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TUNNEL ELECTRIFICATION FOR ROAD USING ESP32 BASED SMART LIGHTING AND SAFETY SYSTEM

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Abstract:

Tunnel electrification is essential for road safety and visibility inside tunnels. Conventional tunnel lighting consumes high power because lights remain ON continuously irrespective of traffic density. This research paper presents an ESP32 based smart lighting and safety system for road tunnels. The system uses sensors such as IR/Ultrasonic sensor for vehicle detection and LDR sensor for ambient light detection. Based on real-time sensor input, the ESP32 controller activates tunnel lighting section-wise, which reduces unnecessary electricity consumption. The system is further expandable with IoT monitoring through Wi-Fi for remote supervision and fault indication. The proposed smart tunnel electrification system improves energy efficiency, enhances safety and provides an economical solution for smart city infrastructure.

Keywords: ESP32, Tunnel Electrification, Smart Lighting, IoT, LED Lighting, Road Safety, Energy Saving

1. INTRODUCTION

Road tunnels are widely used in highways, hilly regions and modern smart cities. Proper lighting is mandatory inside tunnels to provide clear visibility, prevent accidents and ensure safe traffic movement. In traditional tunnel systems, lights remain ON continuously or operate by manual switching/time-based control, leading to large power wastage.

2. PROBLEM STATEMENT

1. Continuous operation of lights even when tunnel is empty.
2. High power consumption and electricity bills.
3. No adaptive control based on light intensity (day/night).
4. Lack of intelligent safety monitoring and fault alert.
5. Higher maintenance cost.

3. OBJECTIVES

1. To develop an ESP32 based smart tunnel lighting system.
2. To implement automatic vehicle detection based control.
3. To achieve section-wise lighting for power saving.

4. To control lighting based on LDR sensor (day/night).
5. To improve tunnel safety using automated electrification.

4. PROPOSED SYSTEM

The proposed system works on sensor-based automation. ESP32 acts as the main controller which processes the sensor input and controls LED lighting sections through driver/relay modules. Main features include automatic ON/OFF control, section-wise lighting, day/night control using LDR, and expandable IoT monitoring using Wi-Fi.

5. METHODOLOGY

1. Detect ambient light conditions using LDR.
2. Detect vehicle entry using IR/Ultrasonic sensor.
3. Process sensor data in ESP32.
4. Turn ON LED sections sequentially based on vehicle movement.
5. Turn OFF previous sections after a delay once vehicle passes.
6. Record/Monitor operation via IoT (optional).

6. BLOCK DIAGRAM

Fig. 1: Block Diagram of Smart Tunnel Electrification System

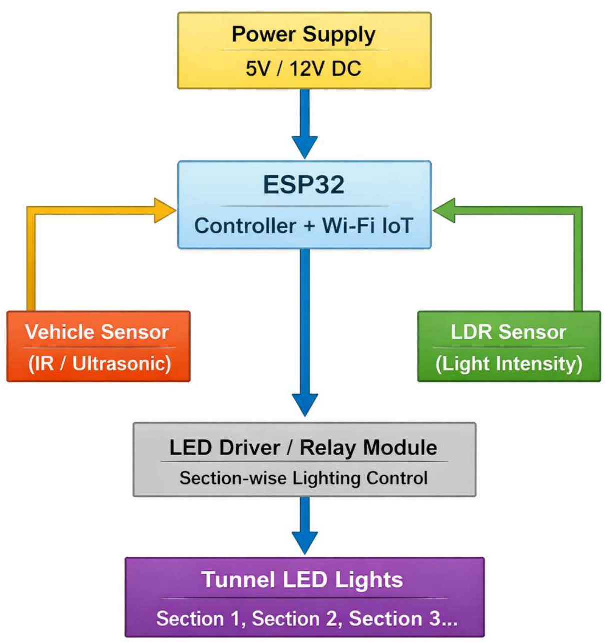

Fig. 1: *Block Diagram of Smart Tunnel Electrification System*

7. FLOWCHART

Fig. 2: Flowchart of System Working

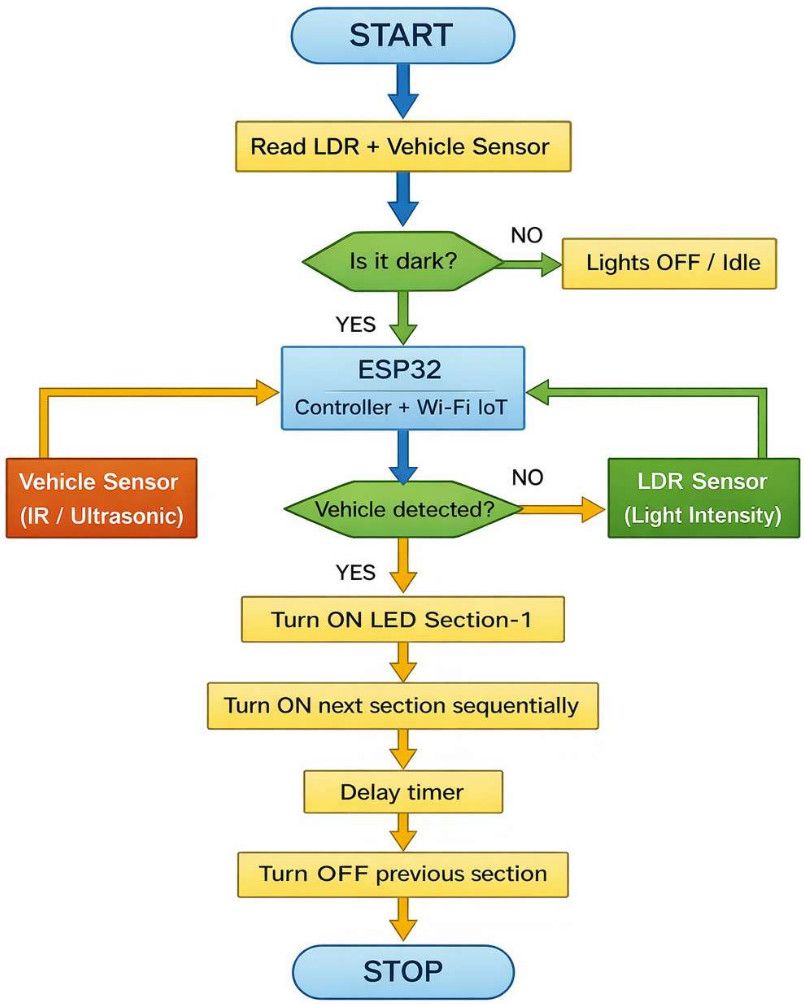

Fig. 2: *Flowchart of System Working*

8. HARDWARE REQUIREMENTS

Sr. No.	Component	Use
1	ESP32	Main controller, Wi-Fi support
2	IR/Ultrasonic Sensor	Vehicle detection
3	LDR Sensor	Day/night detection

4	Relay Module / MOSFET driver	Switching LED sections
5	LED Light Sections	Tunnel lighting
6	Power Supply (5V/12V)	System supply

9. SOFTWARE REQUIREMENTS

Arduino IDE, ESP32 Board Package, Embedded C/C++, Wi-Fi library for ESP32, (Optional) IoT platform (ThingSpeak/Blynk).

10. WORKING PRINCIPLE

1. ESP32 continuously reads LDR and vehicle sensor values.
2. If there is sufficient light (daytime), tunnel lights remain OFF.
3. When it becomes dark (night/low intensity), the system becomes active.
4. If a vehicle enters tunnel, first section lights ON.
5. As the vehicle moves, next lighting sections are turned ON sequentially.
6. Previous sections are turned OFF after time delay, reducing energy wastage.
7. IoT monitoring can be used for system status and fault indication.

11. RESULTS AND DISCUSSION

The system provides energy saving by switching ON only required lighting sections. This reduces total power consumption and improves overall system efficiency. Traditional tunnel lighting uses 100% energy (lights ON always), whereas the proposed smart lighting system can save approximately 40% to 70% energy depending on traffic.

12. ADVANTAGES

1. Large energy saving due to section-wise operation.
2. Automatic, human-free operation.
3. Low cost and easily scalable.
4. Improved road safety.
5. IoT upgrade possible for smart city implementation.

13. APPLICATIONS

Road tunnels, underpass tunnels, smart street lighting in highways, metro/railway tunnel lighting systems.

14. CONCLUSION

This research paper presents an ESP32 based smart tunnel electrification system for road tunnels. By using vehicle detection and LDR-based control, the system provides section-wise lighting operation which saves energy and enhances tunnel safety. The proposed system is reliable, economical and suitable for smart infrastructure development.

15. FUTURE SCOPE

1. Smoke and fire detection system.
2. Solar powered electrification integration.
3. Cloud-based monitoring dashboard.
4. Emergency alert system using GSM module.
5. Camera based vehicle detection and traffic analysis.

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