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An Energy-Efficient Street Lighting with IoT Based Smart Control Fixtures

Nirbhay Borikar[1]*, Jayant Shakya[2], Jitendra Kumar Tandekar[2], Neha Borikar[1] , Swapnil Singh Bargahi[2]

[1]Department of Mechanical Engineering, Samrat Ashok Technological Institute Vidisha, India.

[2] Department of Electrical Engineering, Samrat Ashok Technological Institute Vidisha, India.

ABSTRACT

Road lighting plays a significant role in energy consumption, particularly in developing countries like India. Inefficient lighting fixtures lead to substantial economic losses and safety hazards. Manual systems further contribute to global energy wastage. This study proposes the adoption of energy-efficient LED lights and automated street lighting systems to minimize energy consumption and improve cost-effectiveness. Leveraging IoT technology, a smart prototype for road lights is developed, featuring real-time monitoring and diagnostics capabilities. The system promptly identifies and diagnoses issues, enabling swift and efficient maintenance. By ensuring proper lighting conditions, safety for pedestrians and motorists is enhanced, reducing the risk of accidents and criminal activities. The proposed system optimizes the functionality of street lighting, reducing downtime and inconveniences for visitors. The study highlights the potential for improving energy efficiency, cost savings, and enhanced public safety through the implementation of smart street lighting systems.

KEYWORDS

Road lights; PIR motion detector; Wi-Fi module; Arduino Mega; LED; monitoring; self-diagnostic and LDR; IoT.

1. INTRODUCTION

As we know in towns, road lights are the cause of the largest energy consumption. In towns light turns ON at night before sunset and turns OFF after sunrise when there is sufficient light surrounding this process of switching comes under a manual system. In between the gap from ON time to the OFF time a lot of energy is wasted. It is not known which pole light is not working as there is no real-time diagnostic and monitoring system available for them. Demerits of a current system: Physical switching (ON/OFF) of road lights, huge energy consume, high maintenance cost , and many times maintenance needed, labor power required is more and also has harmful effect of the incandescent lamp[1].

In a paper [2] they proposed a prototype model of the street light system in cleverly manner by using internet technology. They additionally analyzed and defined various sensors and additives that are used in IoT environments. In the paper [3], the author's verified the smart control system for road lights by using PWM control techniques. In paper [4], the author proposes an approach to control illumination based on traffic requirements for high efficiency. A wireless sensor network (WSN) with a data rate of 20Kbits/s is incorporated to account for traffic elements and change illumination at a faster rate. However, the control system shows unpredictable behavior when dealing with non-linear velocity or acceleration conditions, such as when cars are parked. Intake of PV energy that is carried out on LED road lights and an inventive glare device is developed and a Zigbee based unit has been mounted for capacity tracking of road lamps LEDs [5].

In the paper [7], the author defined the growth of road lighting fixtures as combining the deficiencies of modern technology.The machine unifies the site visitors' speed into a non-probabilistic version and endangered outcomes which is more relevant to the actual time site visitors' visits and at the same time making certain protection and security. In the paper [8], the author proposed a device which provided us with an electricity saving mechanism for road lighting fixtures via Wi-Fi infrastructure [6] which is cheap in cost, remotely commendable with easy monitoring of the road-lighting fixtures. This presents a powerful manner to save power by means of thwarting pointless electricity consumption, instigated because of the guide switching or lighting fixtures of road- lighting fixtures when it isn't always necessary. In the paper [9], a smart road lamp system for mist identification is proposed, with the help of UART, a controller board sends signals to the driver of the LED and modifies the colors concerning the temperature of the surroundings. In paper [10], they offered a brand new idea for incorporating smart components in traditional road lamp structures. Here stated gadgets are successful in commanding, evaluating, and manipulating inputs of luminaires in addition to displaying and signup electricity on excellent occasions that have an effect on the electric grid. Paper [11] presents a DC streetlight powered by a Photovoltaic source with battery storage to provide energy when needed. The system incorporates battery protection to prevent overcharging, a motion sensor to reduce power consumption, and a dust cleaning circuit to improve Photovoltaic cell efficiency.

In paper [12], an embedded system and machine learning algorithm are used to predict environmental conditions and operate streetlights. Additionally, a garbage monitoring system is integrated with an ultrasonic sensor and machine learning algorithm to inform authorities of the level of collected garbage. Paper [13] replaces HID lamps with LED and incorporates an LDR to vary light intensity. To improve system stability, DHT11 is used to measure humidity. The system provides maximum intensity light when required, but its initial cost and maintenance are disadvantages. Paper [14] introduces a surveillance system with automatic streetlights. A camera is placed atop the pole and a help button is added to allow people to trigger real-time footage of events on the road to the nearest police station. Paper [15] uses BOLT IoT and Arduino platforms to control and maintain streetlights, with a fault detection system that sends text messages to authorities. In paper [16], the authors introduce a solar tracker as a renewable energy source and a traffic management device to reduce traffic jams. The system is upgraded to include luminous control features and a camera for surveillance and traffic management.

Paper [18] proposes a control system with a GSM modem, control circuits, and electronic devices that can be accessed by sending an SMS to the GSM network. In paper [20], a cloud-based operating and controlling system for streetlights is introduced, which can adjust lighting according to external conditions and traffic inspection. The system also includes a fault detection system and compares power consumption data between conventional and automatic streetlights.

In this study, we propose a cost-effective road lighting system that utilizes Wi-Fi technology for remote monitoring and control of streetlights. The system incorporates a controller mounted on each pole [19], which includes a microcontroller, sensors, and Wi-Fi modules. By leveraging visitor flow, the controller manages LED road lighting, resulting in automatic operation without the need for manual switching. The system provides real-time statistics on light poles, which are transmitted to a cloud server via a gateway channel. This enables access to the information from base stations and remote devices, allowing operators to promptly identify and address specific damaged components, minimizing maintenance costs and efforts. The proposed system offers numerous advantages, including reduced energy consumption, lower maintenance costs, seamless wireless communication with road lights, and minimal environmental impact. Furthermore, the system streamlines labor requirements. This research highlights the potential of the proposed road lighting system to enhance efficiency, reduce costs, and promote sustainable lighting infrastructure.

2. PROPOSED WORK

This study introduces an intelligent street light system that incorporates a controller board capable of adjusting the light output based on usage and occupancy. The system utilizes wireless connectivity to enable remote monitoring and tracking of energy consumption, facilitating energy reduction measures. The implementation includes the replacement of old incandescent lamps with energy-efficient LED lights, ensuring adequate illumination for enhanced safety. Furthermore, a fault detection mechanism is incorporated to monitor the health of each component, enabling timely maintenance. Figure 1 illustrates the smart street poles connected to a gateway for wireless data uploading to a server, facilitating communication with base stations and operator devices. This research showcases the potential of the proposed intelligent street light system to optimize energy consumption, improve maintenance efficiency, and enhance safety on the streets.

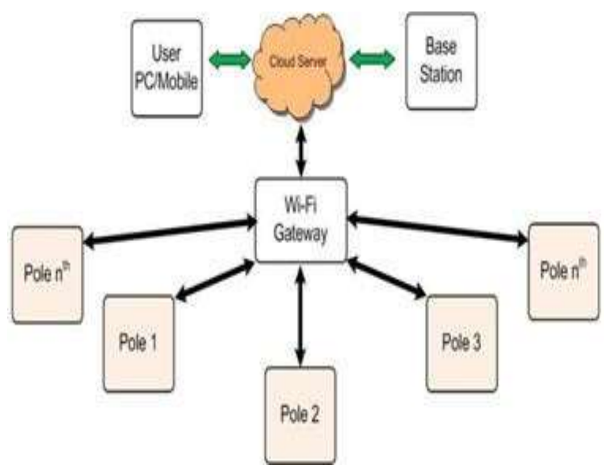

Fig. 2. Street pole connection layout.

Below Figure 2 shows the algorithm structure of system. Observer is a particular component which working result is observed by calculating the total energy consumption of observer this process take place in short span of time [20-23].

2.1. LOGIC BEHIND SELF-DIAGNOSTIC MECHANISM:

By monitoring total current in the system circuit, we can easily find the fault in system.

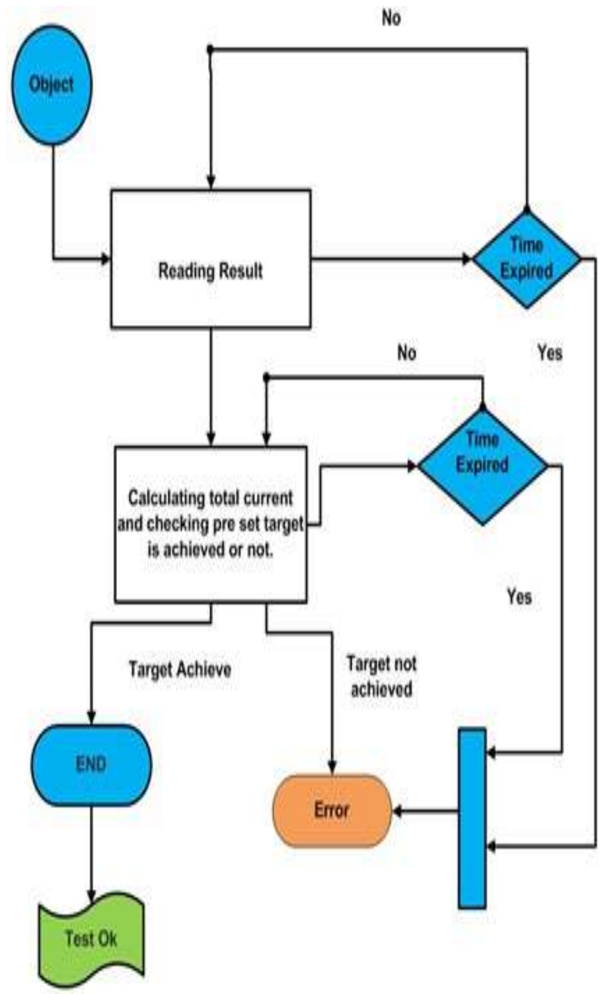

Fig. 2 Self-diagnostic mechanism of the proposed system

The current of components are read by current sensor at certain time limit, then the whole device current is calculated by using separate current reading of the components this also accomplished at certain time limit, and when pre set target value is achieved test will end , but as we require real-time data this loop keep on running and if any stage is taking more time than the expected time , target is not achieved it will give error or start changing its value over the graph of current in cloud platform interface.

We have used the ASC712 sensor with optimized range of current -5 to + 5 A, with a sensitivity of 185(mV/A).Current sensors are connected in series with loads and power supply. Loads are the components such as LDR, relay, LED, Wi-Fi Modules and motion sensor. This current sensor does produce output when there is no flow of current that value is called zero offset. When converted into current it will change value proportional to components ac/dc current drawn. It works on the formula:

Current = (Operating Voltage – Voltage at no load) * Sensitivity.

Whereas operating voltage is the voltage at which the device or a load being operated, voltage at no load means when receiving end of a load is open circuit, and no current flows in an open circuit so voltage is zero here sensitivity is the current sensor sensitivity which is 185mV/A.

All components are connected in parallel in the system, thus in parallel circuit current adds i.e.

Total current $I = I_1 + I_2 + I_3 + I_4$ (1)

For example, In pole 2-

Let I_1 is the current drawn by LDR which is negligible closed to zero, I_2 is the current drawn by PIR motion sensor, it draws 0.06 mA at 5 V, I_3 is the Relay current it draws 40 mA at 5 V, I_4 is the current of LED, LED of 40 watt operating at 230 V draws 173.91 mA current. (LED current calculated by Current = Power(watt)/ Voltage(V)).

So, Total current from equation 1:

$I = I_1 + I_2 + I_3 + I_4 = (0 + 0.06 + 40 + 173.91)$ mA

Total current (I) = 213.97 mA (This value will be act as preset value and we have to check whether our circuit is achieving this value or not)

*But when the condition is false i.e., I ! = 213.97 mA

In the scenario where the current value is measured to be 173.91 mA, which is 40 mA lower than the preset value, we can deduce that the Relay, which draws 40 mA, is the faulty component requiring replacement by the operator. Consequently, error messages generated by the microcontroller will be transmitted via Wi-Fi units to the gateway, then forwarded to a remote server where the data is stored. Users can access this information through a website or app, enabling them to view the error messages on their computer or mobile screen. By comparing the present current value, the preset value, and the current value of the components, the operator can easily identify and diagnose the correct faults.

2.1.1 System Components:

(a) (b) (c)

Fig. 3 (a) Controller box of streetlight, (b) Inside view of controller box components and their connection. (c) Above the controller box there is LDR sensor which is covered by black cloth so that LDR does not absorb light, and system activated then a person showing in picture is crossing the pole and hence motion detected lights on.

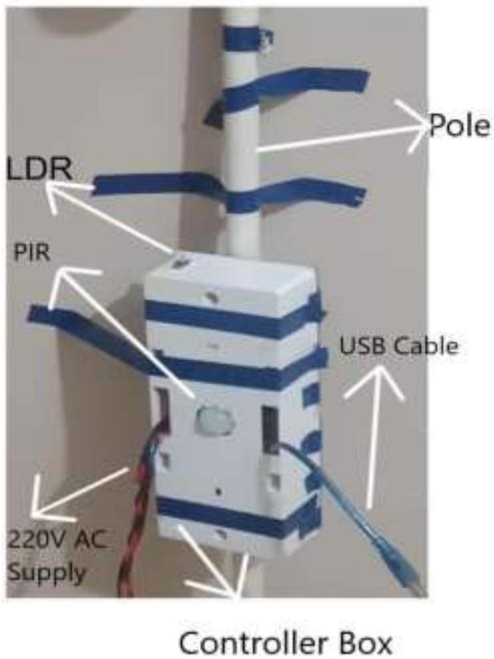

Fig. 4 A exploded view of visible components.

Here is Figure 4. Showing components of the system that can be seen from outside i.e., LDR sensor, Controller box, Wire for current supplying, USB Cable, and PIR Motion sensor.

Figure 5. Representing the inside components of the system: Current Sensor ASC712, LDR, Bread Board, Relay, Arduino Mega 2560 and Wi-Fi ESP8266 Module.

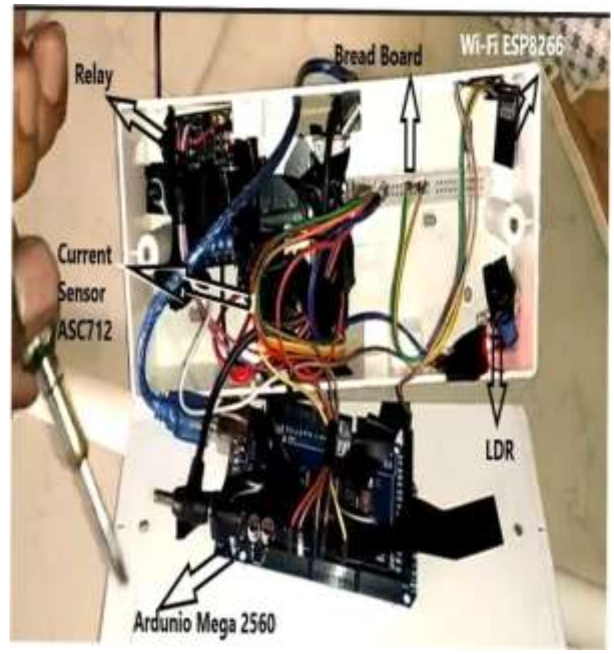

Fig. 5 Inside View of controller box with hardware components

2.2 SOFTWARE AND TECHNOLOGY:

2.2.1 ThingSpeak cloud service:

ThingSpeak consists of internet service (REST API) which helps in storing and retrieving of data. It works with several platforms like arduino, raspberry pi etc.In the proposed system of a road lighting Thingspeak used as a cloud server to collect all status of road lighting system

2.2.2 Arduino IDE:

Arduino IDE - Integrated Developer Environment is software where all programs of the proposed system are written, executed and tested .This written program is uploaded to Arduino hardware.

2.2.3. Gateway:

It is a chunk of networking hardware that permits statistics to waft from one discrete community to another. Here we are using a gateway to connect multiple Wi-Fi nodes of poles at one station so that all the data can be easily transferred to the cloud server.

2.3 HARDWARE COMPONENTS:

In the presented study, an Arduino Mega 2560 microcontroller board is employed, offering multiple features such as 16 analog input pins, 15 pulse width modulation output pins, and 4 UARTs ports. Program uploading to the board is achieved via a USB cable, while an adapter and batteries are utilized for power supply. Light detection is performed using a high-impedance LDR (Light Dependent Resistor), which adjusts its resistance according to the light intensity it receives. Additionally, a PIR (Passive Infrared) sensor is incorporated to detect infrared radiation emitted by objects and differentiate between motion and stillness. The fitness of components is monitored using an ASC712 current sensor, which measures electrical current in the circuit with a sensitivity of 185mA/V. For safety purposes, an electromechanical switch controlled by the microcontroller handles condition-based applications. The proposed system incorporates an ESP8266 Wi-Fi unit that acts as both a host and a slave, facilitating wireless communication. Furthermore, LED lights are utilized to provide illumination without causing excessive brightness, as observed in traditional incandescent lamps. RS Components offers a range of Wi-Fi modules from reputable manufacturers to meet various development, design, and application requirements.

3. WORKING PRINCIPLE

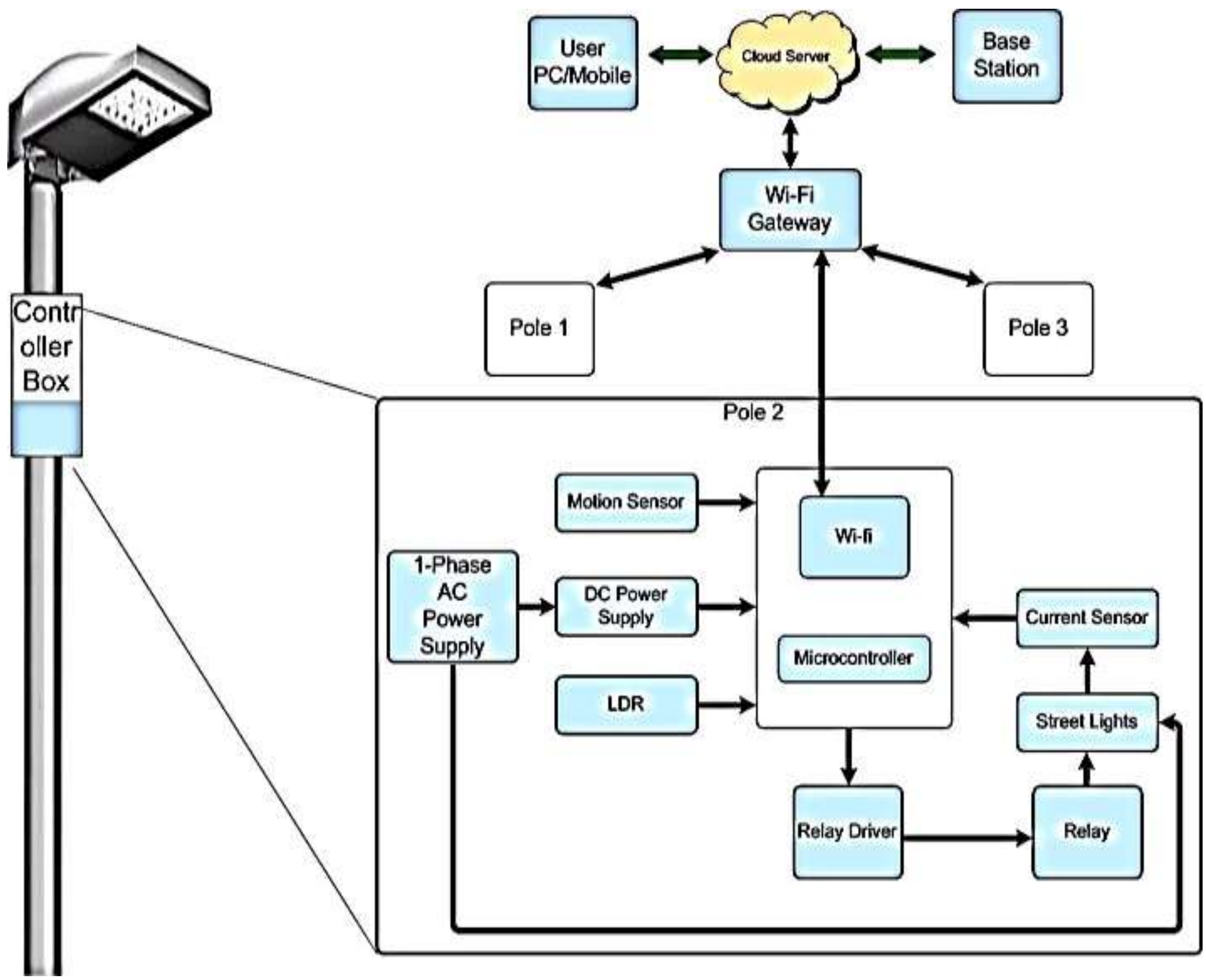

Fig. 6. A flow diagram of the proposed system, master pole contains a gateway and all components below gateway are present in every pole.

Figure 6 illustrates the interconnections between various components, the microcontroller, and the wireless network architecture in our proposed road lighting system. Each pole is equipped with a 1-phase AC power supply, current sensor, relay, relay driver, DC power supply, microcontroller, motion sensor, and Wi-Fi module. The master pole, referred to as pole 2, acts as the central hub, housing all the system components and functioning as the gateway for uploading system status data from the Wi-Fi nodes to the cloud server. This data can then be accessed by the base station and users on their mobile devices or PCs. The gateway also establishes connections with other poles in the street to perform similar tasks.

The system operates in both manual and autonomous modes. In autonomous mode, the road light system automatically turns on when darkness is detected. For stationary objects, an IR sensor is used, while a PIR motion sensor is employed to detect moving objects during nighttime operations. Upon detecting an object or physical motion, the sensor data is transmitted to the microcontroller, which activates the streetlamps.

The lamps remain illuminated until the object or motion disappears. Furthermore, all components, except for the LDR sensor, are deactivated when sufficient natural light is available in the morning. This intelligent feature reduces energy wastage, eliminating the need for manual intervention.

The present status of the road lights system is transmitted through the ESP8266 Wi-Fi module to the gateway, which then uploads the data to the cloud server. The base station can monitor and control the system, while operators can access real-time status updates on their mobile devices or PCs by connecting to the cloud server, where continuous data storage of the road light fixtures is maintained.

The system incorporates a real-time self-diagnostic capability that constantly monitors the components' health. In the event of damage, the controller receives a signal, which is subsequently relayed to the base station. This enables operators to efficiently identify and repair specific pole components without the need to inspect unrelated poles.

The Thing Speak cloud server is utilized for uploading street light data, and all programming for the proposed system is conducted using the ARDUINO IDE.

4. RESULT AND DISCUSSION

The tasks required for system operation are programmed in the Arduino IDE, allowing for efficient execution of different functions. To observe the system's output, the serial monitor displays the results, as depicted in Figure 7.

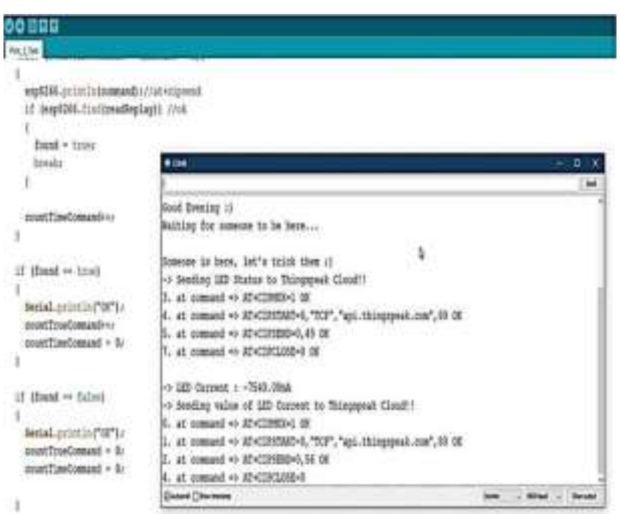

Fig. 7 Showing Arduino code editor screen where the system code is written and a serial monitor on which output displays

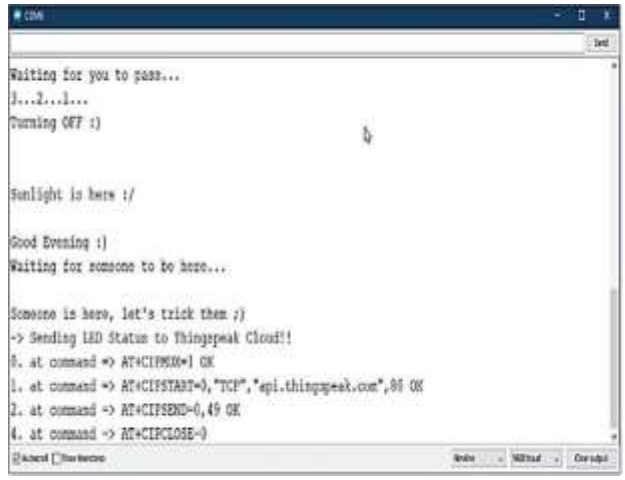

Fig. 8 Serial Monitor showing the output of the proposed system

The display of the system's output can be observed in Figure 7. As individuals pass within the range of the street pole, the current across the system is also shown. Additionally, the status message indicating the transmission of the street pole system's status to Thingspeak can be easily viewed.

Fig. 9 The output of proposed system and LEDcurrent (in mA) showing and sending to ThingSpeak cloud

Fig. 10 ThingSpeak user dashboard (showing pole 2 live status)

Figure 10 illustrates the dashboard of the ThingSpeak cloud server, which provides access to users. The data regarding the status of the poles is uploaded to the cloud server via the Wi-Fi module. On the dashboard, the status of pole 2 is displayed. Figure 11 represents the graph indicating the streetlight's condition, whether it is ON or OFF. Figure 12 depicts the graph showing the consistency or variation in the current consumption of the system.

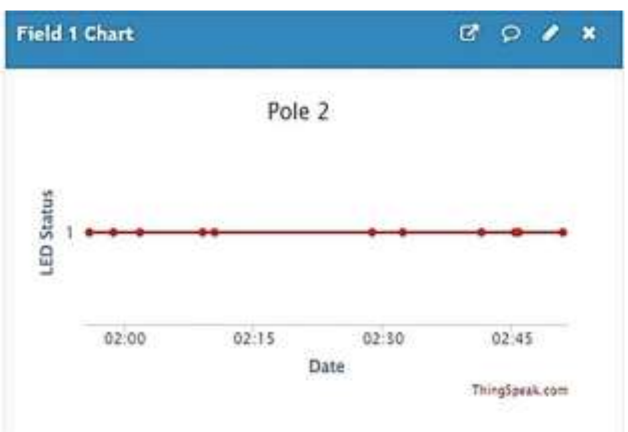

Fig. 11 LED (ON/OFF) status of Pole 2

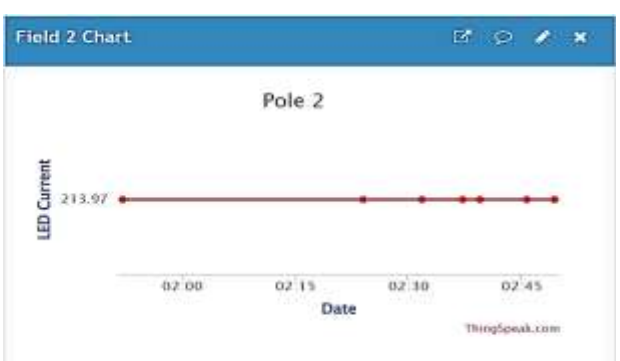

Fig. 12. Pole 2 LED current it includes the total current drop in a system.

The presence of variations in current indicates potential system damage. By analyzing the results from this graph, we can quickly assess the working status of each pole. In the event of any system component damage, we can promptly identify the affected pole and efficiently repair the specific component.

Previous Papers	Key Features	Benefits	Drawbacks
Intelligent Energy Efficient Street Light Controlling System based on IoT for Smart City [19] (2018)	Zigbee,	Low power consumption	Difficult to design
Weather Adaptive Intelligent Street Lighting Management System With Automatic Fault Management Using Boltuino Platform [15] (2021)	DHT11 Sensor, IR sensor	Weather detection	High initial cost and maintenance
A Smart Street Lighting Systen using solar energy [11] (2016)	Photovoltaic (PV), Dust Cleaning circuit.	Renewable energy, very low power consumption	High initial cost
Survey on Energy Efficient Street Lighting System [6] (2017)	Camera, Raspberry pi, GSM	Highaccuracy and efficiency	Complex design and expensive initial cost and maintenance
IoT based Smart and Adaptive Lighting in Streer Lights [14] 2017	Panic Button, IP65 CCTV camera, Zigbee	Crime detection	Difficult to implement

5. CONCLUSIONS

The proposed solution offers a practical and environmentally friendly approach to addressing the challenges faced by streetlights. It effectively addresses the issues of power wastage and the disposal of incandescent lamps. While the initial setup cost may be a consideration, advancements in technology and proper maintenance planning will help reduce these costs over time. The self-diagnostic system integrated into the proposed solution also helps minimize maintenance expenses. LED lights, with their long lifespan, cool light emission, and instant switching capabilities, are utilized in this system, providing numerous advantages over traditional lighting options. Although there may be limitations, such as potential failures of the current sensor or communication devices, the proposed system remains a valuable option for illuminating various settings including colonies, streets, institutes, parking areas, parks, lawns, and gardens. Despite the limitations, it offers significant benefits in terms of energy consumption reduction when compared to existing alternatives.

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AUTHORS

Nirbhay Borikar received his B.Tech degree in Mechanical Engineering from Samrat Ashok Technological Institute Vidisha, India in 2023. His areas of interest are Automobile Part Designing, Embedded System, Robotics, Artificial Intelligence, Machine Learning, Electric Vehicle and Internet of Things.

Corresponding Author E-mail: nirbhayborikar@gmail.com

Jayant Shakya received his B.Tech degree in Electrical Engineering from Samrat Ashok Technological Institute Vidisha, India in 2023.His areas of interest are Internet of Things, Embedded System and Electric Vehicle.

E-mail: jayantshakya3536@gmail.com

Jitendra Kumar Tandekar received his BE degree in Electrical and Electronic Engineering from Truba I.E.I.T. Bhopal, RGPV University, Bhopal, India in 2008. And obtained M.Tech. degree in Electrical Drives and Ph.D. degree in Electrical Engineering from Maulana Azad National Institute of Technology, Bhopal, in 2010 and 2020 respectively. He is currently working as an Assistant Professor in the Department of Electrical Engineering, Samrat Ashok Technological Institute, Vidisha, India. He has more than 9 years of research and teaching (Assistant Professor) experience. His research interests include power quality improvement, multilevel inverters, active power filters, real-time digital controllers for power electronic converters, modulation strategies for power converters and electrical drives.

E-mail:jitendra.tandekar@gmail.com

Neha Borikar received her B. Tech degree in Petrochemical Engineering from Samrat Ashok Technological Institute Vidisha India in 2022. Her area of interest are Aspen plus , Aspen Hysys, MATLAB

E-mail: nehaborikar99@gmail.com

Swapnil Singh Bargahi received his B.Tech degree in electrical Engineering from Samrat Ashok Technological Institute Vidisha, India in 2023. His areas of interest are, Embedded System, autocad, Electric Vehicle and Internet of Things.

E-mail: swapnilsinghbargahi@gmail.com