IoT Based Street Light Controller and Monitoring System

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***Abstract**: Street lighting has become an essential commodity for human life as it provides lighting in cities, towns and most especially on roads to reduce risk of accidents at night. Though necessary, streetlight systems not properly managed can result in risk of accidents, excessive loss of energy, financial losses and dissatisfaction of customers. This paper proposes a smart system to manage streetlight operation, relying on sensors and Internet of Things technologies. The proposed smart streetlight system consisted of hardware and software design. While the hardware makes use of sensors, Arduino board and GPS devices to build an integrated system capable of reporting the state of the street light through available wireless network, the software aspect consisted of an online application, capable of remote monitoring and control. The smart streetlight was conceived, built and tested. Results showed an effective operation, leading to reduced energy consumption of the streetlight, subsequent reduction of carbon footprint, effective detection of fault, effective location of fault owing to GPS devices and reduced downtime. The system is further expandable to cover a whole town/nation streetlight system.*

***Keywords**: IoT, Arduino Uno, LDR Sensor, IR Sensor, GSM Module, LED Street Light, Smart City, Energy Efficiency, Fault Detection, PWM, Automation*

I. Introduction

The Internet of Things (IoT) is a network of physical objects embedded with sensors, processing capability, and software that can connect and exchange data with other devices and systems over the internet or other communication networks [1]. IoT devices communicate with computing systems through wired or wireless networks, enabling the physical environment to be monitored and controlled digitally. The primary goal of IoT is to develop intelligent systems that can operate automatically and share information in real time without continuous human involvement, as illustrated in Figure 1.

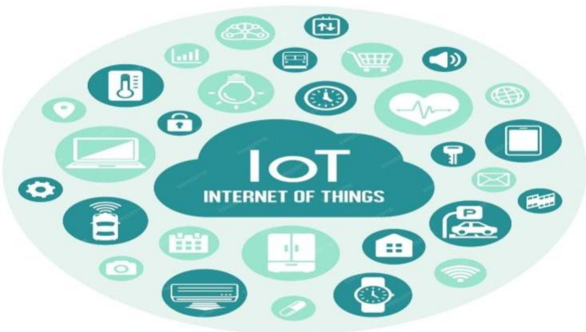

Fig. 1: Internet of Things – Interconnected Smart Devices

Smart city infrastructure has significantly improved with the integration of IoT technologies, enabling efficient management of public utilities such as street lighting [2]. Traditional street lighting systems rely on manual operation or fixed timers, which often result in unnecessary energy consumption and delayed fault detection. An automated and intelligent system is essential to optimize street lighting based on environmental conditions and real-time requirements.

The characteristics of IoT that make it suitable for smart street lighting include connectivity, interoperability, scalability, dynamic adaptability, and security [3]. These features allow IoT devices—including sensors, controllers, and cloud platforms—to interact effectively across diverse hardware platforms and communication technologies, as shown in Figure 2.

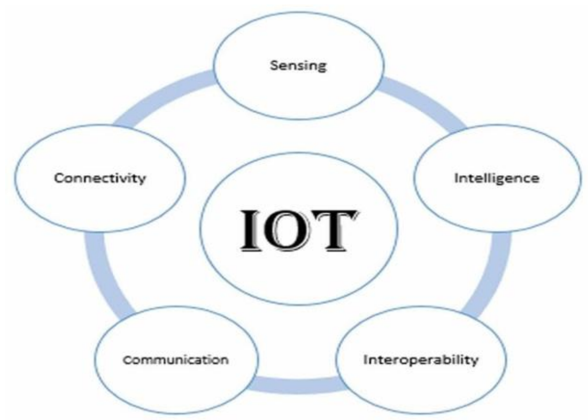

Fig. 2: Key Characteristics of IoT (Sensing, Connectivity, Intelligence, Interoperability, Communication)

This paper presents an IoT-based smart street light controlling and monitoring system that uses an Arduino Uno microcontroller, LDR and IR sensors, a GSM module, and LCD display. The system automatically switches street lights based on ambient light and adjusts brightness based on traffic movement. Fault detection with real-time SMS alerts ensures rapid maintenance response, enabling a scalable, energy-efficient solution for smart city applications [1,2].

II. Literature Review

A survey of literature reveals that numerous technologies have been deployed to remotely control and monitor street lighting systems, most of which are still in the trial phase and carry certain limitations [1]. Evans (2011) predicted that IoT represents the next evolution of the Internet, enabling automation, data gathering, analysis, and distribution [4]. IoT enables interaction between objects by assigning private or public Internet Protocol (IP) addresses, interconnecting physical devices across networks [1].

IoT-based street light control has been demonstrated in multiple studies. Nirosha (2017) proposed an automatic street light ON/OFF application using IoT that significantly reduced manual intervention [1]. Gunasundari (2017) introduced IoT-based smart LED street lighting with adaptive controls [2]. Tseng (2016) presented an intelligent street lamp monitoring and energy management solution using cloud connectivity [5]. Woods (2017) elaborated on smart street lighting as a smart city platform, detailing applications and connectivity best practices [6].

1. ZigBee, built on the IEEE 802.15.4 personal-area network standard, is considered an alternative to Wi-Fi and Bluetooth for low-powered devices. ZigBee WPANs operate at 868 MHz, 902–928 MHz, and 2.4 GHz. The protocol uses AES-128 encryption for security [7,8]. However, cost and expandability remain the major constraints limiting full ZigBee deployment [9,10]. Hsiao et al. (2012) investigated integrating ZigBee lighting control into existing building automation systems, demonstrating practical deployment feasibility [7].

Existing street lighting systems primarily rely on manual control or timer-based mechanisms. Lights operate at full intensity throughout the night without adaptation to real-time environmental conditions such as ambient light or traffic presence [2,3]. There is no centralized system for fault tracking, maintenance is delayed, and energy is wasted during low-traffic periods. Sardar et al. (2013) developed a smart street lighting system that addressed several of these limitations using wireless sensor networks and cloud reporting [8]. The WHO (2004) World Report on Road Traffic Injury Prevention highlights the critical role of proper street lighting in reducing road accidents and improving public safety [3]. These findings collectively justify the need for an intelligent IoT-based street lighting solution.

III. System Architecture and Methodology

The proposed street light controlling and monitoring system is designed using sensor-based automation along with GSM communication for fault alerting. The system consists of sensors, a microcontroller as the central processing unit, a switching mechanism, a communication module, and output devices for monitoring [6]. The overall architecture, illustrated in Figure 3, comprises three main sections: Input Unit, Control Unit, and Output Unit.

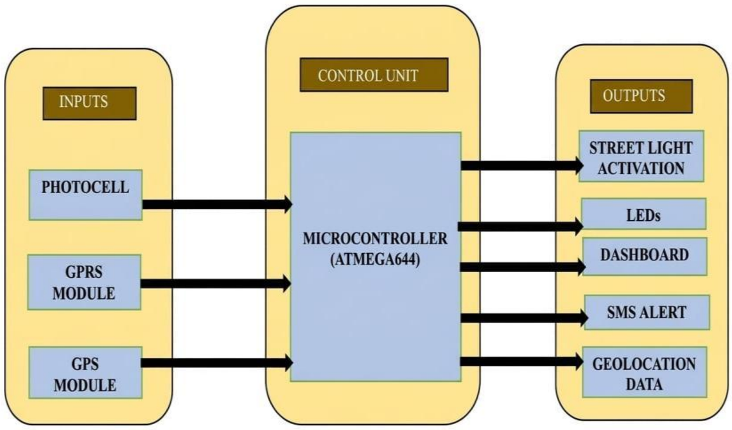

Fig. 3: Block Diagram of IoT Street Light Controlling and Monitoring System

The Input Unit includes a Photocell (LDR), GPRS Module, and GPS Module. The Control Unit is built around the ATmega328P microcontroller (Arduino Uno). The Output Unit includes street light activation (LED), a 16×2 LCD display, SMS alerts via the GSM module, and geolocation data output. Figure 4 shows the complete circuit diagram of the proposed system.

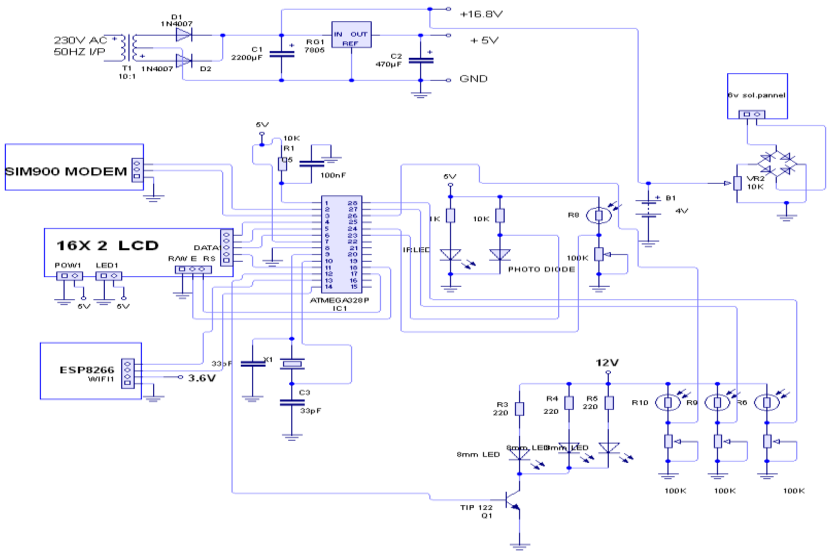

Fig. 4: Complete Circuit Diagram of IoT Street Light System

A. Microcontroller Unit (Arduino Uno)

The Arduino Uno, based on the ATmega328P microcontroller, serves as the central processing unit. It operates at 16 MHz with 14 digital I/O pins (6 PWM-capable) and 6 analog input pins, with 32 KB flash memory and 2 KB SRAM. It interfaces with sensors, the GSM module, relay, and LCD through UART, SPI, and I2C protocols [2]. Figure 5 shows the microcontroller unit schematic.

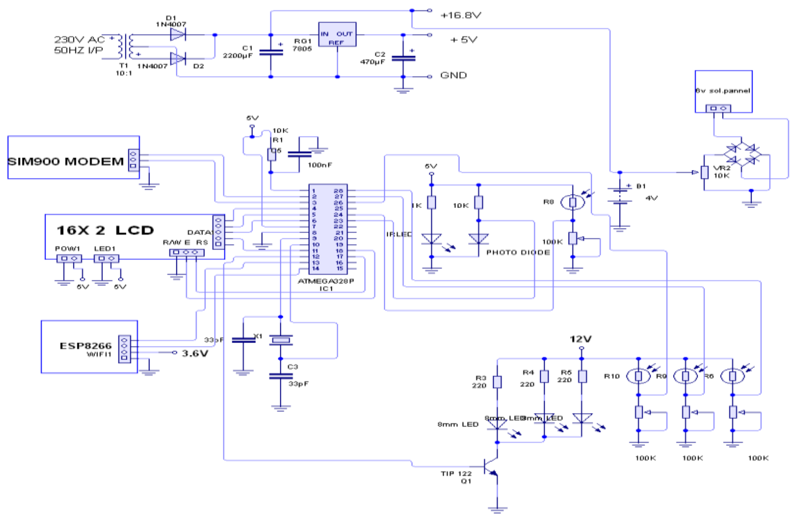

Fig. 5: Microcontroller Unit – ATmega328P Schematic with Peripheral Connections

Figure 6 shows the Arduino Uno development board used in this project. Programming is done via the Arduino IDE using Embedded C. The board includes a built-in voltage regulator and can be powered through USB or an external 9V adapter.

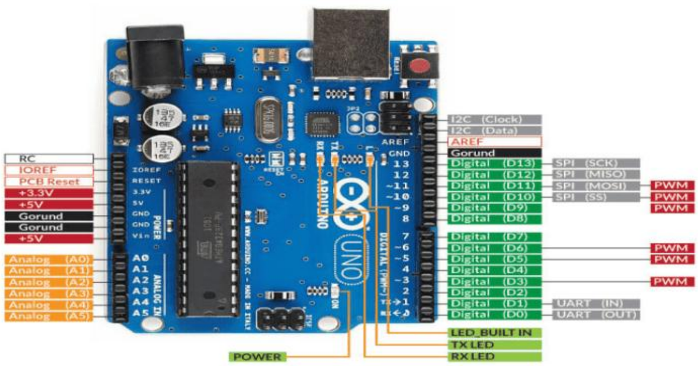

Fig. 6: Arduino Uno Development Board

B. LDR Sensor

The Light Dependent Resistor (LDR) works on the principle of photoconductivity [1]. In bright light, its resistance decreases; in darkness, resistance increases. This variation is converted to a voltage signal through a voltage divider circuit and fed to the microcontroller's analog input (A0). The system compares this against a predefined threshold: if the LDR reading exceeds 30%, the system identifies daytime and keeps the lights OFF; below 30% indicates nighttime and the lights are activated. Figure 7 shows the LDR module used.

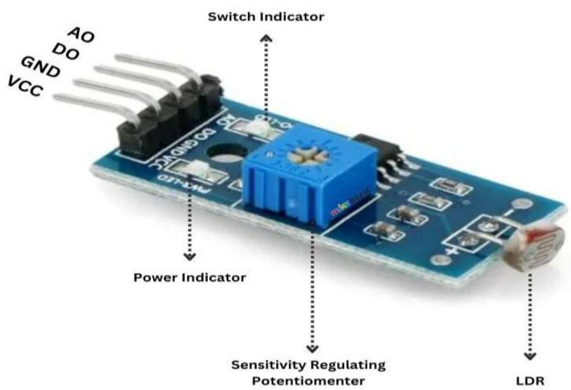

Fig. 7: LDR (Light Dependent Resistor) Sensor Module

C. IR Sensor

The IR sensor detects motion using infrared radiation. It consists of an IR transmitter and a receiver. When a vehicle or pedestrian passes, reflected IR rays trigger the receiver, generating a digital signal to the microcontroller. This enables dynamic brightness control — dim mode at approximately 30% brightness when no motion is detected, and full brightness (100%) upon detection — conserving energy while maintaining road safety [2,5]. Figure 8 illustrates the IR sensor module and its pin configuration.

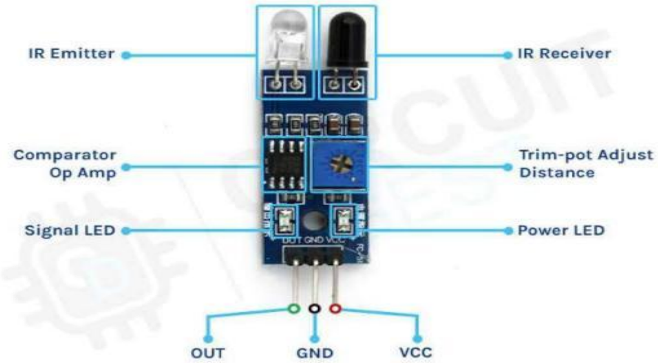

Fig. 8: IR Sensor Module with Pin Configuration (OUT, GND, VCC)

D. GSM Module (SIM900)

The GSM module (SIM900) communicates with the microcontroller via UART serial communication using AT commands and a SIM card over the cellular network [8]. When a fault is detected (e.g., a street light failing to operate as expected), the microcontroller triggers the GSM module to dispatch SMS alerts to predefined maintenance personnel numbers. This feature ensures rapid fault response without manual inspection. The GSM module also provides wide coverage in remote areas where internet connectivity is limited. Figure 9 shows the GSM module assembly.

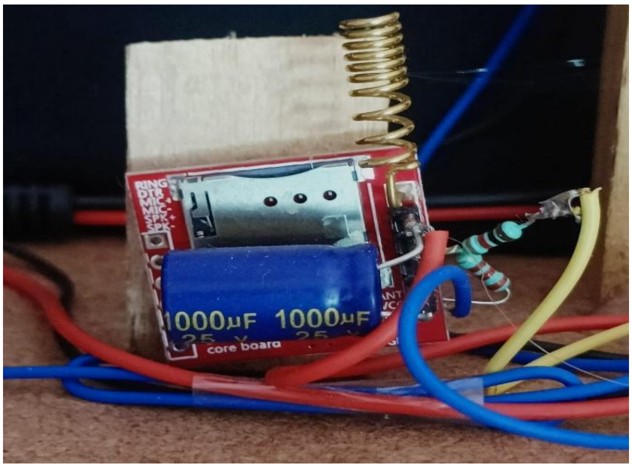

Fig. 9: GSM Module (SIM900) with Capacitors for Stable Operation

E. LCD Display (16×2)

A 16×2 LCD display is interfaced with the microcontroller via digital I/O pins. It displays real-time system information including light ON/OFF status, LDR sensor readings, temperature/humidity from the DHT11, and fault alerts. Figure 10 shows the LCD module.

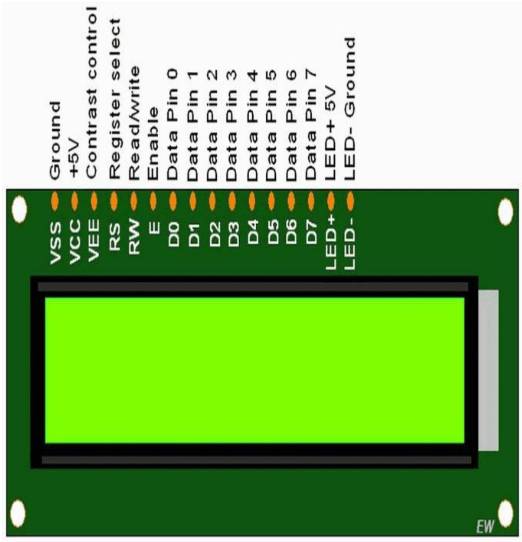

Fig. 10: 16×2 LCD Display Module with Pin Configuration

F. LED Street Light Module

The 12V LED module serves as the lighting output. It is controlled through a relay module connected to the microcontroller via a TIP122 transistor driver. Based on LDR and IR sensor inputs, the microcontroller sends PWM signals to control brightness levels — a value of 10 for dim mode (approx. 4%) and 200 for full brightness (approx. 78%) [1]. LED lights offer high energy efficiency, long operational lifespan, and low heat generation compared to traditional lighting. Figure 11 shows the LED module.

Fig. 11: 12V LED Street Light Module

G. Power Supply and Voltage Regulator

The system is powered from 230V AC mains through a step-down transformer producing 12V-0-12V AC. This is rectified using 1N4007 diodes and filtered with capacitors. The 7805 LM78XX series linear voltage regulator provides a stable 5V DC output to power the microcontroller and peripheral modules. It offers internal thermal overload protection and short-circuit current limiting. Figure 12 shows the power supply circuit diagram, and Figure 13 shows the 7805 voltage regulator.

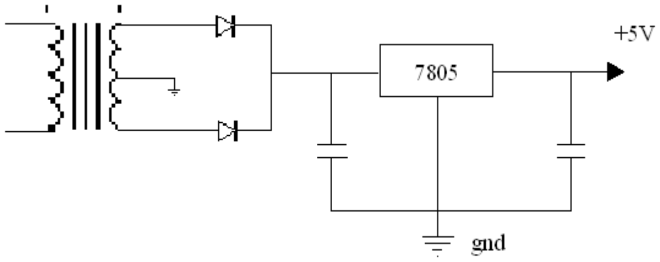

Fig. 12: Power Supply Circuit Diagram (230V AC to 5V DC)

Fig. 13: 7805 Positive Voltage Regulator (LM78XX Series)

H. PCB, Perf Board, and Supporting Components

All hardware components are assembled on a Perf Board (General Purpose PCB) that provides soldered, stable electrical connections between the microcontroller, sensors, GSM module, relay, and LED driver. Figure 14 shows the perf board, Figure 15 shows jumper wires used for inter-component connections, and Figure 16 shows a resistor used for current limiting in the LDR voltage divider and LED protection circuits.

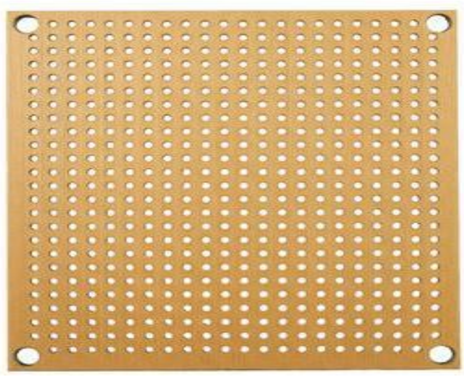

Fig. 14: Perf Board (General Purpose PCB) for Component Assembly

Fig. 15: Jumper Wires for Circuit Interconnection

Fig. 16: Resistors for Current Limiting and Voltage Divider Circuits

IV. Implementation and Testing

The system was implemented using the Arduino IDE, which supports Embedded C/C++ programming for the ATmega328P [2]. The Arduino program (sketch) includes a setup() function that initializes all hardware interfaces and a loop() function that continuously executes the sensing and control logic. Analog LDR values from pins A0–A3 are read and mapped to a 0–100% range using the map() function. If the primary LDR (A0) reading falls below 30%, the system activates night-mode street lighting.

Motion detection via the IR sensor uses a digital read of the obstacle pin. When a vehicle is detected (LOW signal), the PWM output is set to 200 (full brightness). When no motion is detected, PWM is set to 10 (dim mode). Fault detection monitors secondary sensors (A1–A3): if the main LDR is below 30% but a secondary light sensor reads below 60%, a light failure is assumed. The LCD displays the fault and the GSM module dispatches SMS alerts to predefined numbers using AT commands (AT+CMGF=1 and AT+CMGS).

The system also transmits monitoring data to the ThingSpeak IoT cloud platform using the ESP8266 Wi-Fi module via TCP/IP connection (api.thingspeak.com port 80), enabling real-time remote monitoring of all four light channels. Integration testing was performed with all hardware modules interconnected and tested as a unified system under varying light intensity and motion detection scenarios [5,6]. Figure 17 shows the assembled system during integration testing.

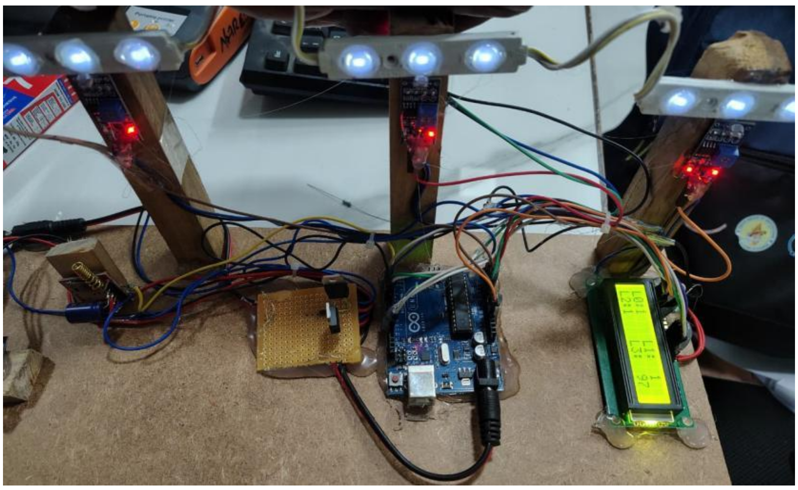

Fig. 17: System Integration Testing – Assembled Hardware Prototype

V. Results

The system was evaluated under four key operational scenarios. All components performed as expected in each case, confirming the effectiveness of the proposed design [8].

Case 1 – Daytime Condition (Lights OFF)

During daytime or high ambient light conditions, the LDR sensor detected light intensity above the 30% threshold and signaled the microcontroller to keep the street lights OFF. This prevents unnecessary energy consumption during daylight hours. Figure 18 shows the system with lights OFF under simulated daytime conditions.

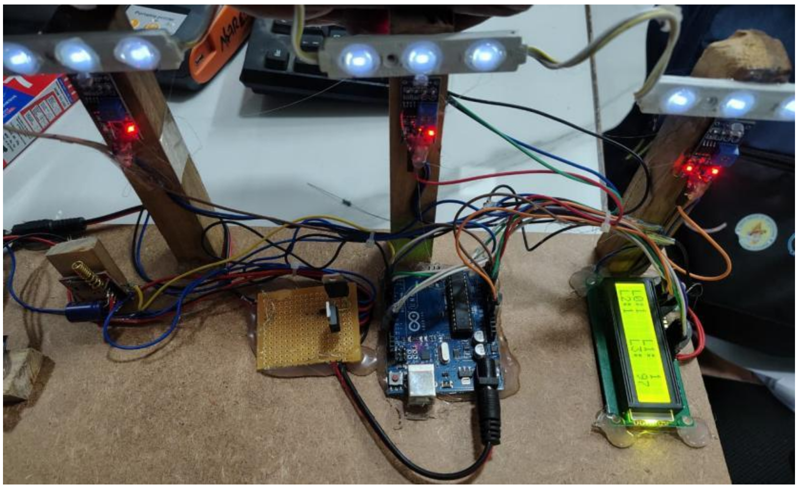

Fig. 18: Result – Street Lights OFF During Daytime (LDR High)

Case 2 – Nighttime, No Motion (Dim Mode – 30%)

When ambient light intensity fell below the threshold, the system activated the LED street lights in dim mode at approximately 30% brightness using PWM. This energy-efficient approach maintains minimum safe illumination while conserving power during low-traffic periods [1,5]. The transition from OFF to dim mode was smooth and stable. Figure 19 shows the lights in dim mode.

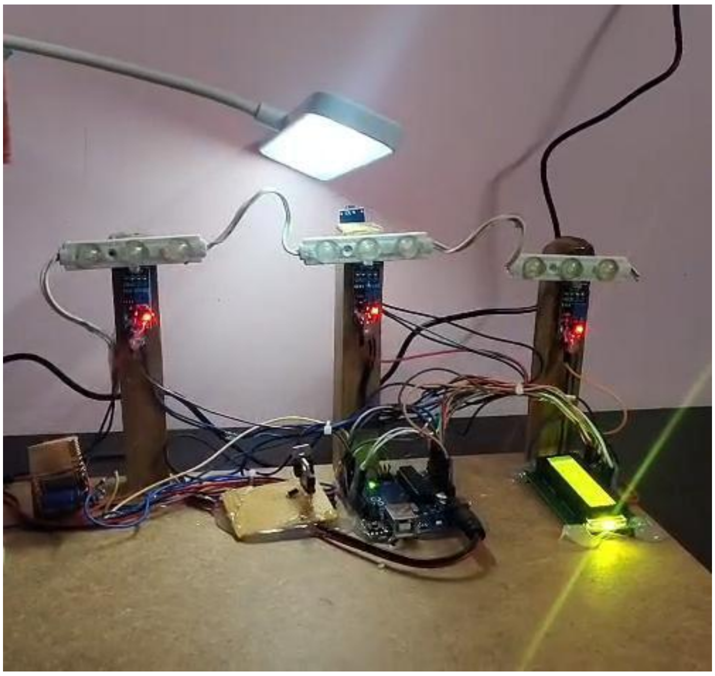

Fig. 19: Result – Street Lights in Dim Mode (30%) at Night with No Vehicle Detected

Case 3 – Object/Vehicle Detection (Full Brightness – 100%)

Upon detection of a vehicle or pedestrian by the IR sensor, the system immediately switched the LED lights from dim mode to full brightness (PWM = 200) within milliseconds. After the object moved away and no further motion was detected, the system automatically reverted to dim mode. Response time was fast and reliable, demonstrating the effectiveness of adaptive motion-based lighting [2,5]. Figure 20 shows the lights at full brightness during vehicle detection.

Fig. 20: Result – Street Lights at Full Brightness (100%) When Vehicle Detected

Case 4 – Fault Detection (GSM Alert System)

When a light failure was simulated (primary LDR < 30% but secondary light sensor < 60%), the microcontroller detected the fault condition. The LCD immediately displayed the alert message and simultaneously triggered the GSM module to send SMS notifications to predefined maintenance personnel [6,8]. Figure 21 shows the LCD fault display, Figure 22 shows the SMS sending status on LCD, and Figure 23 shows the received SMS alert on the mobile device.

Fig. 21: LCD Displaying Light Failure Alert – "LIGHT 1 FAILED PLEASE CHECK"

Fig. 22: LCD Displaying SMS Transmission Status – "SENDING SMS PLEASE WAIT"

Fig. 23: SMS Alert Received on Mobile – "LIGHT 1/2 FAILED PLEASECHECK"

Table 1: Summary of System Test Results

Test Case	Condition	Expected Output	Observed Result
Case 1	Daytime (LDR > 30%)	Street Lights OFF	Pass – All Lights OFF
Case 2	Nighttime, No Motion	Dim Mode (30%)	Pass – 30% Brightness, Stable
Case 3	Vehicle Detected (IR)	Full Brightness (100%)	Pass – Instant Switch to 100%
Case 4	Light Failure Simulated	LCD Alert + SMS Sent	Pass – SMS Received Instantly
Cloud Upload	ESP8266 + ThingSpeak	Data Sent to Cloud	Pass – All 4 Channels Posted

VI. Advantages and Applications

The proposed system provides the following key advantages over conventional street lighting [1,2,5]: (1) Energy efficiency through automatic LDR and IR-based adaptive control; (2) Fully automatic operation eliminating manual switching; (3) Reduced maintenance costs via GSM-based instant fault alerts; (4) Cost-effective implementation using widely available low-cost components; (5) Improved road safety with full brightness on vehicle detection; (6) Real-time monitoring through LCD display and cloud (ThingSpeak) connectivity; (7) Scalability for large-scale smart city deployments; (8) Reliable communication even without internet via GSM cellular network; (9) Extended LED lifespan through controlled brightness and dimming; and (10) Reduced carbon footprint through energy conservation [3,6].

Applications include: smart street lighting in urban roads and national highways [2]; smart city infrastructure integration for centralized control; parking area automation; industrial zone and campus lighting; rural areas where GSM-based alerts function without internet; and integration with renewable energy sources such as solar panels for sustainable operation [6].

VII. Conclusion and Future Scope

The proposed IoT-based street light controller and monitoring system successfully demonstrates an efficient, intelligent, and automated solution for modern lighting infrastructure. By integrating LDR-based day/night detection, IR-based adaptive brightness control, GSM fault alerting, and cloud-based monitoring via ESP8266, the system addresses all major limitations of conventional street lighting [1,2].

The system was rigorously tested under four operational scenarios — daytime shutdown, nighttime dim operation, vehicle-triggered full brightness, and fault detection — and performed correctly in every case. Energy conservation is achieved through adaptive lighting; safety is enhanced through responsive full-brightness activation; and maintenance efficiency is improved through real-time SMS fault notification [5,8]. The use of LED lights, PWM-based brightness control, and PCB-based assembly ensures durability, reliability, and cost-effectiveness suitable for real-world deployment.

Future enhancements include: (1) Integration with solar panels and battery storage for renewable energy operation [6]; (2) Migration to a dedicated IoT cloud platform (AWS IoT, Google Cloud IoT) for advanced monitoring; (3) AI-based traffic pattern analysis for predictive lighting schedules; (4) Mobile application for real-time remote control; (5) Current sensors for more precise fault detection; and (6) Integration with smart traffic management and surveillance systems for comprehensive smart city infrastructure [4,5].

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