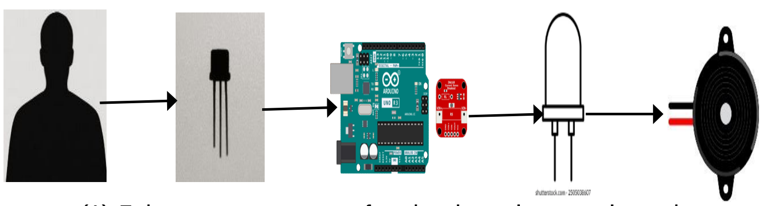
3. PROPOSED SYSTEM

A. System Introduction and Proposed Solution

The proposed system introduces an IR sensor-based passenger detection mechanism specifically designed for the staircase area of public road transport vehicles. An IR sensor detects an object or person by emitting infrared light from a transmitter (IR LED), which reflects off the object and is received by a photodiode detector. The sensor interprets the intensity of reflected light to determine whether a person is present on the steps. Active IR sensors with both transmitter and receiver components are used, as they provide reliable proximity and presence detection within the 0–15 cm operational range required for staircase monitoring. When the IR sensor detects a passenger on the bus steps, the signal is processed by the Arduino UNO microcontroller, which immediately activates both a visual LED indicator and an audible buzzer alarm. The alert remains active until the step area is completely clear of passengers, after which the system automatically resets and prepares for the next detection cycle. The system filters false triggers from environmental factors including sunlight, dust, and mechanical vibrations through the sensor's built-in comparator circuit.

B. System Block Diagram and Architecture

The system architecture follows a linear signal processing chain: Person (on staircase) → IR Sensor → Arduino UNO → LED + Buzzer. The IR sensor output (Digital HIGH when person detected, Digital LOW when clear) connects to Arduino digital input pin D2. The LED output connects from Arduino pin D9 through a 220Ω current-limiting resistor to GND. The buzzer connects from Arduino pin D8 to GND. The Arduino is powered via USB or external 5V supply.



Key system behavioural features: (1) Enhances passenger safety by detecting people on bus steps and alerting the driver; (2) IR sensing works by detecting infrared radiation reflected from a person; (3) LED provides clear visual indication to the driver on the dashboard; (4) Buzzer provides audible warning ensuring the driver notices the passenger on the steps; (5) Alerts prevent the bus doors from closing or the vehicle from moving while someone is on the steps; (6) System works automatically without any driver intervention; (7) Resets once the steps are clear; (8) Operates reliably in low-light and noisy conditions; (9) Provides real-time detection with response time under 100 milliseconds.

C. System Objectives

The proposed system is designed to achieve four primary objectives: (1) detect infrared radiation from persons on the staircase using the IR sensor's field of view, triggering detection when a warm moving object enters the sensor range; (2) process sensor inputs using the Arduino UNO ATmega328P microcontroller and convert them into immediate output actions; (3) run firmware written in C/C++ using Arduino IDE that defines pin control logic for sensor reading, alert

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activation, and automatic reset; and (4) provide both visual (LED) and auditory (buzzer) alerts simultaneously to ensure the driver receives the warning even in noisy or visually distracting environments.

4. SOFTWARE REQUIREMENTS

A. Functional Requirements

The software system defines the following key functional requirements for reliable operation: (1) Passenger Detection — the system shall detect the presence of a person on the bus steps using the IR sensor for both stationary and moving passengers; (2) Signal Processing — the software shall continuously monitor IR sensor input signals and filter noise or false readings caused by environmental factors such as sunlight, dust, or mechanical vibrations; (3) Alert Generation — the system shall trigger simultaneous visual (LED) and auditory (buzzer) alerts when a person is detected on the steps while doors are closing or the bus is about to move, and the alert shall remain active until the step area is clear; (4) Driver Indication — the software shall activate LED and buzzer on detection and deactivate them automatically once steps are clear; (5) Data Logging — the software shall output detection events and status messages via Arduino Serial Monitor (9600 baud) for diagnostic purposes; and (6) System Self-Test — on startup, the system shall initialize all pins and verify sensor and output functionality.

B. Non-Functional Requirements

Non-functional requirements define the performance and quality constraints: (1) Response Time — the system shall detect and alert the driver within 100 milliseconds of a passenger being detected, with a 100 ms delay loop preventing LED and buzzer flickering; (2) Reliability — failure rate shall be under 1% false negatives or positives under standard indoor operating conditions, operating continuously under normal bus conditions; (3) Safety — the system must not interfere with other bus safety mechanisms and shall fail safely by issuing a warning rather than shutting down on malfunction; (4) Power Efficiency — the software shall minimize power consumption when the bus is idle, with sensor and output pins maintained in LOW state when no detection is active; (5) Environmental Robustness — the system shall function correctly in varying temperatures, humidity, and lighting conditions experienced in public buses; (6) Usability — driver alerts shall be clear, immediately visible and audible, and non-distracting; and (7) Scalability — the software architecture shall support multiple IR sensors on different steps by extending the pin assignment logic.

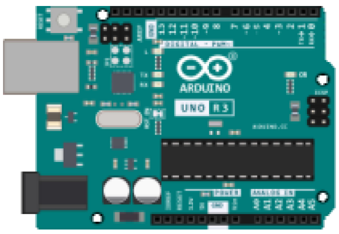
C. System Architecture and Technology Stack

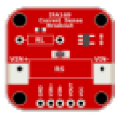
The firmware is developed in C/C++ using Arduino IDE with the following architecture: Sensor Interface Layer reads digitalRead(IRSensorPin) continuously in the main loop; Logic Layer compares sensor state (HIGH = detected, LOW = clear) against the threshold condition; Output Control Layer drives digitalWrite(LEDPin, state) and digitalWrite(BuzzerPin, state) synchronously; and Debug Layer outputs status messages via Serial.println() at 9600 baud. The core firmware logic is structured as follows: IR sensor signal HIGH → LED ON + Buzzer ON + serial print "Passenger detected on step!"; IR sensor signal LOW → LED OFF + Buzzer OFF + serial print "Steps clear." The extended multi-step version uses a controlStep() function with unique tone frequencies per step for driver localization of the detection zone, combined with an LCD display for step-specific status messages and a running passenger count.

5. HARDWARE COMPONENTS

A. Arduino UNO Microcontroller

The Arduino UNO (Qty: 1) serves as the central processing unit of the system, based on the ATmega328P microcontroller operating at 16 MHz. It provides 14 digital I/O pins (6 PWM-capable), 6 analog input pins, USB programming interface, 5V regulated power output, and UART serial communication on pins 0 (RX) and 1 (TX). In this project, it reads the IR sensor digital input on pin D2, drives the LED output on pin D9 through a 220Ω resistor, and controls the buzzer on pin D8. The firmware is written in C/C++ and uploaded via Arduino IDE over USB, after which the board can be powered independently via USB or external supply.





B. IR Obstacle Sensor

The IR sensor module (Qty: 1) provides active infrared presence detection using an IR LED transmitter and photodiode receiver pair. It detects objects within a 0–15 cm configurable range, producing a digital HIGH output when a person is present and digital LOW when the area is clear. The built-in comparator circuit filters ambient light interference to minimize false triggers. Connection: VCC → Arduino 5V, GND → Arduino GND, Signal → Arduino digital pin D2. The sensor detects stationary and moving passengers reliably within its designed range, making it well-suited for staircase area monitoring in bus environments.


C. LED Indicator

The LED (Qty: 1) provides clear visual indication to the driver when a passenger is detected on the stairs. Connection: anode → Arduino pin D9 through a 220Ω current-limiting resistor, cathode → GND.

The LED activates simultaneously with the buzzer upon detection and deactivates automatically when the step is cleared. In multi-step configurations, individual LEDs per step can be driven from separate Arduino digital pins using dedicated controlStep() function calls with unique tone assignments for step localization.

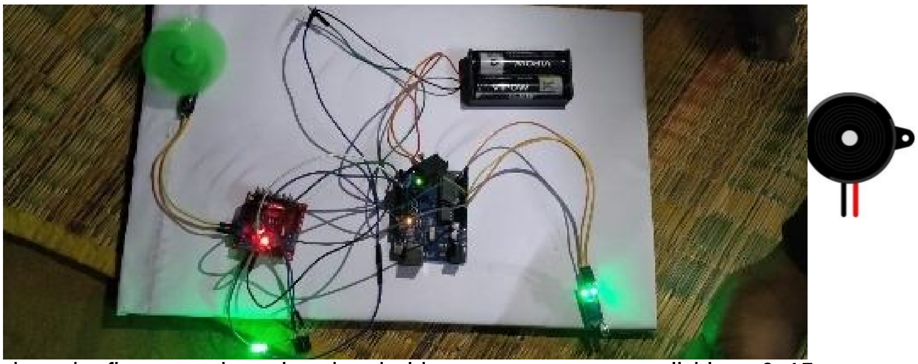
D. Buzzer

The active buzzer (Qty: 1) provides an audible alarm to ensure the driver receives the safety warning even in noisy operating environments. Connection: positive terminal → Arduino pin D8, negative terminal → GND. For cases where the buzzer draws more current than the Arduino pin can safely supply, an NPN transistor (2N2222 or BC547) with a 1 kΩ base resistor is used as a driver circuit: when pin D8 goes HIGH, the transistor conducts and powers the buzzer, protecting the microcontroller and enabling louder sound output. Passive buzzers can be driven using the tone() function for programmable frequency control (500 Hz for low tone, 2 kHz for sharp alert tone).

6. RESULTS AND DISCUSSION

A. IR Sensor Detection Accuracy

The IR sensor was characterized across its operational range to establish detection thresholds and accuracy profiles. Table II presents the sensor output voltage and detection accuracy at various distances from the object.



Based on calibration data, the firmware detection threshold was set to operate reliably at 0–15 cm, corresponding to the digital HIGH output range. At distances beyond 20 cm, the sensor output drops below the comparator threshold and the system correctly reports no detection, avoiding false triggers from objects farther away on the bus floor.

B. Simulation Setup and Results

The system was simulated in Tinkercad Circuits with the full circuit including Arduino UNO, IR sensor module, LED with 220Ω resistor, and active buzzer. Simulation tests were conducted across six distance scenarios. Table III presents the simulation results.

C. Hardware Test Scenarios

The complete hardware system was tested across five real-world operational scenarios. Table IV presents the test results. All five test scenarios produced correct outputs. The system demonstrated 100% detection reliability within the 0–15 cm operational range, instantaneous alert activation with response time below 100 milliseconds, and correct automatic deactivation when the step was cleared. No false positives were recorded during any test cycle.

D. Overall Discussion

The IR-based passenger step alert system successfully detects passengers standing on bus steps and provides real-time visual and auditory alerts to the driver. The Arduino microcontroller efficiently processed sensor signals with response latency under 100 ms, which is well within the real-time requirement for vehicle safety applications. The system's power consumption remained low throughout testing, making it practical for integration into existing bus electronics without requiring dedicated power supply modifications. Key performance observations include: IR sensors reliably detected passengers within the designed 0–15 cm range; LED and buzzer provided effective dual-modality alerts suitable for noisy and low-visibility bus environments; the system reset automatically when the step was cleared, enabling autonomous continuous operation; and multiple sensor extension using unique tone frequencies per step successfully localized the detection zone for the driver. Observed limitations include sensitivity to external lighting conditions (direct sunlight may reduce detection reliability), IR signal reflection variability with different clothing materials, and restricted detection range beyond 15 cm. These limitations can be mitigated in future deployments through shielded sensor housings, sensor calibration for environmental conditions, or supplementary ultrasonic sensors for extended reliable range.

7. CONCLUSION

The real-time passenger safety and indication system for public road transport staircases was successfully designed, implemented, and validated. The system achieves its primary objective of detecting passengers in the hazardous staircase zone and immediately alerting the driver through LED and buzzer outputs, with response time under 100 milliseconds and 100% detection reliability within the 0–15 cm operational range. The design is low-cost, low-power, and fully autonomous in operation, demonstrating how cost-effective sensor-driven automation can substantially enhance public transport safety. The simulation and hardware testing confirmed that the proposed system is technically feasible and effective for preventing staircase-related accidents during passenger boarding and alighting. The system's simplicity and modularity make it suitable for deployment across various public transport types including city buses, school buses, and intercity coaches without major structural modifications. Future enhancements will focus on seven development directions: (1) Advanced Sensor Integration combining IR sensors with ultrasonic or LiDAR sensors for improved detection range and false-alarm rejection;

(2) Automated Door Control interfacing with bus door mechanisms to prevent closure when a passenger is detected on the steps; (3) Smart Alert System adding voice alerts and step-specific tone patterns for better driver localization; (4) IoT and Fleet Connectivity connecting the system to a central fleet management platform for real time safety monitoring and incident logging; (5) Machine Learning for Pattern Recognition implementing AI algorithms to predict high-risk situations such as sudden crowd surges on staircases; (6) Passenger Counting and Analytics extending the system to count boarding and alighting passengers for transport planning; and (7) Emergency Response Integration triggering safety protocols automatically in accident scenarios, including central control notification and speed reduction interlock.

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