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BUS SAFETY: INTELLIGENT PEDESTRAIN DETECTION SYSTEM

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Abstract

The Bus Footboard Detection and Safety Control System is an intelligent safety mechanism developed to reduce accidents caused by unsafe passenger boarding and standing on bus footboards. In many public transportation systems, passengers often travel while standing near the entrance or exit footboard, creating a serious risk of falling during vehicle movement. This project introduces an automated monitoring and control solution using an Arduino-based embedded system integrated with infrared (IR) sensors, Bluetooth communication, DC motor control, buzzer alerts, and an I2C LCD display. Two IR sensors are positioned at the front and rear footboards of the bus to continuously monitor passenger presence. The sensors operate on active-low logic, where detection of a person triggers a safety response. When a passenger is detected standing on either footboard, the system immediately stops the bus motor, activates an audible buzzer alarm, and displays warning information on the LCD screen. Additionally, the system sends alert messages through Bluetooth communication to a mobile device, informing the driver or operator about the specific footboard location where unsafe boarding is detected. The project also incorporates Bluetooth-based manual movement control using an HC-05 module, enabling directional commands such as forward, backward, left, right, and stop. Safety monitoring has higher priority than movement commands, ensuring that bus operation is automatically disabled whenever a hazardous condition is detected. The system supports both uppercase and lowercase command recognition for user convenience. This low-cost and efficient safety system demonstrates how embedded technology can enhance public transport security by preventing unsafe movement during passenger boarding. The proposed solution is suitable for prototype-level smart transportation applications and can be further expanded with wireless networking, GPS tracking, or cloud-based monitoring for advanced vehicle safety systems.

Keywords: Bus Footboard Safety, Arduino Uno, IR Sensor Detection, Bluetooth-Based Vehicle Control.

1. Introduction

Road transportation is one of the most widely used modes of travel worldwide, with buses serving as a primary means of public transportation due to their affordability, accessibility, and ability to transport large numbers of passengers efficiently. Despite their advantages, buses are frequently involved in accidents related to pedestrian collisions, particularly in densely populated urban environments, school zones, bus terminals, and intersections where pedestrian movement is unpredictable. Limited driver visibility caused by blind spots, adverse weather conditions, poor lighting, and human fatigue significantly increases the likelihood of accidents. Consequently, enhancing pedestrian safety has become a critical objective in the development of intelligent transportation systems (ITS) and advanced driver assistance systems (ADAS) **[1]**.

Recent advancements in computer vision, artificial intelligence (AI), and embedded sensing technologies have enabled the development of intelligent pedestrian detection systems capable of identifying vulnerable road users in real time. These systems utilize cameras, radar, LiDAR, ultrasonic sensors, or multimodal sensor fusion to continuously monitor the surroundings of a vehicle and detect pedestrians with

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high accuracy. Deep learning algorithms, particularly convolutional neural networks (CNNs), vision transformers, and object detection frameworks such as YOLO, SSD, and Faster R-CNN, have significantly improved the capability of detecting pedestrians under varying environmental and traffic conditions **[2]**. The integration of these algorithms with embedded computing platforms has further facilitated real-time deployment in commercial transportation systems.

Bus safety presents unique challenges compared with passenger vehicles because buses have larger dimensions, wider blind spots, and frequent stopping operations that increase pedestrian interaction. Children, elderly individuals, and persons with disabilities are especially vulnerable during boarding and alighting operations. Traditional safety measures such as mirrors and manual driver observation are often insufficient for detecting pedestrians in critical blind zones. Therefore, intelligent pedestrian detection systems equipped with automated warning mechanisms can assist drivers by providing timely alerts before potential collisions occur, thereby reducing reaction time and improving operational safety **[3]**.

The rapid growth of smart cities has accelerated the adoption of Internet of Things (IoT)-based transportation infrastructures, where connected vehicles exchange information with roadside units and cloud platforms to improve traffic management and accident prevention. Intelligent bus safety systems can leverage IoT communication, edge computing, and vehicle-to-everything (V2X) technologies to receive contextual traffic information, monitor pedestrian movement, and support proactive decision-making. Such integrated systems contribute to safer urban mobility while enabling efficient fleet management and predictive maintenance of transportation assets **[4]**.

Machine learning techniques have further enhanced pedestrian detection by enabling adaptive learning from diverse traffic scenarios. Modern detection models are trained on large-scale datasets containing pedestrians of different poses, clothing variations, occlusions, and environmental conditions, thereby improving generalization performance. Furthermore, attention mechanisms and feature pyramid networks have been introduced to improve small-object detection, making it possible to accurately identify pedestrians at greater distances or under partial occlusion **[5]**. These advancements have substantially increased detection accuracy while maintaining computational efficiency suitable for real-time applications.

Despite considerable progress, several challenges remain in developing reliable pedestrian detection systems for buses. Environmental factors such as rain, fog, nighttime illumination, and heavy traffic congestion can reduce sensor performance and detection accuracy. Similarly, dynamic urban environments often contain multiple moving objects that increase computational complexity and may result in false alarms or missed detections. Addressing these limitations requires robust sensor fusion strategies, optimized deep learning architectures, and efficient real-time processing techniques capable of maintaining high accuracy under diverse operating conditions **[6]**.

Recent research has also emphasized the importance of integrating intelligent pedestrian detection with automatic emergency braking (AEB), driver monitoring systems, and collision avoidance frameworks. By combining pedestrian recognition with risk assessment algorithms, buses can predict potential collision trajectories and initiate warning or intervention mechanisms before accidents occur. Such intelligent safety frameworks not only improve passenger and pedestrian protection but also support compliance with evolving transportation safety regulations and autonomous driving standards **[7]**.

Motivated by these developments, this study proposes an **Intelligent Pedestrian Detection System for Bus Safety** that leverages modern computer vision and AI-based detection techniques to enhance pedestrian awareness around buses. The proposed framework aims to achieve accurate real-time pedestrian detection, minimize false detections, and provide timely alerts to drivers under varying environmental conditions. By integrating efficient object detection algorithms with intelligent decision-making mechanisms, the proposed system seeks to improve road safety, reduce pedestrian-related accidents, and contribute to the advancement of next-generation intelligent public transportation systems **[8]**.

2. Literature Review

Recent studies have explored deep learning-based pedestrian detection techniques for intelligent transportation systems to improve road safety and minimize collisions involving vulnerable road users. Modern object detection frameworks based on convolutional neural networks have demonstrated superior performance over traditional feature extraction methods by learning complex visual representations directly from large-scale datasets. These approaches achieve high detection accuracy under normal traffic conditions while maintaining real-time processing capabilities suitable for deployment in smart vehicles. However, performance degradation remains a concern in adverse weather conditions, low illumination, and partial occlusions, highlighting the need for more robust detection strategies. **[9]**

Several investigations have focused on integrating multiple sensing modalities, including cameras, LiDAR, radar, and ultrasonic sensors, to overcome the limitations of individual sensors. Sensor fusion techniques combine complementary information from different sources, improving pedestrian localization, distance estimation, and object classification. Such integrated systems have shown improved reliability in challenging urban environments where traffic density, dynamic obstacles, and environmental uncertainties affect detection performance. Nevertheless, increased computational complexity and higher implementation costs remain significant challenges for practical deployment in public transportation systems. **[10]**

Research on real-time pedestrian detection has increasingly adopted one-stage object detection models due to their balance between computational efficiency and detection accuracy. Architectures such as YOLO and SSD have demonstrated the ability to process video streams at high frame rates while accurately identifying pedestrians in complex traffic scenarios. Continuous improvements in feature extraction mechanisms, multi-scale detection, and attention modules have further enhanced the detection of small and partially occluded pedestrians, making these models suitable for embedded edge devices installed in buses and other commercial vehicles. **[11]**

Recent advancements have emphasized the application of artificial intelligence within Advanced Driver Assistance Systems (ADAS) to provide collision avoidance and driver warning functionalities. Intelligent pedestrian detection modules have been integrated with automatic emergency braking, lane monitoring, and driver alert systems to reduce reaction time during hazardous situations. These integrated safety frameworks have demonstrated significant improvements in preventing pedestrian-related accidents by continuously monitoring the surrounding environment and generating timely warnings when collision risks are detected. **[12]**

The emergence of Internet of Things (IoT) technologies and vehicle-to-everything (V2X) communication has enabled connected transportation systems capable of exchanging real-time traffic and environmental information. Intelligent pedestrian detection systems integrated with cloud computing and edge computing platforms facilitate faster decision-making by processing critical information closer to the vehicle while maintaining centralized monitoring capabilities. Such connected architectures improve traffic awareness, optimize route safety, and enhance overall transportation efficiency, although issues related to communication latency, cybersecurity, and data privacy continue to require further investigation. **[13]**

Recent studies have also investigated transformer-based vision models and attention mechanisms for pedestrian detection. Unlike conventional convolutional approaches, transformer architectures effectively capture long-range spatial dependencies and contextual information within images, resulting in improved detection performance under crowded and highly dynamic traffic environments. Hybrid models combining convolutional neural networks with

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transformer-based feature extraction have demonstrated enhanced robustness against variations in pedestrian appearance, scale, and background complexity while maintaining competitive inference speeds for real-time applications. **[14]**

Despite substantial progress in intelligent pedestrian detection technologies, existing approaches continue to face challenges related to environmental adaptability, computational efficiency, false alarm reduction, and deployment on resource-constrained embedded platforms. Current research trends focus on developing lightweight deep learning architectures, optimizing sensor fusion strategies, and incorporating predictive risk assessment techniques to improve detection accuracy without compromising real-time performance. These advancements are expected to play a crucial role in enhancing bus safety and reducing pedestrian-related accidents within future intelligent transportation systems. **[15]**

3. Analysis and Design System Overview

The Bus Footboard Detection and Safety Control System is an embedded safety solution developed to monitor passenger presence near bus footboards and prevent unsafe vehicle operation. The system combines sensing, wireless communication, alert generation, and motor control to create an automated passenger safety mechanism. It is designed using an Arduino Uno as the main controller, which coordinates all hardware components and executes safety decisions. The overall system consists of two infrared sensors placed at the front and rear footboards of the bus. These sensors continuously monitor passenger activity and operate using active-low logic. When a passenger is detected near either footboard, the corresponding IR sensor outputs a low signal to the controller. The microcontroller immediately processes this input and determines whether the bus movement should be stopped. The system includes dual DC motors to simulate bus movement. These motors are controlled through directional commands received from Bluetooth communication. The Bluetooth functionality is implemented using an HC-05 Bluetooth Module, allowing a mobile device to send commands such as forward, backward, left, right, and stop. The system supports both uppercase and lowercase commands for improved usability. Passenger safety is treated as the highest operational priority. When either footboard sensor detects a person, the controller overrides all movement commands and stops the motors immediately. At the same time, a buzzer alarm is activated to provide an audible warning, and alert information is displayed on the I2C LCD screen. Additionally, Bluetooth messages are transmitted to notify the user about the detected footboard condition.

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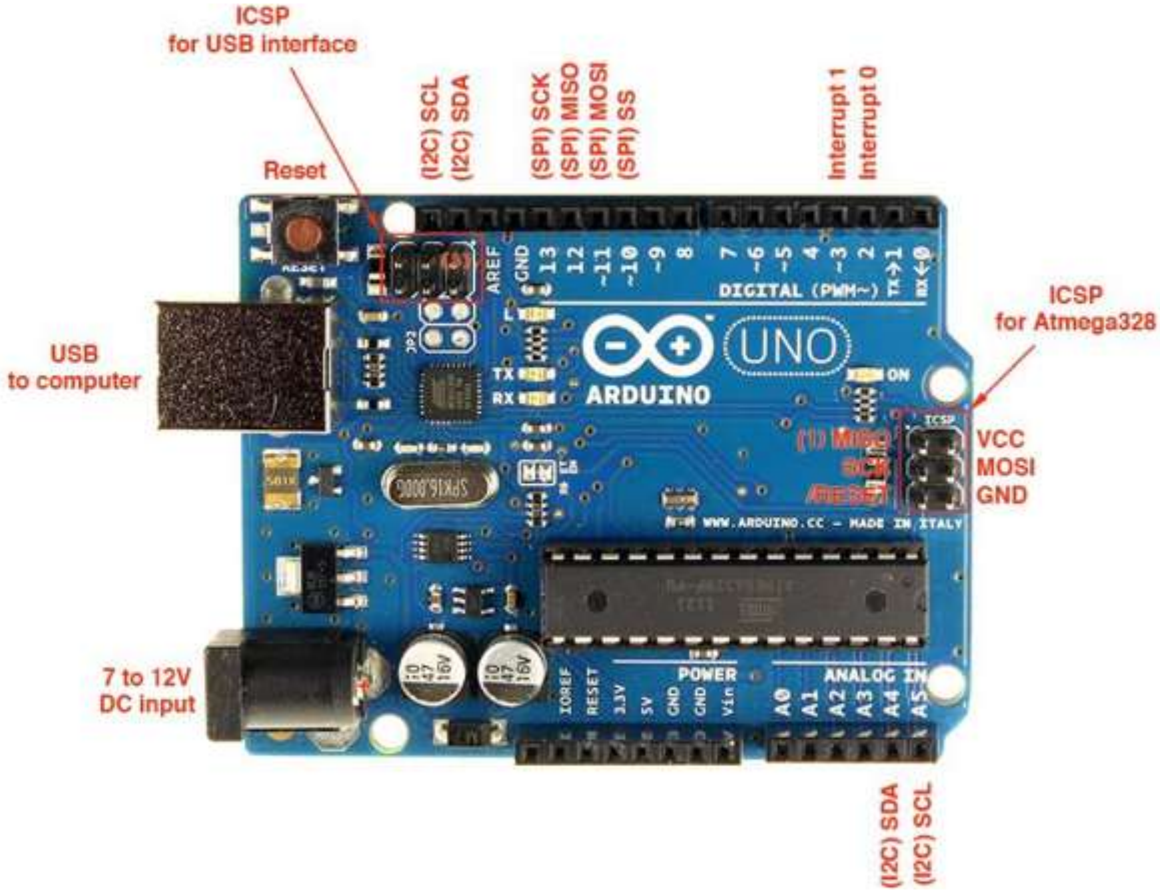

Input and Output Each of the 14 digital pins on the Arduino Uno can be used as an input or output, using pinMode(), digitalWrite(), and digitalRead() functions. They operate at 5 volts. Each pin can provide or receive a maximum of 40 mA and has an internal pull-up resistor (disconnected by default) of 20-50 kOhms.

In addition, some pins have specialized functions:

Serial: pins 0 (RX) and 1 (TX). Used to receive (RX) and transmit (TX)

TTL serial data. These pins are connected to the corresponding pins of the ATmega8U2 USB-to-TTL Serial chip. External Interrupts: pins 2 and 3.

These pins can be configured to trigger an interrupt on a low value, a rising or falling edge, or a change in value. See the attachInterrupt() function for details.

PWM: 3, 5, 6, 9, 10, and 11. Provide 8-bit PWM output with the analogWrite() function.

SPI: 10 (SS), 11 (MOSI), 12 (MISO), 13 (SCK). These pins support SPI communication using the SPI library.

LED: 13. There is a built-in LED connected to digital pin 13. When the pin is HIGH value, the LED is on, when the pin is LOW, it's off. The Uno has 6 analog inputs, labeled A0 through A5, each of which provide 10 bits of resolution (i.e. 1024 different values).

By default they measure from ground to 5 volts, though is it possible to change the upper end of their range using the AREF pin and the analogReference() function.

Additionally, some pins have specialized functionality: TWI: A4 or SDA pin and A5 or SCL pin. Support TWI communication using the Wire library.

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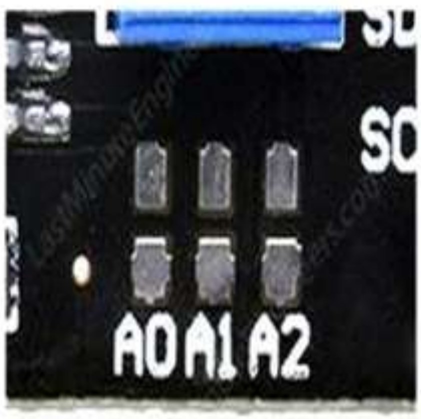
There are a couple of other pins on the board: AREF. Reference voltage for the analog inputs.

Used with analogReference(). Reset. Bring this line LOW to reset the microcontroller. Typically used to add a reset button to shields which block the one on the board.

I2C Address of LCD

If you are using multiple devices on the same I2C bus, you may need to set a different I2C address for the board, so that it does not conflict with another I2C device. To do so, the board has three solder jumpers (A0, A1 and A2) or solder pads.



Each of these is used to hardcode the address. If a jumper is shorted with a blob of solder, it sets the address. An important point here is that many companies manufacture the same PCF8574 chip: Texas Instruments and NXP Semiconductors to name a few. And the I2C address of your LCD depends on the chip manufacturer.

4. Implementation

The implementation of the Bus Footboard Detection and Safety Control System involves both hardware integration and software programming to achieve real-time passenger safety monitoring and vehicle movement control. The system is developed using an embedded platform where sensors, communication modules, output devices, and motor drivers are interconnected with an Arduino Uno.

Hardware Implementation

The hardware implementation begins with the integration of the Arduino Uno as the central controller responsible for processing sensor inputs and controlling system outputs. Two infrared sensors are installed at the front and rear footboards of the bus to detect passenger presence. These sensors operate using active-low logic, meaning the output becomes low when an object is detected.

An I2C LCD display is connected to the Arduino through the SDA and SCL communication pins to provide real-time system status information. A buzzer is used as an audible warning indicator whenever unsafe conditions are detected. Two DC motors are connected through motor driver control pins to simulate bus movement in different directions. Wireless communication is established using an HC-05 Bluetooth Module. The Bluetooth module communicates with the Arduino using serial communication, enabling mobile devices to transmit movement commands and receive safety notifications.

5. Software Implementation

The software implementation is developed using the Arduino IDE environment. The program continuously monitors the status of both IR sensors and executes predefined safety logic. When a sensor detects a passenger on the footboard, the controller immediately stops the motors, activates the buzzer, updates the LCD display, and sends an alert message through Bluetooth. The program also manages directional control through Bluetooth commands. Commands such as forward, backward, left, right, and stop are processed by the controller to operate the motors accordingly. The software is designed to recognize both uppercase and lowercase characters to improve user interaction. A status-tracking mechanism is implemented to avoid repeated Bluetooth message transmission. The system only sends alerts when a change in safety status occurs, reducing communication redundancy and improving efficiency.

Results and Discussion

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The Bus Footboard Detection and Safety Control System was successfully implemented and tested using an Arduino Uno, infrared sensors, DC motors, buzzer, I2C LCD display, and an HC-05 Bluetooth Module. The system demonstrated reliable performance in detecting passenger presence near the footboard and executing automatic safety actions. During testing, both infrared sensors were positioned at the front and rear footboard locations. The sensors continuously monitored passenger presence and responded using active-low logic. When no object was detected, the system remained in safe mode, allowing Bluetooth-based movement control. The LCD displayed system readiness, and the bus model responded correctly to movement commands such as forward, backward, left, right, and stop.

When a person or object was placed near the front IR sensor, the system immediately identified the unsafe condition. The DC motors stopped automatically, preventing bus movement. Simultaneously, the buzzer activated to provide an audible alert, and the LCD displayed a warning message indicating front footboard detection. Bluetooth notification messages were successfully transmitted to the connected mobile device, improving operator awareness. Similarly, when the rear footboard sensor detected an object, the system responded by disabling movement and generating a rear footboard alert. When both sensors detected occupancy simultaneously, the system displayed a combined warning message and ensured complete motor shutdown.

This demonstrated the effectiveness of multi-location monitoring. The Bluetooth communication system functioned reliably with uppercase and lowercase command recognition. The addition of command normalization improved user convenience and reduced input restrictions. The system also avoided repeated Bluetooth alerts by transmitting messages only when the safety state changed. The experimental results confirmed that the safety logic had higher priority than movement commands. Even when movement instructions were received through Bluetooth, the motors remained disabled during unsafe conditions. This behavior ensured that passenger protection was always maintained. The developed prototype proved to be cost-effective, responsive, and suitable for small-scale intelligent transportation safety applications.

Conclusion

The Bus Footboard Detection and Safety Control System was successfully designed and implemented as an intelligent safety solution for public transportation applications. The system effectively addresses the problem of unsafe passenger boarding by continuously monitoring footboard areas and preventing vehicle movement during hazardous conditions. By integrating infrared sensing, motor control, Bluetooth communication, buzzer alerts, and LCD notification, the project demonstrates a practical approach to improving passenger safety. The use of an Arduino Uno enabled efficient coordination between hardware components and real-time decision-making. Two IR sensors positioned at the front and rear footboards provided reliable passenger detection using active-low logic. Whenever unsafe occupancy was detected, the system successfully stopped the motors, activated warning alarms, displayed alerts, and transmitted Bluetooth notifications through an HC-05 Bluetooth Module. The system also supported Bluetooth-based directional control, allowing movement commands such as forward, backward, left, right, and stop. Safety control maintained higher priority than manual operation, ensuring that vehicle movement was always restricted during dangerous conditions. The experimental results confirmed stable performance, effective sensor response, and improved operational reliability. Overall, the project provides a low-cost, easy-to-implement, and efficient embedded safety system suitable for prototype-level smart transportation applications. It highlights the importance of automation in reducing accidents and enhancing passenger protection.

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