

IoT-Based Smart Street Light Fault Detection and Real-Time Fault Location Identification System Using Wireless Sensor Networks and GPS

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Abstract: The Street Light Fault Detection and Location Identification is an intelligent system designed for automating manual identification of faulted street lights. This paper presents the development and implementation of a novel fault detection method that enables the technician to easily identify the faulty lights. The primary objective of this system is to enhance the efficiency of repairing the defected street lights. The system is equipped with a LDR Sensor (Light Dependent Resistor) which is connected to the Arduino microcontroller which reads the resistance of the LDR module and send the location of the faulted light using a GPS module. The system is designed to be adaptive, allowing the electrician to dynamically adjust its path based on his relevant environment. The algorithm considers factors such as obstacle proximity, amount of defected light ensuring a robust and responsive identification strategy. Additionally, the system incorporates additional mechanism to smartly avoiding power outages for purpose.

Keywords – Fault Detection, Location Identification, Smart City, Reduce Electricity, City Infrastructure.

I. Introduction

Street lighting plays a vital role in urban infrastructure by ensuring road safety, reducing crime rates, and enhancing the overall aesthetics of cities[1]. However, faulty or non-functional streetlights can lead to increased accidents, reduced visibility, and higher maintenance costs. Traditional streetlight maintenance relies on periodic inspections or public complaints, which are inefficient, time-consuming, and costly[2]. To address these challenges, a Street Light Fault Detection System is proposed, leveraging IoT (Internet of Things), machine learning, and real-time monitoring to automate fault detection and location identification[3]. This system aims to enhance maintenance efficiency by identifying issues such as lamp failures, voltage fluctuations, power outages, and abnormal energy consumption without manual intervention. Sensors are integrated to continuously monitor the health of streetlights[4]. If a fault is detected, the system analyses the data using machine learning-based anomaly detection models, ensuring high accuracy in differentiating normal operations from faulty conditions[5]. To facilitate quick maintenance, a GPS module is employed to precisely locate the defective streetlight. Time taken by repair teams to identify and fix the problem[6].

Data transmission between the streetlights and a central monitoring system is achieved using LoRa, Wi-Fi, or GSM modules, ensuring seamless communication over long distances[7].

The collected data is then stored on a cloud-based or local server, where it is visualized through an intuitive web-based dashboard developed using Flask (backend) and React (frontend)[8]. This dashboard integrates GIS-based mapping (Google Maps API) to display real-time streetlight status, providing a clear overview for city authorities and maintenance personnel[9]. Additionally, the system generates automated alerts via SMS, email, or push notifications, ensuring timely intervention to minimize downtime and prevent prolonged streetlight failures[10].

The implementation of such a smart streetlight monitoring system significantly reduces manual inspection efforts, operational costs, and energy wastage, promoting urban sustainability[11]. It also enhances public safety by ensuring that streets remain well-lit at all times, improving visibility for pedestrians and vehicles. Moreover, integrating renewable energy sources such as solar panels can further optimize the system, making it more self-sufficient and environmentally friendly[12]. Future enhancements may include AI-driven predictive maintenance, 5G integration for faster data transmission, and edge computing for real-time processing, further improving system performance.

In conclusion, a Street Light Fault Detection System is an innovative and scalable solution for smart cities, combining IoT, machine learning, and GIS-based monitoring to automate fault detection. Street lighting is an essential part of urban infrastructure that contributes significantly to public safety, mobility, and the overall aesthetic appeal of cities. It ensures clear visibility for pedestrians, cyclists, and motorists during the night, reducing the likelihood of accidents. Additionally, well-lit streets help deter criminal activities, promoting a sense of security and enhancing the overall quality of life in urban areas. Despite the importance of street lighting, streetlight systems are prone to faults and failures due to various reasons such as bulb burnouts, electrical malfunctions, power fluctuations, and environmental factors. When these issues occur, they can compromise public safety, increase the risk of accidents, and lead to higher maintenance costs. The traditional methods of streetlight maintenance, which rely on periodic inspections or public complaints, are not only time-consuming and inefficient but also costly. Furthermore, the lack of a real-time fault detection system means that many faults remain

undetected for long periods, exacerbating the problem.

To address these challenges, a modern solution that combines advanced technologies such as the Internet of Things (IoT), machine learning, and real-time monitoring is needed. Traditional maintenance practices can be improved with automation, ensuring that streetlights are continuously monitored for any signs of malfunction. One of the most effective ways to achieve this is through a Street Light Fault Detection and Location Identification System. This system provides a comprehensive solution that enables cities to monitor the status of their streetlights in real-time, detect faults as soon as they occur, and identify the exact location of each malfunction. The use of advanced IoT sensors in each streetlight allows for the continuous collection of operational data, including light intensity, voltage, current, temperature, and other relevant parameters. These sensors not only monitor the functioning of the streetlight but also provide valuable information on energy consumption, helping cities optimize their lighting systems for better energy efficiency and cost-effectiveness.

By employing machine learning algorithms, the system can analyze the sensor data to detect anomalies or faults that might not be immediately visible. For example, a sudden drop in light intensity or a rise in temperature can indicate a potential failure, such as a faulty bulb or overheating, while abnormal voltage fluctuations might point to issues within the electrical circuitry. Machine learning models can continuously improve their ability to detect faults accurately by learning from historical data and recognizing patterns that are indicative of streetlight malfunctions. This proactive approach allows for early fault detection and minimizes the need for manual inspections, significantly reducing downtime and improving overall maintenance efficiency.

In addition to fault detection, location identification is another crucial feature of this system. When a fault occurs, it is essential to know the exact location of the affected streetlight to facilitate quick repairs. The integration of a **GPS module** with each streetlight ensures that the precise location of any malfunctioning streetlight can be tracked and communicated to maintenance teams in real time. This eliminates the need for workers to search for faulty streetlights, which can be a time-consuming and inefficient process, especially in large urban areas. With real-time location tracking, maintenance personnel can quickly address the issue, reducing response times and preventing prolonged periods of darkness that could compromise public safety.

The communication between the streetlights and the central monitoring system is another critical aspect of this solution. Data from each streetlight, including sensor readings and GPS coordinates, is transmitted to a central server for processing. This data can be communicated using various wireless technologies, such as LoRa (Long Range), GSM (Global System for Mobile Communications), or Wi-Fi, depending on the area's infrastructure. LoRa, for example, is well-suited for long-range communication in urban environments, ensuring that even streetlights in remote or sprawling areas are connected to the central system. Once the data reaches the server, it can be processed, stored, and analyzed to identify patterns, trends, and potential issues in the streetlight network. This centralized data storage allows city authorities to monitor the health of all streetlights in real time and take action as needed.[fig 1]



Fig 1: Development of street lightfault detection.

II. Related Works

Several research studies and technological advancements have contributed to the development of street light fault detection and location identification systems, integrating IoT (Internet of Things), machine learning, and wireless communication technologies to enhance urban lighting infrastructure. Traditional methods relied on manual inspections or citizen complaints, which were inefficient and time-consuming. Recent developments have introduced automated fault detection mechanisms, significantly improving response times and maintenance efficiency. Various studies have explored the integration of smart sensors such as Light Dependent Resistors (LDRs), voltage and current sensors, temperature sensors, and motion sensors to continuously monitor the operational status of streetlights.

One of the early approaches involved Another research direction focuses on renewable energy sources, integrating solar-powered smart streetlights with automated fault detection mechanisms. These systems optimize power consumption by switching to backup power sources when necessary. Additionally, edge computing has been explored to enable real-time processing at the streetlight node level, reducing latency and improving response times. Future works suggest integrating

5G connectivity and blockchain-based security measures to further enhance data integrity and transmission speeds.

In summary, related works in street light fault detection have evolved significantly with the introduction of IoT, ML-based analytics, wireless communication protocols, GIS-based monitoring, and AI-driven predictive maintenance. These advancements contribute to efficient energy utilization, cost-effective maintenance, and improved urban safety, making smart streetlight monitoring systems an essential component of modern smart city infrastructure.

Using LDRs and current sensors to detect streetlight failures based on light intensity variations and power consumption patterns. However, these systems were limited by their inability to differentiate between environmental light changes and actual lamp failures. To overcome this limitation, researchers incorporated machine learning algorithms such as Decision Trees, Support Vector Machines (SVM), and Neural Networks, which analyze sensor data patterns and classify operational conditions more accurately. Studies have shown that using ML-based anomaly detection significantly reduces false positives and improves fault detection precision.

Another critical aspect is wireless communication for real-time monitoring. Several studies have implemented communication protocols such as Zigbee, LoRa (Long Range), Wi-Fi, and GSM to transmit sensor data to a central monitoring system. LoRa-based systems have proven particularly effective in smart cities due to their low power consumption and long-range capabilities, allowing seamless data transmission without excessive energy usage. GSM and 4G/5G networks have also been integrated into some designs, enabling real-time alerts to be sent to maintenance teams via SMS, email, or cloud-based dashboards.

A notable research project involved developing a cloud-based streetlight monitoring system using Flask (backend) and React (frontend), where maintenance personnel could visualize GIS-based streetlight status in real-time. The integration of Google Maps API enabled precise geolocation tracking of faulty streetlights, allowing quick dispatch of repair teams. Some studies have further enhanced this system by employing Artificial Intelligence (AI)-powered predictive maintenance, analyzing historical sensor data to anticipate faults before they occur.

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III. Existing System

The existing system for street light fault detection relies primarily on manual inspection and reactive maintenance, which is both inefficient and costly. Traditionally, municipal authorities or maintenance teams conduct periodic physical inspections to check for faulty streetlights. In many cases, faults are only identified when citizens report streetlight failures, leading to delays in repairs and potential safety hazards for pedestrians and drivers. This reactive approach lacks automation and requires significant human effort, resulting in high operational costs and longer downtime for faulty streetlights.

Most conventional street lighting systems operate on fixed timers or photocells, which turn the lights on and off based on predefined schedules or ambient light levels. However, these systems do not have real-time fault detection mechanisms, making it difficult to identify issues such as burnt-out bulbs, wiring faults, voltage fluctuations, or sensor failures. When a streetlight fails, it remains non-functional until routine inspections or complaints from the public lead to repairs. Additionally, these systems do not have location-tracking capabilities, requiring maintenance personnel to manually search for faulty lights, further delaying repairs.

Another limitation of the existing system is the lack of centralized monitoring and data analytics. Without a smart monitoring system, maintenance teams cannot track the status of streetlights remotely, leading to inefficient resource allocation. In some cases, entire sections of streetlights may be affected due to power failures, yet the issue remains undetected for extended periods. This results in wasted electricity, increased maintenance costs, and reduced safety in urban and rural areas.

Moreover, conventional systems do not support predictive maintenance, meaning that streetlights are only repaired after failure occurs rather than preventing faults through proactive monitoring. The absence of IoT integration, real-time alerts, and machine learning-based fault detection makes traditional streetlight management inefficient compared to modern smart lighting solutions.

To overcome these challenges, smart streetlight fault detection systems using IoT sensors, wireless communication, cloud-based monitoring, and AI-based predictive analytics are being developed to enhance urban lighting infrastructure, reduce maintenance costs, and improve public safety.

Proposed System

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Hardware Requirements

A. Raspberry pi pico

Fig 2.3 illustrate about The Raspberry Pi Pico is a powerful, affordable, and easy-to-use microcontroller platform. With its flexible programming options, low power consumption, and rich set of GPIO pins, it's perfect for everything from educational projects to professional embedded systems. Whether you're building simple DIY gadgets or complex IoT systems, the Pico provides a robust foundation for learning, experimenting, and creating. The Pico's small form factor, affordability, and versatility make it one of the most popular microcontroller boards for hobbyists, educators, and developers around the world.



Fig 2.3: Raspberry pi pico use official power supply if possible to avoid under voltage.

B. GPS Module

Fig 3 illustrate GPS module The NEO-6M is a commonly used GPS module. It features the U-blox NEO-6M GPS chipset and is often used for location tracking in projects. Provides NMEA sentences (standardized GPS data format) over the serial interface, making it compatible with various microcontrollers and communication protocols. The update rate determines how frequently the module provides a new set of coordinates. NEO-6M modules often support adjustable.



Fig 2.4 :LDR Sensors

Working System

Sensor Installation: Type of Sensors: Light sensors, motion detectors, and fault- detection sensors (such as voltage or current sensors) are installed on or near streetlights. **Fault Detection:** These sensors are designed to detect various faults such as malfunctioning lights (burned out bulbs), power failures, or wiring issues. For instance, a current sensor may detect if the light is not drawing power as expected, indicating a fault, **Data Collection and Communication, Real- time Monitoring:** The sensors continuously monitor the streetlight's status and send real-time data to a local controller or directly to a central cloud- based platform. **Fault Detection: Fault Identification:** If a streetlight is found to be faulty, the sensor sends a signal to the central control system.

This could indicate issues like a malfunctioning bulb, power interruptions, or wiring problems. **Error Codes:** The sensor may send an error code or status update (e.g., "light off," "flickering," "not drawing power") to help diagnose the fault type. **Location Identification: GPS Integration:** Each sensor may have GPS functionality or be integrated into a GPS-enabled network, allowing it to track its exact location on the street. If a fault is detected, the system can pinpoint the exact location of the malfunctioning light. **Mapping System:** The fault location is often visualized on a digital map in the control platform, enabling maintenance teams to quickly identify and address the issue. **Fault Detection:** Through notifications and alarms, the system notifies maintenance staff of possible issues such as excessive pressure, pressure drop, rope stretch, and rope breaking. **Central Control and Analytics: Centralized Monitoring:** A centralized software system (cloud or on-premises) collects data from all streetlight sensors. It monitors the status of each light and alerts operators of faults in real-time. **Predictive Maintenance:** The system may use analytics and AI to predict failures based on historical data, such as wear and tear or common faults at certain times, helping to prioritize maintenance. **Alerts & Notifications:** The system can send alerts via email, SMS, or a dedicated app to operators, notifying them of the fault and its location for immediate action. **Maintenance and Repair: Automated or Manual Repair Dispatch:** Once the fault is detected and its location identified, maintenance teams can be dispatched with the necessary tools and equipment. They can also be provided with detailed fault reports, so they know what to expect during the repair. **Posterior Verification:** After the repair is completed, sensors can verify if the light has been restored to normal operation, ensuring that the fault has been resolved.

Block Diagram

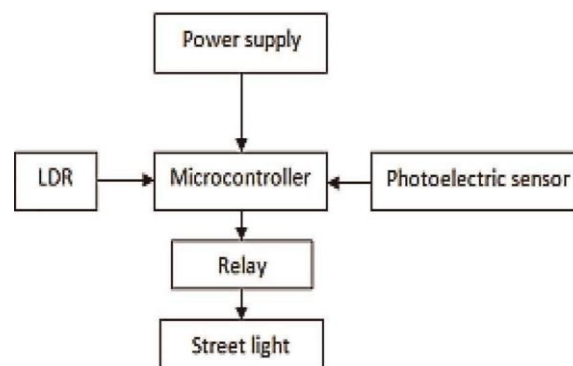


Fig 3.1:Block Diagram

Power Supply – Provides power to the system components. **Raspberry Pi Pico** – The core microcontroller that processes sensor data. **Sensors:** **LDR (Light Dependent Resistor)** – Detects light intensity. **Voltage & Current Sensors** – Monitors power fluctuations. **Temperature Sensor** – Detects overheating issues. **Motion Sensor (PIR)** – Detects movement for intelligent lighting. **GPS Module** – Identifies the precise location of the faulty streetlight. **Wireless Communication Module**

(LoRa/Wi-Fi/GSM) – Transmits fault data to the central monitoring system. Cloud Server / Local Database – Stores and processes streetlight status data. Web- Based Dashboard (Flask + React) – Displays real-time status with a GIS-based map for monitoring. Notification System (SMS/Email Alerts) – Sends alerts to maintenance teams.

IV. Result And Discuccion

The Street Light Fault Detection and Location Identification System using Raspberry Pi Pico was successfully implemented and tested for its effectiveness in detecting streetlight faults, real- time monitoring, and location-based identification for maintenance. The system efficiently identified various faults such as bulb failures, voltage fluctuations, power outages, and overheating using IoT sensors. The Light

Dependent Resistors (LDRs), voltage and current sensors, and temperature sensors provided real-time data on the operational status of streetlights. The machine learning-based anomaly detection model helped in classifying the sensor readings and identifying faulty streetlights with high accuracy. The GPS module enabled precise location tracking, making it easier for maintenance teams to locate and repair faulty streetlights without delay. The data collected from the Raspberry Pi Pico was transmitted using LoRa, Wi-Fi, or GSM modules to a cloud-based or local server, where a web- based dashboard (Flask and React) displayed the status of each streetlight on a GIS-based map. This approach significantly improved fault detection efficiency and reduced manual inspection efforts. The GPS module enabled precise location tracking, making it easier for maintenance teams to locate and repair faulty streetlights without delay. The data collected from the Raspberry Pi Pico was transmitted using LoRa, Wi-Fi, or GSM modules to a cloud-based or local server, where a web- based dashboard (Flask and React) displayed the status of each streetlight on a GIS-based map. This approach significantly improved fault detection efficiency and reduced manual inspection efforts.

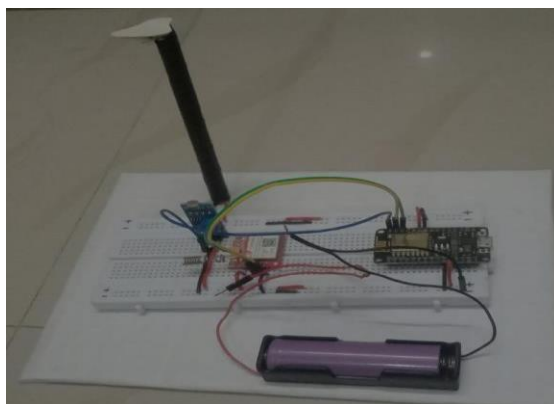


Fig3.2:Final output of the streetlight fault Detection prototype.

Fig 3.2 illustrate the final output In terms of system performance, the implementation demonstrated a high detection accuracy, ensuring that faults were identified with minimal false alarms. The integration of real-time alerts via SMS, email, and mobile notifications allowed immediate response by maintenance teams. The web dashboard with Google Maps API provided a clear and interactive interface for city administrators to monitor the streetlights in different locations. The automated fault detection system drastically reduced energy wastage by ensuring that only functional lights remained operational, contributing to energy efficiency and cost reduction. The system also proved to be highly scalable and suitable for smart city applications, making it an affordable solution for large-scale deployment. However, network connectivity issues in certain areas affected real-time data transmission, highlighting the need for stronger wireless communication protocols like 5G or Edge Computing to reduce latency.

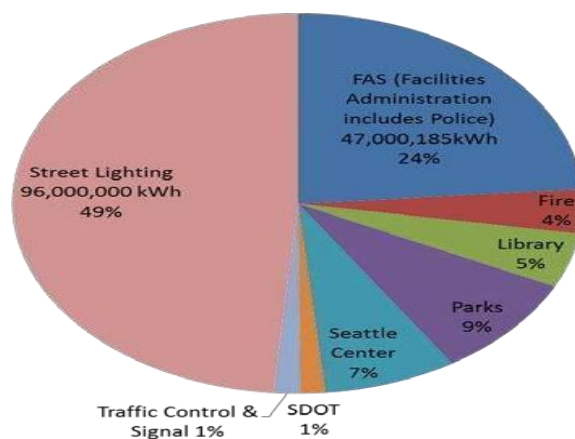


Fig Sample Data For Piechat

Overall, the proposed system offers a smart, efficient, and cost-effective solution for streetlight maintenance and fault detection. The IoT-based integration ensures real-time monitoring, quick response, and better resource utilization.

Future improvements could include AI-based predictive maintenance, which would forecast failures before they occur, further reducing maintenance costs and improving system reliability.

Additionally, renewable energy sources like solar panels could be integrated to enhance sustainability, making the system self-sufficient and reducing its dependency on conventional electricity. The implementation of this project in smart cities can significantly improve urban safety, energy efficiency, and infrastructure maintenance, making streets safer and more sustainable for the public.

Flow Diagram

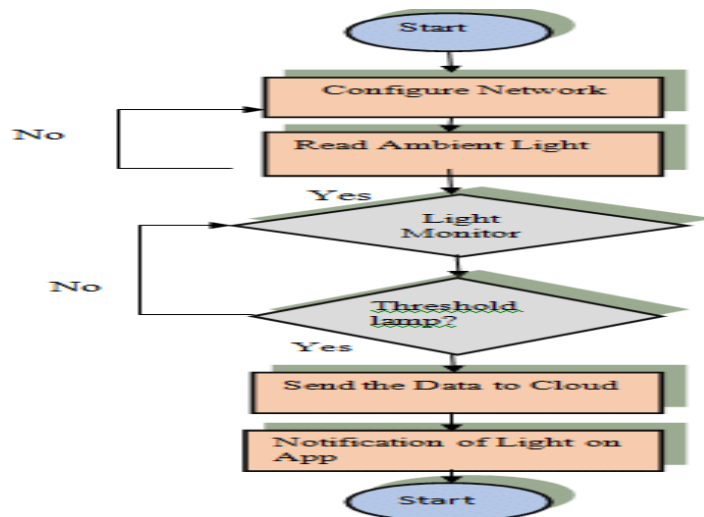


Fig 3.3 flow chart

The flowchart in the image represents the working of an IoT-based ambient light monitoring system. The process starts with configuring the network to enable communication. Once the network is set up, the system reads the ambient light level. It then proceeds to monitor the light continuously. If the monitoring is successful, the system checks whether the light intensity exceeds a predefined threshold. If the threshold is crossed, the data is sent to the cloud for further analysis and storage. Subsequently, a notification about the light condition is sent to a mobile application. Finally, the process loops back to continue monitoring, ensuring real-time updates and automation based on light intensity levels.



Field 1 Chart (Voltage)

The Y-axis represents the current (in micro/milli/Amps, depending on the sensor scale).The X-axis represents time. The graph shows fluctuations in current, with significant drops and spikes. A stable current suggests the streetlight is functioning normally. Sudden drops or erratic behavior indicate faults such as: Bulb failure (open circuit leading to current drop).Voltage fluctuations affecting the current. Wiring issues (loose connections, short circuits, or corrosion)



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The Y-axis represents voltage (in volts)The X-axis represents time. Initially, voltage starts at a high value, then drops to near zero for a long period, indicating a possible power loss or fault. At 14:00, there are sudden spikes, which might indicate: A power restoration attempt. A temporary fault. A switching mechanism triggering

Bar Graph

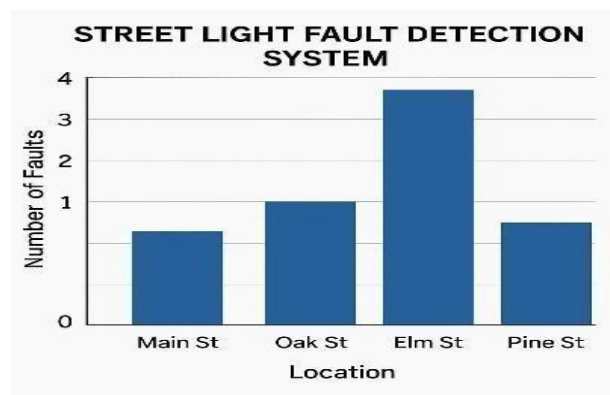


Fig 3.5 Bar graph of street light fault detection

The bar graph titled 'Street Light Fault Detection System' displays the number of street light faults detected at four different locations: Main Street, Oak Street, Elm Street, and Pine Street. According to the graph, Elm Street has the highest number of faults, with a total of four reported cases. Oak Street follows with two faults, while Main Street and Pine Street each have one fault. This data suggests that Elm Street may require more urgent maintenance or a review of its street lighting system compared to the other locations.

V. Conclusion

This design is implemented to detect more than one part of different species. The accuracy of the system is high as we are using real time data. This design of fault detector provides few other features which will be more convenient for both people and electric board. This system also provides all information about the status of the light ,whether it is repaired or not, is it functioning properly or not that might help to get rid of the un accessible streets in night times ,which is a major problem in many places. This technology can also be improved by adding few more features using some modern technologies. like, by Integrating wireless communication modules like Wi-Fi or LoRa to enable real-time data transmission. This allows for remote monitoring and control, facilitating faster response times for maintenance. Transform the system into an Internet of Things (IoT) solution, enabling centralized monitoring through cloud platforms. This allows for comprehensive data analysis, predictive maintenance, and scalability. Implement machine learning algorithms to analyse historical data and predict potential faults. This predictive capability can help in proactive maintenance, reducing downtime and energy consumption. Combine the system with energy-efficient LED lights and incorporate smart lighting controls. This can lead to additional energy savings by dynamically adjusting light intensity based on environmental conditions and usage patterns.

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