IoT-Enabled Adaptive Smart Street Lighting System with Fault Detection and Dual Communication Architecture

Abstract

This proposal presents an IoT-enabled smart street lighting system designed to reduce energy consumption, enhance automation, and improve fault management in urban and highway environments. The system dynamically adjusts LED brightness using ambient light and motion sensors, and includes an integrated fault detection mechanism that alerts maintenance teams in real time. A novel dual-communication architecture using both Wi-Fi and LoRaWAN enables flexible deployment across diverse geographic locations. Preliminary testing demonstrates up to 80% energy savings with significant improvements in operational efficiency and scalability.

Keywords: IoT (Internet of Things), Smart Street Lighting, Fault Detection, Energy Efficiency, Adaptive Lighting, Wi-Fi, LoRaWAN, ESP32, Dual Communication, PWM Control, Real-time Monitoring

Objectives

- Achieve up to 80% reduction in energy consumption using adaptive lighting control.

- Enable real-time fault detection and proactive maintenance using IoT connectivity.

- Support scalable deployment in both urban and highway environments using dual communication (Wi-Fi and LoRaWAN).

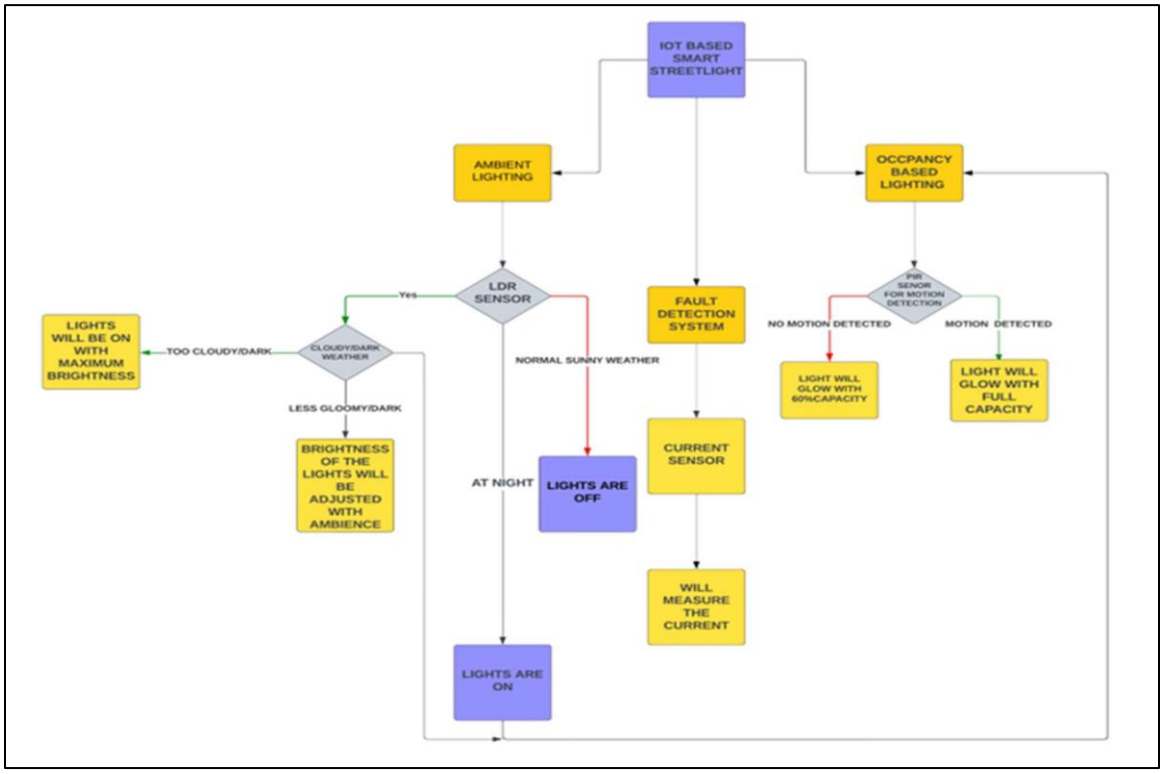
- Design a cost-effective and modular solution using open hardware (ESP32 Devkit V1).

Concept & Innovation

The innovation lies in integrating a dual-protocol communication framework (Wi-Fi and LoRaWAN) with adaptive lighting logic. Ambient light and motion detection sensors (LDR, IR, PIR) trigger dynamic brightness adjustments, while a fault detection system monitors and reports power, network, sensor, and LED anomalies. Unlike existing static systems, this solution responds in real time, is easily deployable, and significantly reduces operational costs.

Market Potential

The proposed system has high commercial viability in line with India's Smart Cities and AMRUT missions. With over 3.5 crore streetlights nationwide and growing demand for energy efficiency, the solution offers a scalable, low-cost alternative for municipal bodies, infrastructure developers, and private communities. Its flexibility across urban and rural deployments enhances its market relevance.



Block diagram of the proposed smart street lighting system architecture

Potential Areas of Application

- Smart cities and municipalities for public lighting automation

- Highway and rural road management using LoRaWAN

- Industrial parks and SEZs for automated lighting and fault alerts

- Gated communities and real estate for energy-efficient smart lighting

Technology Stack

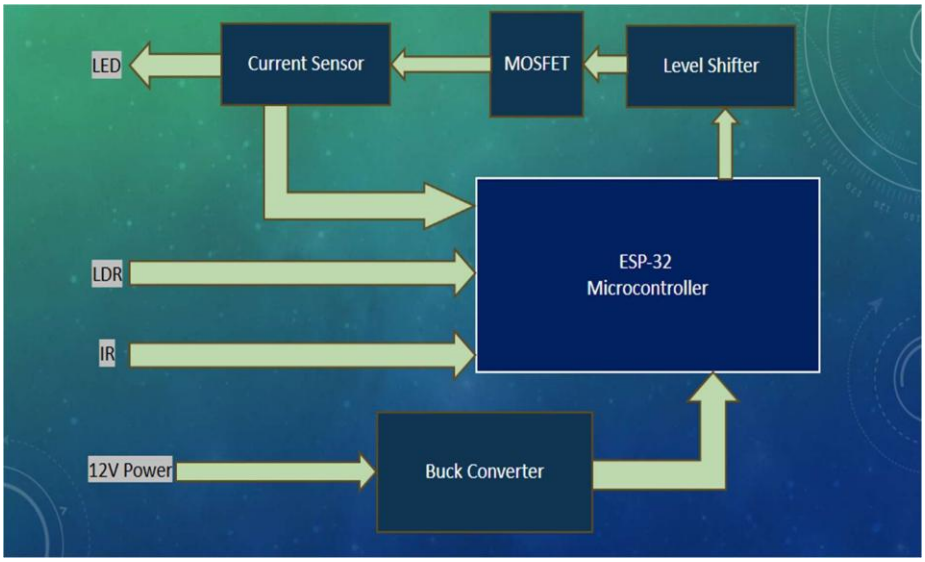
- Microcontroller: ESP32 Devkit V1

- Sensors: LDR, IR (prototype), PIR (field), voltage and current monitors

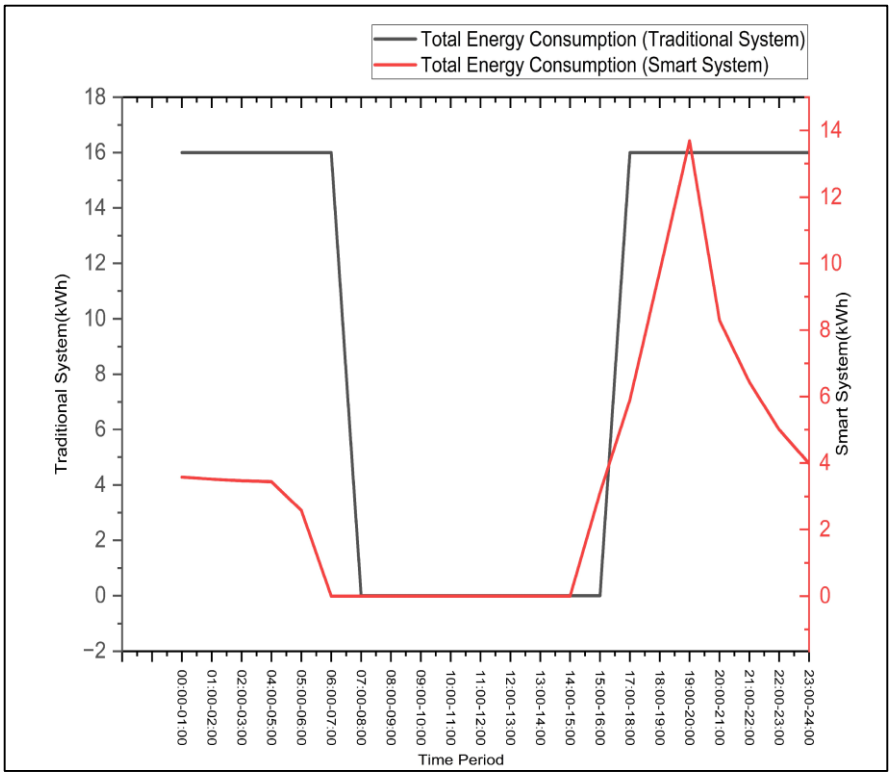
- Communication: Wi-Fi and LoRaWAN

- Power: 400W LED luminaires with PWM dimming

- Monitoring: Real-time data upload and fault alerting via cloud



Circuit schematic of the hardware prototype



Hourly Comparison of Energy Consumption Between Traditional and Smart Street Lighting Systems

Results Summary

Testing on a 1 km, 3-lane road segment showed up to 80% energy savings under low traffic using adaptive brightness control. The system reliably detected motion, adjusted lighting, and reported simulated faults within 2 seconds. Power consumption was reduced from 144 kWh/day to as low as 28.8 kWh/day. The proposed model outperformed GSM and static systems in terms of efficiency and responsiveness.

Conclusion

IoT-based smart street lighting system offers a robust, scalable, and sustainable solution for future-ready infrastructure. Its dual-communication capability, real-time fault detection, and adaptive lighting control make it ideal for smart city and highway deployments. The system's affordability and modularity support wide adoption across sectors, contributing to energy savings and operational resilience.

Assembled Hardware Prototype of the Smart Street Lighting System