International Journal of Research in Engineering, Science and Management
Volume 8, Issue 3, March 2025
https://www.ijresm.com | ISSN (Online): 2581-5792

Smart Pedestrian Safety System for Urban Crosswalks

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***Abstract*: The growing demand for smart city solutions has led to the development of intelligent transportation systems. This paper presents a Pedestrian Safety System that integrates pedestrian and vehicle detection to optimize street lighting. The system employs TCRT5000 IR sensors, HC-SR04 ultrasonic sensors, PIR motion sensors, and NeoPixel LEDs to enhance pedestrian safety and energy efficiency. The proposed model dynamically adjusts streetlight brightness based on real-time detection, providing enhanced visibility and energy savings. Experimental results demonstrate the system's effectiveness in reducing unnecessary power consumption while ensuring road safety.**

***Keywords*: Energy efficiency, NeoPixel LED, pedestrian detection, smart streetlight, urban safety, vehicle detection.**

1. Introduction

With rapid [1] urbanization and increasing vehicular traffic, conventional streetlighting systems have become a major contributor to energy consumption. [2] Traditional systems remain illuminated at full brightness throughout the night, leading to unnecessary power wastage. Moreover, such systems fail to adapt to changing traffic conditions, compromising both energy efficiency and pedestrian safety.

The proposed Smart Streetlight System aims to overcome these limitations by incorporating real-time pedestrian and vehicle detection. By utilizing [3] TCRT5000 IR sensors, HC-SR04 [3] ultrasonic sensors, and PIR motion sensors, the system ensures that streetlights operate at optimal brightness levels only when necessary. Additionally, the system integrates NeoPixel LEDs for dynamic brightness control and a buzzer alert system to warn pedestrians in case of potential hazards.

The key objectives of the system are:

- *Energy conservation*: Reduce unnecessary energy consumption by dimming or turning off streetlights in the absence of movement.
- *Enhanced pedestrian safety*: Improve visibility when pedestrians are detected at crosswalks.
- *Intelligent vehicle detection*: Adjust streetlight brightness based on approaching or departing vehicles.
- *Cost-effectiveness*: Minimize operational costs by implementing an [14] efficient and automated lighting system.

By addressing these aspects, the proposed smart streetlighting solution contributes to sustainable urban development, aligning with global smart city initiatives.

2. Literature Review

A. Existing Smart Street Lighting Systems

Several studies have explored adaptive street lighting solutions using motion sensors, image processing, and IoT-based control. Systems utilizing [4] PIR sensors for motion-based activation have demonstrated effectiveness in reducing energy consumption, while computer vision-based detection systems offer precise object recognition but require high computational resources.

In [5], a PIR and IR sensor-based system was proposed to dim or activate streetlights based on pedestrian movement. However, this approach had limitations in differentiating between human and non-human motion. Another study in [6] utilized ultrasonic sensors for vehicle detection but lacked a pedestrian safety mechanism. Research in [7] explored machine learning techniques to predict traffic patterns and adjust lighting, though the computational complexity made real-time implementation challenging.

B. Contribution of this Work

Our system builds upon previous studies by integrating TCRT5000 IR sensors, HC-SR04 ultrasonic sensors, and PIR motion sensors to achieve precise pedestrian and vehicle detection. [8] [9] The use of NeoPixel LEDs for dynamic brightness control optimizes visibility while conserving energy. Furthermore, a buzzer alert system ensures pedestrian safety at crosswalks, making this system more robust compared to previous implementations.

3. System Architecture

A. Hardware Components

- *TCRT5000 IR Sensors*: Detect pedestrian footsteps at key crosswalk points.
- *HC-SR04 Ultrasonic Sensors*: Identify pedestrians waiting to cross and detect approaching vehicles.
- *PIR Sensors*: Detect motion of pedestrian approaching the crosswalk

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Table 1
Output control

Components	Mode of Operation
Streetlights	Low Beam (idle), High Beam (pedestrian detected), Flashing Red (emergency)
LED Warning Strips (WS2812B)	Green (No pedestrian), Orange (Pedestrian walking), Red (Emergency Alert)
Buzzer	OFF (normal), Short Beeps (pedestrian detected), Continuous Beep (emergency alert)

Table 2
Decision making algorithm

Condition	Streetlight	LED Strip	Buzzer
No pedestrian detected	Low Beam (Idle Mode)	Green	OFF
Pedestrian waiting at sidewalk	High Beam	Orange	OFF
Pedestrian walking on crosswalk	High Beam	Orange	OFF
Vehicle detected within range & pedestrian on crosswalk	High Beam	Red	ON (Emergency Alert)
Both pedestrian & vehicle detected together (Collision Risk)	High Beam	Flashing Red	Continuous ON

- *NeoPixel LED*: Controls streetlight brightness dynamically.
- *Buzzer*: Alerts pedestrians in case of simultaneous pedestrian and vehicle presence.
- *Arduino Microcontrollers*: Process sensor data and control lighting behavior.

B. Working Mechanism

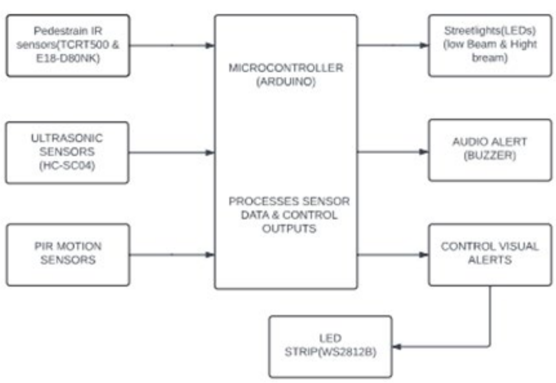

Fig. 1. Block diagram of pedestrian safety system

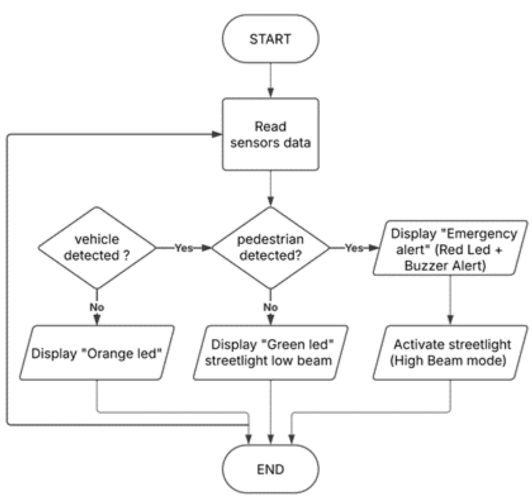

Fig. 2. Work flow of pedestrian safety system

1. *Pedestrian Detection*: TCRT5000 IR and PIR sensors detect movement at the crosswalk, activating the streetlight.
2. *Vehicle Detection*: HC-SR04 ultrasonic sensors identify approaching vehicles and adjust lighting accordingly.
3. *Dynamic Lighting*: NeoPixel LED adjusts brightness based on detection, switching between low and high beam.
4. *Safety Alert*: If both pedestrian and vehicle detection occur simultaneously, the system triggers a buzzer alarm.

4. Implementation and Testing

The Smart Pedestrian Safety System is implemented using a microcontroller-based setup that integrates various sensors and output devices to detect pedestrians, monitor vehicle movement, and [10] control streetlights. The implementation consists of hardware assembly, software development, and integration testing.

A. Hardware Implementation

Circuit Connection & Setup

1) Microcontroller (Arduino/ESP32) Connections:

- IR sensors & PIR sensors connected to analog & digital input pins.
- Ultrasonic sensors (HC-SR04) connected to digital input & output pins.
- LED strips and streetlights controlled via PWM outputs.
- Buzzer & relay modules triggered by digital outputs.

2) Power Supply Considerations:

- 5V DC supply for sensors & microcontroller.
- 12V DC supply for LED streetlights.

3) System Integration & Assembly:

- Sensors were mounted on poles and pavement near the crosswalk.
- LED strips were installed along pedestrian pathways.
- Streetlights were configured for brightness adjustment based on sensor inputs.

B. B. Software Implementation

1) Programming Platform:

- Arduino IDE used for coding, compiling, and uploading to Arduino UNO R3.

2) Libraries Used:

Adafruit_NeoPixel.h – Controls WS2812B LED strip.

- Code Functionality:
- Reads sensor data continuously.
- Processes pedestrian & vehicle detection using decision logic.

Table 3
Testing methodology

Test Scenario	Expected Outcome	Result
No pedestrian detected	Streetlight stays in low beam (idle mode)	Passed
Pedestrian waiting at sidewalk	Streetlight turns to high beam, LED strip orange	Passed
Pedestrian crossing without a vehicle	Streetlight remains high beam, LED strip orange	Passed
Pedestrian & vehicle detected together	Red LED alert & buzzer activated	Passed
Night-time operation	Streetlights remain dim when no pedestrian detected	Passed

- Controls streetlight brightness & LED strip colours dynamically.
- Triggers buzzer alert for emergency situations.

3) Algorithm Execution:

- If pedestrian detected: Streetlight switches to high beam, LED strip turns orange.
- If vehicle detected within range: Red LED alert & buzzer triggered.
- If no pedestrian detected: Streetlight remains in idle mode (low beam, warm white).

C. Testing and Validation

Once implemented, the system was tested under different real-world conditions to verify its accuracy, efficiency, and reliability.

5. Applications

A. Enhanced Pedestrian Safety

- Detects pedestrians in real-time and provides immediate alerts to both pedestrians and drivers.
- Reduces the risk of accidents at crosswalks, especially in low-visibility conditions.

B. Automated & Intelligent System

- Eliminates the need for manual push-button crossings.
- Uses sensors and microcontrollers to automate pedestrian and vehicle detection.

C. Adaptive Street Lighting for Energy Efficiency

- Streetlights operate in low-power mode when no pedestrians are present, saving electricity.
- Increases brightness automatically when a pedestrian is detected, improving visibility at night.

D. Emergency Alert System

- If both pedestrians and vehicles are detected simultaneously, the system activates red LED warnings and a buzzer alert to prevent accidents.

E. Real-Time Monitoring & Smart City Integration

- Can be integrated with IoT or smart traffic management systems for data analytics and remote monitoring.
- Helps city planners analyze pedestrian and vehicle traffic trends to improve urban planning.

F. Cost-Effective & Scalable Solution

- Uses low-cost sensors (IR, ultrasonic, PIR) and LED-based lighting, making it affordable.
- Can be scaled for different types of crosswalks in urban, suburban, and rural areas.

6. Conclusion and Future Scope

This paper presents a pedestrian safety system capable of real-time pedestrian and vehicle detection using multiple sensor technologies. The system enhances road safety and energy efficiency by dynamically adjusting lighting.

Pedestrian safety is a critical concern in urban environments, where increasing traffic congestion and poor visibility contribute to accidents at crosswalks. The Smart Pedestrian Safety System offers a technologically advanced solution that integrates sensor-based detection, adaptive street lighting, and real-time alerts to enhance safety and optimize energy consumption.

This Paper Successfully Implements:

- Real-time pedestrian detection using TCRT5000 IR sensors, E18-D80NK sensors, and PIR motion sensors.
- Vehicle monitoring using ultrasonic sensors to assess potential collision risks.
- Adaptive street lighting, which automatically increases brightness when pedestrians are present.
- Color-coded LED warning strips to provide visual alerts for pedestrians and drivers.
- Emergency alert activation, where a buzzer and red LED warning prevent pedestrian-vehicle collisions.

The system provides an energy-efficient, cost-effective, and scalable solution for improving pedestrian safety. Additionally, it can be integrated with smart city frameworks, IoT-based monitoring, and AI-powered analytics to further enhance safety measures.

By combining real-time sensor technology, automation, and intelligent decision-making, this project demonstrates a smart and efficient approach to minimizing pedestrian accidents and improving urban mobility. With future enhancements, such as AI-based pedestrian detection and vehicle-to-infrastructure (V2X) communication, this system can revolutionize pedestrian safety in modern cities.

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