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Tunnel Electrification for Road Using ESP32 Based Smart Lighting and Safety System

[1]Suraj Rajiv Jaybhaye, [2]Sandhyarani Balasaheb Kunjir, [3]Pradeep Sanjay Kapse, [4]Abhishek Sunil Adagale
Department of Electrical Engineering (Diploma), Bhivrabai Sawant Polytechnic, Wagholi, Pune – 412207
Guide: Mrs. Adagle P. M. | Academic Year: 2025–2026

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Abstract:
Tunnels play a crucial role in modern transportation infrastructure by enabling smooth and uninterrupted traffic flow through mountains, densely populated urban areas, and long highway routes. Unlike open roads, tunnels operate in enclosed environments where natural sunlight is limited; therefore artificial lighting is essential. This paper presents an intelligent, automated, and energy-efficient tunnel lighting and safety monitoring system using the ESP32 microcontroller. IR sensors detect vehicle presence to enable section-wise lighting control, an LDR adapts operation to ambient light, DHT11 monitors temperature/humidity, and an MQ-2 smoke sensor detects smoke and hazardous gases. Relays provide safe switching of LED tunnel lights, alarms and ventilation. The proposed system improves safety, reduces energy consumption, and minimizes human intervention, making it suitable for MSBTE diploma projects.

Keywords — Tunnel electrification, ESP32, smart lighting, IR sensor, LDR, MQ-2 smoke sensor, DHT11, relay control, safety system.

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I. INTRODUCTION
Tunnels help reduce travel distance, fuel consumption and congestion while improving transportation efficiency. Because tunnels have limited natural light and air circulation, electrification becomes critical for safety.
Traditional tunnel lighting operates continuously at full brightness, causing high energy consumption and maintenance cost. The proposed ESP32 based automation addresses this by operating lights and safety systems only when required.

II. PROBLEM STATEMENT
Conventional installations depend on manual control and do not respond automatically to changing conditions. In tunnels, delayed detection of smoke, gas or temperature rise can lead to accidents and severe losses.
Many modern solutions are cloud dependent, introducing network dependency and latency. A locally controlled ESP32 solution provides faster response and reliable operation even without internet connectivity.

III. OBJECTIVES
- To design an automated tunnel lighting system using ESP32.
- To use two IR sensors for vehicle/obstacle detection inside the tunnel.
- To activate 12V LED lights only when a vehicle/obstacle is detected.
- To detect ambient light using LDR sensor for efficient lighting control.
- To monitor temperature/humidity using DHT11 sensor.
- To detect smoke/fire hazards using MQ-2 smoke sensor.
- To control lights, alarms and exhaust/ventilation using relay modules.
- To improve energy efficiency and safety inside tunnels.

IV. APPLICATIONS

• Road tunnel lighting automation with energy saving control.
• Safety monitoring in tunnels and enclosed infrastructures.
• Smart street/tunnel lighting in smart city applications.
• Industrial safety and monitoring systems.
• Educational embedded systems and IoT based automation projects.

V. LITERATURE REVIEW

IoT based automation systems provide remote monitoring but depend on internet connectivity and may face latency issues. Security and privacy concerns also increase complexity.
Bluetooth based local automation offers low latency and reliable offline operation. ESP32 supports Bluetooth Classic and BLE, making it suitable for short-range monitoring.
Multi-sensor integration increases accuracy and reduces false triggers. Combining IR, LDR, smoke and temperature sensors enables robust decision making for safety-critical environments.

VI. SYSTEM ARCHITECTURE AND DESIGN

Block Diagram of Tunnel Electrification System

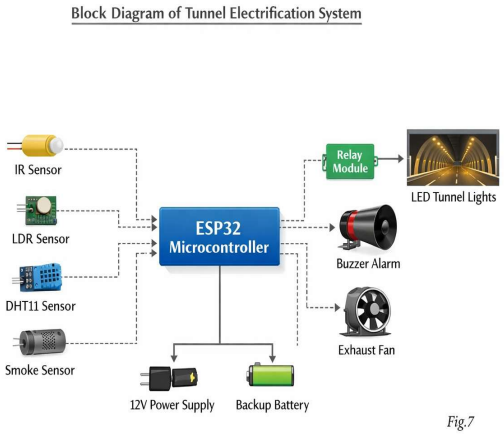

Fig.7

The system consists of ESP32 microcontroller, sensors (IR sensors, LDR, MQ-2 smoke sensor, DHT11), actuators (relays, buzzer, DC motor/fan) and power supply.

ESP32 reads sensor data, compares it with thresholds and controls the tunnel lights, street lights, ventilation and alarm automatically. Bluetooth communication can be used for local status monitoring.

The overall system flow includes initialization of ESP32, reading sensor values, comparing with thresholds and controlling relays/buzzer/fan accordingly. The logic repeats continuously for real-time operation.

VIII. PIN CONFIGURATION

• IR Sensor – GPIO 4
• LDR – GPIO 33
• Smoke Sensor – GPIO 32
• DHT11 – GPIO 27
• Relay 1 – GPIO 21
• Relay 2 – GPIO 18
• Buzzer – GPIO 26
• DC Motor/Fan – GPIO 19

IX. IMPLEMENTATION AND RESULTS

The system is programmed using Arduino IDE with ESP32 board support. Libraries used include BluetoothSerial and DHT sensor library.
All sensors and actuators are interfaced as per pin configuration. Proper grounding and power isolation are ensured using relay modules.
Testing shows reliable sensor detection and timely actuation: IR triggers lighting, LDR controls lighting based on darkness, MQ-2 triggers buzzer on smoke, and DHT11 activates fan on high temperature.

X. CONCLUSION

This project demonstrates an ESP32 based smart tunnel electrification system using multi-sensor automation. The system improves tunnel safety through smoke/temperature monitoring and reduces energy consumption through demand-based lighting control.
The solution is cost-effective, reliable and scalable for real tunnel deployment with industrial-grade sensors and control systems.

XI. FUTURE SCOPE

• Integration of Wi-Fi and cloud dashboard for remote monitoring.

• Mobile application for live status and alerts.
• AI based anomaly detection and predictive maintenance.
• CCTV integration and smart evacuation guiding lights.

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