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IoT Based Real-Time Street Light Fault Detection and Maintenance System with Machine Learning Driven Solution Prediction

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Abstract*: The proposed system provides a complete solution for fault prediction with suggested fixes, accurate position tracking, automated real-time streetlight fault detection, and an effective maintenance strategy. For both general city beauty and public safety, street lighting functionality is essential. Our technology makes use of the Internet of Things (IoT) to continuously monitor streetlights in real-time and quickly identify problems through machine learning. Every streetlight has sensors installed that can detect abnormalities instantly and provide information to a central control system for prompt defect finding. By ensuring a responsive and effective system, this method shortens the period between defect discovery and repair. The system's ability to provide accurate geographic information, offer remedies for errors that are recognized, and help maintenance workers locate and resolve problems more rapidly are some of its important features. By integrating geographic data, maintenance operations are directed and efficient, reducing downtime and improving system reliability overall. This study explores the technical features of the sensor-based system and highlights how effectively it functions as a reliable and straightforward option for regions trying to enhance their maintenance procedures for streetlights*

Keywords: Internet of Things, Machine Learning

I. INTRODUCTION

1.1 Internet of Things (IoT)

The network of networked objects, gadgets, or "things" that are integrated with sensors, software, and other technologies to gather and share data via the internet is known as the Internet of Things (IoT). These gadgets might be anything from commonplace items like wearable technology and home appliances to infrastructure pieces and industrial gear. IoT technology makes it easier to create smart environments, increases productivity, and opens up new services and applications for a variety of industries, including manufacturing, transportation, healthcare, and agriculture. It does this by allowing these devices to communicate and interact with one another on their own.

1.2 Sensor

A sensor is an apparatus or module that recognizes and reacts to external physical inputs. It takes measurements of particular parameters, such motion, light, pressure, or temperature, and transforms them into signals that other systems or devices can understand or use. Sensors are essential for many applications, such as consumer electronics, healthcare, environmental monitoring, and industrial automation. They make it possible to gather data in real-time, which can then be evaluated to automate procedures, increase overall efficiency, and make wise judgments. A number of categories can be used to group sensors according to their construction and functionality. Examples of these categories include pressure, motion, temperature, and proximity sensors.

1.3 Machine Learning

In the field of artificial intelligence (AI), machine learning focuses on creating methods and algorithms that let computers learn from data and become more efficient at certain activities without needing to be explicitly programmed. It entails building models with the ability to examine big datasets, spot trends, and draw conclusions or predictions from the data that is actually observed. Depending on the kind of data provided and the intended result, machine learning algorithms can be divided into three categories: supervised learning, unsupervised learning, and reinforcement learning. Numerous applications, such as natural language processing, recommendation systems, driverless cars, predictive maintenance, and picture and audio recognition, make extensive use of this technology.

1.4 Smart Street Light

Through the integration of cutting-edge technologies, smart street lights represent a revolutionary development in urban lighting infrastructure like control systems, sensors, and communication modules. These cutting-edge lighting solutions have many advantages, such as improved safety and security features like cameras and motion sensors, energy efficiency thanks to LED technology and intelligent dimming, remote monitoring and management capabilities for proactive maintenance, and seamless integration with other smart city systems. Environmental sensors also monitor temperature and air quality. Smart street lights use these features to create more resilient, efficient, and sustainable urban landscapes that improve citizens' quality of life while lowering energy costs and operating expenses for municipalities.

II. RELATED WORKS

By using insights from a thorough analysis of relevant literature, the proposed project seeks to develop an innovative IoT-based real-time streetlight defect detection and maintenance system with ML-driven solution prediction. A range of scholarly publications, such as [1]–[13], provide insights into many facets of streetlight management, such as hardware architectures, automatic brightness adjustment methods, and the use of wireless sensor networks for streetlight control. Additionally, studies on energy-efficient street lighting systems and sensor network applications for smart city projects provide important new information about how to maximize energy use and improve urban infrastructure management.Works such as [1] and [2] examine the design and implementation of IoT-enabled smart street lighting systems, offering important insights into the integration of IoT technologies for streetlight control. The foundation for the creation of the proposed project is laid by these studies, which include approaches for sensor integration, communication protocols, and system architecture design. Furthermore, studies of wireless sensor network-based automatic street light control systems, as covered in [3] and [4], offer workable solutions for real-time streetlight monitoring and control, enabling effective energy management and defect detection.Additionally, [5] highlights the significance of responsive and adaptive lighting systems in urban areas by presenting a real-time street lighting control system. The project investigates how illumination levels can be dynamically changed in response to user needs and environmental conditions by utilizing sensor data and feedback systems. This strategy is in line with the objectives of the project, which is to create an adaptable and agile streetlight management system that can react to changing circumstances instantly.Additionally, [6] looks into Internet of Things (IoT)-based smart street light systems, highlighting the use of data analytics and sensor networks to maximize energy efficiency and performance of streetlights. The proposed project's approach to problem detection and predictive maintenance is based on the notion of data-driven decision-making, which is emphasized in the study on the relevance of streetlight management. The system can minimize downtime and optimize resource allocation by identifying probable defects and recommending preventative maintenance measures through the utilization of sensor data and machine learning techniques.Research like [7] and [8] illustrate how IoT technology might improve quality of life and revolutionize urban infrastructure by focusing on smart street lighting systems for smart cities. These studies highlight the significance of interoperability and scalability in urban development projects as they address the integration of streetlight control systems with larger smart city initiatives. The suggested project's emphasis on comprehensive and linked solutions that address both streetlight management and more general urban concerns is informed by the insights gained from these research.Additionally, [9] and [10] provide insightful analyses of data analytics methods, deployment tactics, and user interface design considerations for IoT-based smart street light systems. Additionally, [11] presents a sensor-network-

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based smart street light system with an energy-saving feature, highlighting the potential of IoT technology to advance resource efficiency and sustainability. The study looks at ways to maximize energy use while keeping proper illumination levels, which is in line with the objectives of the suggested project, which is to operate streetlights in an energy-efficient manner.A smart street light automation and fault detection system's design and implementation are also covered in [12], which emphasizes the significance of automated fault detection and maintenance workflows for guaranteeing the dependability and efficiency of streetlight infrastructure. The proposed solution intends to optimize maintenance operations and reduce disturbances to urban inhabitants and businesses by incorporating automated notification and maintenance processes with fault detection algorithms. In conclusion, [13] investigates measurement and fault detection in intelligent wireless systems, providing information on fault detection techniques and deployment strategies for sensor networks. The proposed project's defect detection and predictive maintenance algorithms rely heavily on the study's insightful information on sensor calibration, data validation, and fault diagnosis methodologies.

III. LITERATURE REVIEW

Reviews	Factors					
	Internet of Things	Machine learning	Street Light	Sensor	Fault detection	ESP32 Microcontroller
D. Santhosh Kumar et al [2023]		-	-		-	
P Karthikeyan et al [2022]		-				-
Siddarthan Chitra Suseendran et al [2018]	-	-		-	-	-
Prabu Mohandas et al [2019]	-				-	-
Seher Yusnieva et al [2017]		-	-		-	-
Sk Mahammad Sorif et al [2021]		-		-	-	-

IV. METHODOLOGY

Sensor integration:

Sensor integration plays a major role in the process of developing the proposed IoT-based real-time streetlight problem detection and maintenance system with ML-driven solution prediction. Smart sensors installed in streetlights gather data in real time on many aspects like lighting intensity, electricity consumption, and ambient conditions. The selection of these sensors was done with great care, considering aspects such as accuracy, stability, and compatibility with the system architecture. The integration process involves installing sensors on each streetlight and configuring them to collect and transmit data to a central computer for analysis. In addition, procedures for sensor validation and calibration are conducted in order to ensure the accuracy and consistency of the data collected. Due to effective sensor integration, the system can continuously monitor the streetlight performance and ambient conditions, providing valuable data for predictive maintenance and issue detection.

Machine learning:

Our approach is based on using machine learning (ML) to provide customized fixes for the wide range of issues that arise with streetlight infrastructure. Our machine learning algorithms identify patterns and correlations between fault

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circumstances and their corresponding cures by examining past fault data. When a malfunction is identified by the system's analytics and sensors, the machine learning model assesses the fault's characteristics and, using its acquired knowledge, suggests the optimal fix. These suggestions range from simple fixes like swapping out bad light bulbs or fixing wiring to more complex ones like readjusting fixtures or calibrating sensors.

Location tracking:

Our method tracks each streetlight's location using a unique identification instead of GPS sensors. When a streetlight malfunctions, its unique identification helps locate the light within the system. The maintenance crew can use this identifier as a point of reference to pinpoint the exact location of the streetlight when using the infrastructure or documentation that is already in place. By using unique IDs, the technique enables accurate location monitoring without the need for additional GPS gear, which reduces costs and simplifies installation. This technology speeds up the fault resolution process and allows for timely interventions to address issues and minimize downtime in streetlight operations by providing maintenance personnel with precise location data.

Alerts and notification:

The alerts and notification process built into our system is designed to promptly notify maintenance personnel of any problems that are discovered with the streetlights. When a flaw is found, the system triggers an alert mechanism that rapidly notifies maintenance personnel through email, SMS, or a mobile application. This instant notification guarantees that issues are quickly brought to the attention of the appropriate staff members. Thanks to machine learning analysis, the system also provides precise information about the nature of the issue and possible solutions, going beyond simple warning. Equipped with this knowledge, streetlight maintenance staff can take a proactive approach to minimize downtime by skillfully addressing issues.

User interface:

The user interface design of our system provides a thorough platform for controlling and viewing streetlight data. Users can access the interface and view real-time fault information, power consumption data, and streetlight placements using web or mobile applications. The interface's interactive graphics and intuitive navigation make it easy for users to explore and assess streetlight data. In addition, the interface offers customization options for alerts, system parameter adjustments, and historical data retrieval for trend analysis. The interface makes it easier to manage and keep an eye on the streetlight infrastructure by giving users access to relevant data in an intuitive manner. This enables people to address problems on their own initiative and make wise selections.

Data Flow Diagram:

A Data Flow Diagram (DFD) for an IoI-based Real-Time Street Light System enhanced with Machine Learning (ML) showcases how data flows and interacts between different elements of the system.

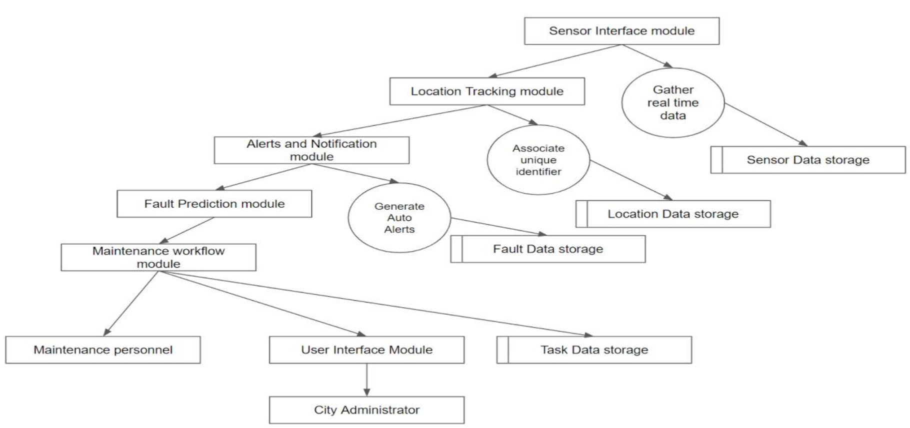

Fig. 1.Data Flow Diagram

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Use Case Diagram:

The use case diagram for our system encompasses three primary actors: Street Light, System Administrator, and Maintenance Personnel. The Street Light actor communicates with the system by sending information and getting alerts about errors. The system administrator can monitor the system, send out alerts, and give maintenance personnel duties to do. On the other side, maintenance personnel are capable of doing maintenance activities, updating task statuses, detecting defects, and receiving notifications. These exchanges show how information moves from street lights to administrators and maintenance staff within the system, facilitating preemptive defect detection and effective maintenance procedures.

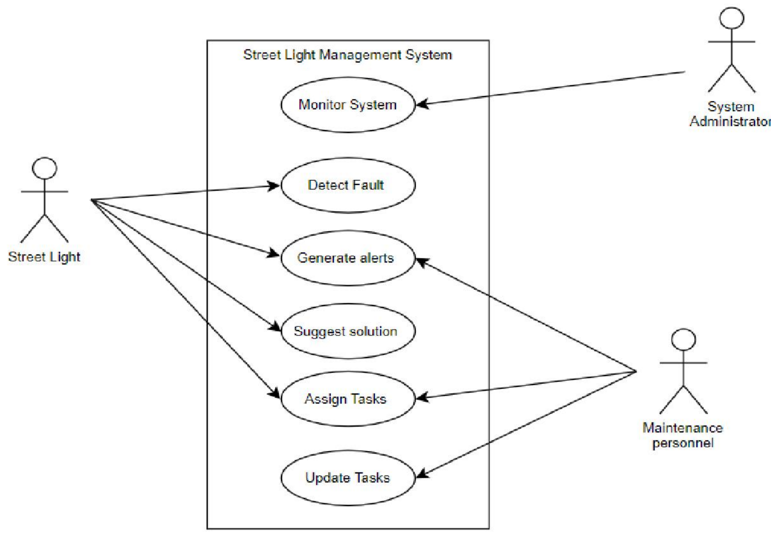

Fig. 2. Use Case Diagram

V. COMPONENTS

ESP32 Microcontroller:

ESP WROOM 32 is a powerful, generic WiFi-BT-BLE MCU module that targets a wide variety of applications, ranging from low-power sensor networks to the most demanding tasks.At the core of this module is the ESP32S chip, which is designed to be scalable and adaptive. There are 2 CPU cores that can be individually controlled or powered, and the clock frequency is adjustable from 80 MHz to 240 MHz.

1. 4 MB Flash.
2. Current: 80 mA.
3. Supply Voltage: 2.2 V ~ 3.6 V.
4. Data Rate: 54 Mbps.
5. Frequency: 2.4 GHz.

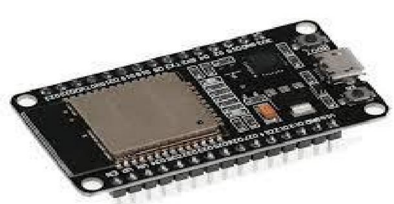

Fig. 3. Esp32 Microcontroller

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LDR sensor:

The LDR Module is used to detect the presence of light / measuring the intensity of light. The output of the module goes high in the presence of light and it becomes low in the absence of light. The sensitivity of signal detection can be adjusted using the potentiometer.

1. Operating Voltage: 3.3V to 5V DC.
2. Operating Current: 15ma..

Fig. 4. LDR sensor

Current sensor:

The 30A range Current Sensor Module ACS712 consists of a precise, low-offset, linear Hall circuit with a copper conduction path located near the surface of the die. Applied current flowing through this copper conduction path generates a magnetic field in which the Hall IC converts into a proportional voltage.

1. Supply Voltage: 4.5V~5.5V DC
2. Measure Current Range: 30A
3. Sensitivity: 100mV/A

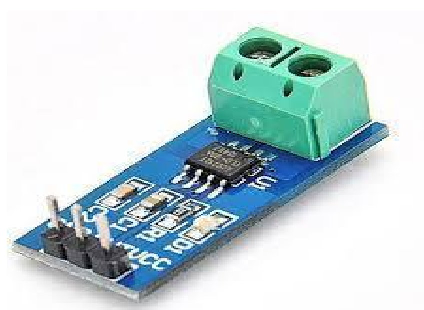

Fig. 5. Current sensor

Vibration sensor:

A vibration sensor is a device that measures the amount and frequency of vibration in a given system, machine, or piece of equipment.

1. Operating voltage 3.3V ~ 5V
2. Output format: digital switching output (0 and 1)

Fig. 6. Vibration sensor

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IR Sensor:

IR Sensor Module has a pair of infrared transmitting and receiving tubes. When the transmitted light waves are reflected back, the reflected IR waves will be received by the receiver tube. The onboard comparator circuitry does the processing and the green indicator LED comes to life.

1. Detection distance: 2 - 80cm.
2. operating voltage: 3.3v

Fig. 7. IR sensor

VI. SYSTEM ARCHITECTURE

The system architecture is a cohesive network of interconnected modules designed to streamline real-time streetlight fault detection and maintenance. It comprises a Sensor Interface Module for data collection, a Location Tracking Module for precise fault location, and an Alerts and Notification Module for automated fault alerts. A Fault Prediction Module uses machine learning to predict issues proactively, while a Maintenance Workflow Module manages tasks efficiently. A User Interface Module provides a user-friendly interface for monitoring and managing streetlight status. This integrated architecture optimizes fault detection, notification, and maintenance processes, ensuring enhanced efficiency and reliability in streetlight management.

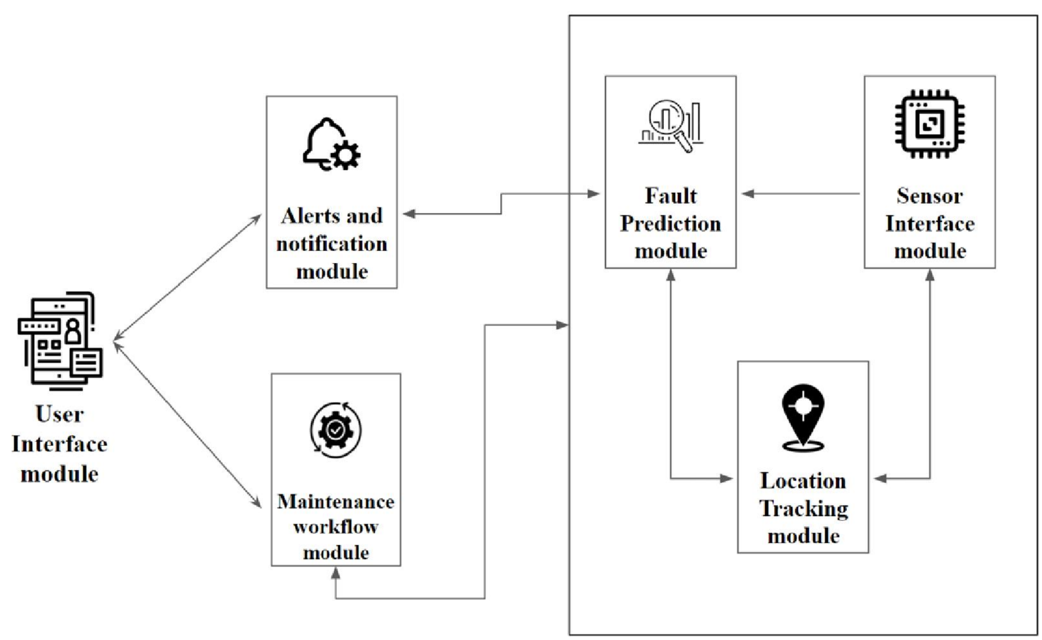

Fig. 8. System Architecture

VII. IMPLEMENTATION

We have integrated all of the sensors in our system to construct the prototype in execution. Initially, each sensor was tested independently. Two LDR sensors were utilized; one was used to detect darkness in the surrounding area. Since

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this sensor is shared by all street lights, one LDR sensor needed to be installed for each street. Every street light has a second LDR sensor to identify any problems with the light. To identify any vibrations in the street light, a vibration sensor is attached. The purpose of a current sensor is to measure current flow and identify any issues with the street light. The street light fixture position change is detected by an infrared sensor. For this, we have integrated and operated every sensor using an ESP32 microcontroller.

Step 1: Initialize sensor communication and streetlight location data reception.
Step 2: Continuously read sensor data and associate unique identifiers with each streetlight.
Step 3: Store sensor data and streetlight locations in the cloud for centralized access.
Step 4: Analyze incoming data for fault detection signals.
Step 5: Generate automated alerts with detailed fault information.
Step 6: Send notifications to maintenance personnel via various channels.
Step 7: Collect relevant data from alerts and notifications, including fault types.
Step 8: Preprocess collected data by cleaning, filtering, and transforming it for analysis.
Step 9: Analyze preprocessed data to identify fault patterns and correlations.
Step 10: Select and train a suitable machine learning model for fault prediction.
Step 11: Implement the trained model for real-time fault prediction and solution suggestions.
Step 12: Receive and display task details on the user interface for maintenance personnel.
Step 13: Allow personnel to update task statuses and integrate with existing maintenance systems.
Step 14: Continuously monitor system status, displaying real-time data and insights.
Step 15: Provide city administrators with options to configure system parameters as needed.

VIII. FLOWCHART

The flowchart shows how our system's processes are organized in an organized way. It starts with initializing the sensor to enable real-time data collection. The data is then sent to the web application using API integration. After data analysis, if any fault occurs in the streetlights, notifications are sent to maintenance staff via email or SMS with the particular fault details and related fixes. This organized process guarantees timely fault identification, precise diagnosis, and effective resolution measure communication, improving the streetlight management system's overall efficacy and responsiveness.

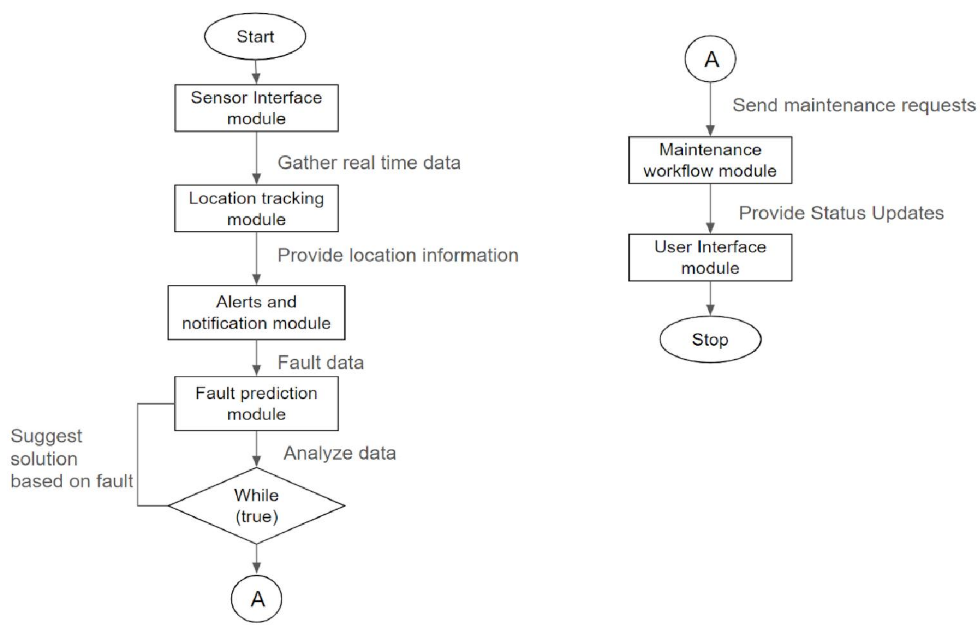

Fig. 9. FlowChart

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IX. GRAPH

The power consumption range differences between our suggested system and the current system are depicted in this graph. The year is shown on the X-axis, and the power usage in kilowatts is shown on the Y-axis. This graph shows the reduction in power consumption in our suggested system when compared to the current system.

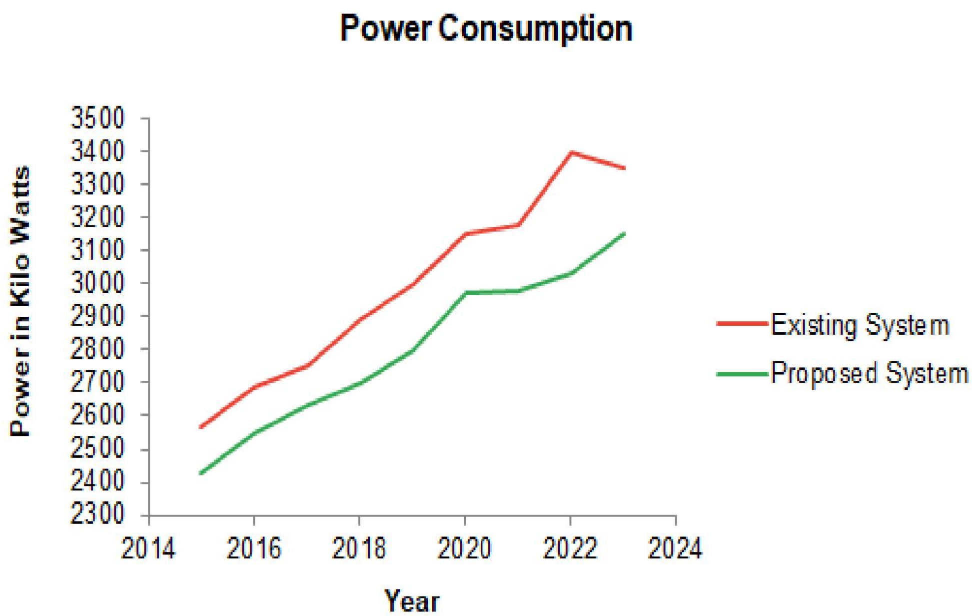

Fig. 10. Power Consumption history

X. RESULT

Detailed access to streetlight facts, such as precise location, power consumption measurements, and real-time status updates about on/off functionality, is provided by the maintenance personnel-designed user interface. Maintenance staff may effectively control system configuration parameters with this interface, guaranteeing peak performance and quick response to maintenance requirements. The user interface's clear controls and comprehensive information presentation enable maintenance staff to make well-informed decisions and promptly address any problems that may occur in the streetlight network, thereby helping to improve the system.

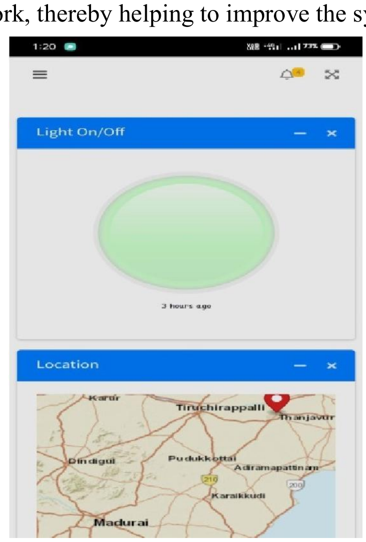

Fig. 11. UI in Mobile View

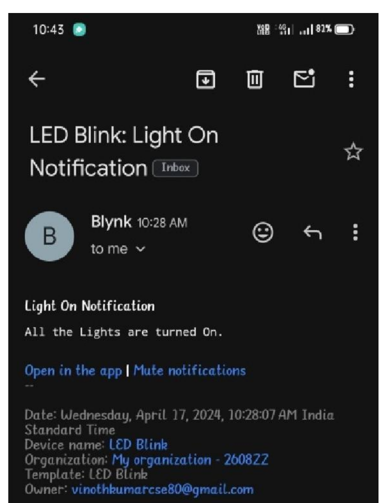

Fig. 12. Test Case

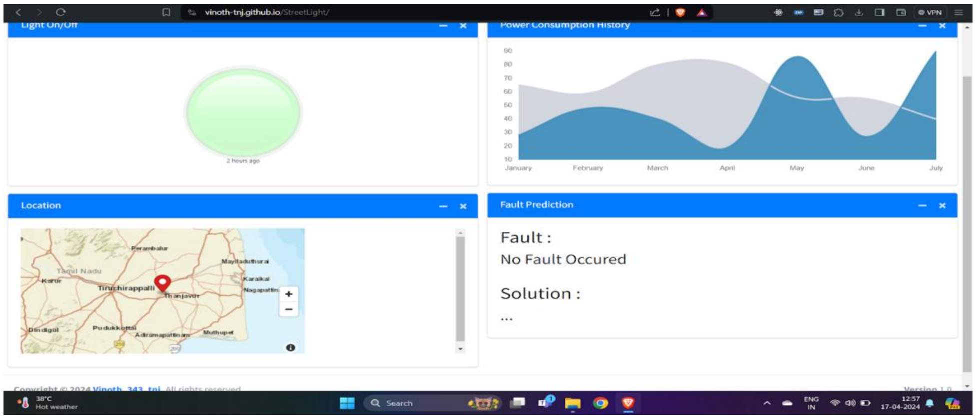

Fig. 13. UI in Web View

XI. CONCLUSION

In conclusion, the automated system that has been suggested offers a revolutionary approach to managing streetlights by utilizing cutting-edge technologies to enhance defect identification, accurate location tracking, and maintenance effectiveness. This solution promotes proactive maintenance, which lowers downtime and increases overall reliability by integrating smart sensors, real-time analytics, and improved workflows. Its efficacy is further enhanced by the addition of automated alarms, thorough notifications, and predictive maintenance features, which guarantee quick resolution of problems and optimize the functionality of streetlight infrastructure. When combined, these systems represent a major breakthrough in streetlight control, offering safer and more effective operations in smart cities.

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