Centralized Monitoring System for Street Light Fault Detection and Location Tracking Hardware Smart Automation.

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Abstract - This paper presents the design and implementation of a centralized monitoring system for street light fault detection and location tracking using smart hardware automation. The objective is to enhance the operational efficiency of urban street lighting by enabling real-time monitoring, automated fault identification, and accurate location tracking. The proposed system integrates a microcontroller-based unit equipped with current sensors, light sensors, and a GPS module, allowing it to detect faulty street lights and transmit their status and location to a centralized control unit via wireless communication. A custom dashboard provides visualization and management capabilities for maintenance teams. The methodology significantly reduces the need for manual inspection, optimizes maintenance schedules, and ensures better energy utilization. Field testing demonstrated high accuracy in fault detection and prompt reporting, contributing to improved public safety and reduced operational costs. This system is scalable and can be integrated with broader smart city infrastructure for enhanced urban management.

Key Words: Smart street lighting, fault detection, location tracking, centralized monitoring, IoT automation, GPS-based system.

1.INTRODUCTION *(Size 11, Times New roman)*

Urban street lighting plays a critical role in ensuring public safety, enabling transportation, and enhancing the quality of life in cities. However, maintaining large-scale street lighting networks poses significant challenges, especially when faults go undetected or are identified only after public complaints or routine inspections. Traditional maintenance methods are labor-intensive, time-consuming, and inefficient. To address these limitations, this paper proposes a centralized monitoring system equipped with smart automation hardware for real-time fault detection and location tracking of street lights. The system leverages microcontroller-based units integrated with current sensors, GPS modules, and wireless communication technologies to continuously monitor the operational status of each light. By transmitting fault data and precise location information to a centralized dashboard, the system enables timely intervention, reduces energy waste, and minimizes downtime. This approach not only optimizes maintenance operations but also aligns with the growing push towards smart city infrastructure and sustainable urban development.

2. Existing Systems

Current methods for checking if streetlights are working often involve people physically looking or using partly automated tools. In many cities, repair crews follow set schedules or only react when someone reports a problem. This can mean delays, higher costs, and lights staying broken for longer. Some systems use simple timers or light sensors to control when lights turn on and off, but they don't provide live updates and can't tell when a single light fails. More advanced systems use SCADA or wireless sensor networks, offering some monitoring, but these can be pricey, hard to expand, and don't always pinpoint exactly where a fault is. Plus, most systems don't give specific location information, making it tough to find broken lights in a big city. Because of this, there's a real need for a cheaper, easier-to-grow, and more accurate system that can constantly track streetlight status, spot problems, and send location details instantly. This need is the reason for developing a better central monitoring system using smart technology.

For a long time, keeping our streetlights working has meant people physically checking them and fixing them on a set schedule. This takes a lot of effort and isn't always the most efficient way. When a light goes out, it often takes a while for someone to notice and get it fixed. This can make it harder to see at night, increase the chance of accidents, and lead to people complaining.

Some cities have tried to make things easier by using timers or light sensors to automatically turn lights on and off. This helps save energy and makes sure the lights follow a more consistent schedule. However, these systems can't tell if a single light bulb has burned out or if there's another problem. They just follow the schedule, whether the light is working or not.

More recently, some cities have started using more advanced technology like SCADA or GSM modules to monitor the lights from a distance. But these systems can be expensive to set up and might not work well when you need to monitor a lot of lights. They usually give a general idea of how things are working in a larger area, but they can't tell you exactly which light is broken. Also, wireless systems like ZigBee or Wi-Fi can have trouble reaching all the lights in a big city and might not always be reliable.

3. Implementation

The new system for keeping an eye on streetlights and finding problems uses smart gadgets connected to a central brain. This brain is an ESP32 microcontroller, which is powerful but doesn't use much energy. It also has built-in Wi-Fi and Bluetooth, making it perfect for smart city projects. Each streetlight will have a light sensor (LDR) that detects when it's getting dark or light outside, automatically turning the light on or off to save energy.

To know if a streetlight is actually working, a current sensor (ACS712) will check if electricity is flowing. If not, it means the light is broken. A voltage sensor (ZMPT101B) will also keep an eye on the power levels to spot problems like cut wires or low voltage. A relay will act like a remote switch, allowing the central system to control the lights.

To pinpoint the exact location of a faulty light, a GPS module (Neo-6M) will be attached. This will give precise coordinates, so repair crews can go directly to the problem, fixing things much faster. To send information back to the city's main computer, the system will use a SIM card module (like SIM800/900 or a faster LTE version) to communicate over phone networks. Wi-Fi and Bluetooth can also be used if there's a good local network available.

A steady power supply will make sure all these electronics work reliably, even when the weather is bad. The system is designed to constantly check the sensors and send out alerts if anything goes wrong. When a problem is found, the type of fault and its exact location will be sent immediately to a central computer that city officials can see. This will help repair teams prioritize their work and fix problems quickly, improving how the city is run and the quality of services for everyone.

This new system aims to rely less on people having to report broken lights. Instead, it will allow for fixing problems before they're even noticed. It's a smart and expandable solution for managing city infrastructure, making the work of repair crews easier and supporting the bigger goal of using technology to govern cities effectively in India.

The system continuously monitors sensor inputs, triggering real-time alerts with fault type and GPS coordinates to a centralized server accessible to municipal authorities, enabling proactive maintenance, reduced reliance on manual reporting, and a scalable, intelligent solution for urban infrastructure management, ultimately simplifying workflows and supporting digital governance in Indian cities.

The goal here is to move away from relying on people to manually report broken streetlights. Instead, we're aiming for a system that can predict when a light might fail and fix it before it even goes out. This creates a solution that can easily grow as the city expands and uses smart technology to manage our urban infrastructure more effectively. This smart automation isn't just about making things easier for the repair crews; it's also about supporting a bigger picture of digital governance and smart urban planning across Indian cities.

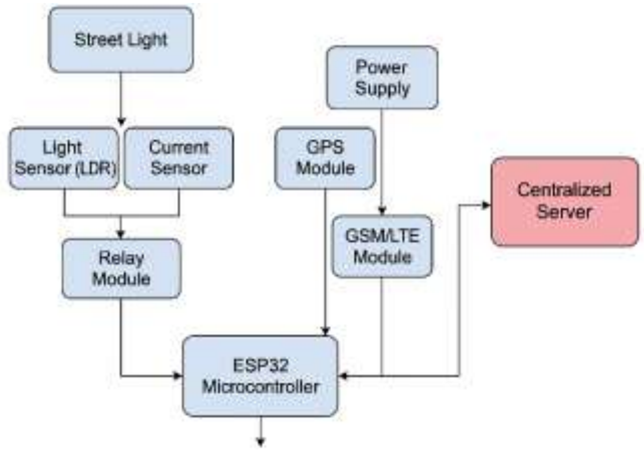

Figure 1 : Flowchart of Centralized Monitoring System for Automated Street Light Fault Detection and Location Tracking

Figure 1 describes the architecture of a proposed centralized monitoring system for smart street lighting, detailing the interconnected hardware components and their interaction in achieving real-time fault detection, location tracking, and remote management. At the core of each individual smart streetlight unit lies the ESP32 microcontroller, represented as a central processing hub receiving inputs from various sensors and controlling output mechanisms. The ESP32's selection is predicated on its robust dual-core processing capabilities, integrated Wi-Fi and Bluetooth connectivity, and energy-efficient operation, making it a suitable choice for Internet of Things (IoT) applications within a smart city infrastructure.

The system incorporates several key sensors to monitor the operational status and environmental context of the street light. A Light Dependent Resistor (LDR), labeled as "Light Sensor (LDR)" in the flowchart, is directly associated with the "Street Light" and feeds data into the "Relay Module." The LDR functions as an ambient light sensor, its resistance varying with the intensity of light. In low-light conditions, the resistance increases, signaling the need to turn the streetlight ON. Conversely, in daylight, the resistance decreases, indicating sufficient ambient illumination to switch the streetlight OFF. This automated ON/OFF functionality, controlled by the ESP32 based on the LDR readings and the state of the "Relay Module," contributes to energy conservation by ensuring that streetlights operate only when required.

Complementing the LDR for operational monitoring is the "Current Sensor," positioned to monitor the electrical current flowing to the "Street Light." This sensor plays a crucial role in fault detection. If a streetlight bulb fails or there is an interruption in the electrical circuit, the current flow will cease or deviate significantly from normal operating parameters. The "Current Sensor" detects these anomalies and transmits the data to the "ESP32 Microcontroller." By analyzing the current readings, the microcontroller can identify non-functional lights or potential issues like current leakage, which could indicate wiring problems or other electrical faults.

The "Relay Module" acts as an electromechanical switch, controlled by the "ESP32 Microcontroller," to physically turn the "Street Light" ON or OFF. The decision to toggle the relay is based on the input from the "Light Sensor (LDR)" and any fault conditions detected by the "Current Sensor" and potentially other sensors (though not explicitly shown for voltage monitoring in this simplified flowchart, as described in the preceding text). The microcontroller processes the sensor data and sends appropriate signals to the relay to manage the power supply to the streetlight.

To enable the crucial feature of real-time location tracking of faulty streetlights, a "GPS Module" is integrated into the system. This module receives signals from the Global Positioning System satellites and calculates the precise geographic coordinates (latitude and longitude) of the streetlight unit. The location data is then transmitted to the "ESP32 Microcontroller." When a fault is detected by the "Current Sensor" (or potentially a voltage sensor, as mentioned in the earlier description but not explicitly in this diagram), the microcontroller retrieves the current GPS coordinates from the "GPS Module."

For communication with the central monitoring infrastructure, a "GSM/LTE Module" is employed. This module utilizes cellular network technology (either GSM, which is a 2G standard, or LTE, a 4G standard offering higher data rates) to transmit data over long distances. The "ESP32 Microcontroller" packages the fault information (e.g., no current flow, abnormal current) along with the corresponding GPS coordinates obtained from the "GPS Module" and sends this data via the "GSM/LTE Module" to the "Centralized Server." The choice between GSM and LTE would depend on factors such as data transmission requirements, network availability in the deployment area (Bengaluru, Karnataka, India, in this context), and cost considerations, keeping in mind that LTE offers faster data speeds and is generally preferred for more bandwidth-intensive applications, although basic fault reporting and location data can be efficiently transmitted over GSM as well.

The "Power Supply" block represents the source of electrical energy for all the electronic components within the smart streetlight unit, including the ESP32 microcontroller, the LDR, the current sensor, the relay module, the GPS module, and the GSM/LTE module. A stable and regulated power supply is essential for the reliable operation of these components, especially in the variable and often harsh outdoor environment of street lighting infrastructure in Bengaluru, Karnataka, India, which can experience significant temperature fluctuations, humidity, and dust. The power supply would typically be derived from the main power grid that also feeds the streetlight itself, with appropriate voltage regulation to meet the requirements of the electronic modules (e.g., 5V or 3.3V for the microcontroller and sensors, 12V or 24V for the relay, etc.).

The "Centralized Server," depicted with a distinct rounded-rectangle and a different fill color (indicating it might be a separate entity or system), is the destination for the data transmitted by the "GSM/LTE Module" from each smart streetlight unit. This server would host a software platform or application responsible for receiving, processing, storing, and visualizing the data. Municipal authorities and maintenance personnel in Bengaluru, Karnataka, India, would access this platform through a user interface (e.g., a web-based dashboard) to monitor the status of all connected streetlights in real time.

When a fault occurs (e.g., a streetlight bulb burns out, detected by the lack of current flow reported by the "Current Sensor" to the "ESP32 Microcontroller"), the microcontroller sends an alert containing the fault information and the precise GPS coordinates to the "Centralized Server" via the "GSM/LTE Module." The server then processes this information and can display it on a map interface, pinpointing the exact location of the faulty streetlight. This location-specific data significantly streamlines the maintenance process by enabling maintenance crews to be dispatched directly to the проблематic unit, reducing response times and the need for manual巡检 to locate faults within the extensive network of streetlights in Bengaluru, Karnataka, India.

The centralized server can also perform data analytics on the collected information, such as tracking the frequency and types of faults, identifying areas with higher failure rates, monitoring energy consumption patterns across the city's streetlight network, and generating reports for infrastructure management and planning in Bengaluru, Karnataka, India. This data-driven approach can lead to more efficient maintenance schedules, optimized resource allocation, and better overall management of the city's street lighting infrastructure.

Furthermore, the system's architecture allows for potential future enhancements and integrations. For instance, while not explicitly shown, additional sensors could be incorporated to monitor environmental parameters like air quality or temperature, turning the streetlight infrastructure into a broader urban sensing network. The ESP32's capabilities also support over-the-air (OTA) updates, allowing for remote software upgrades and bug fixes to the streetlight units without requiring physical access to each node in Bengaluru, Karnataka, India.

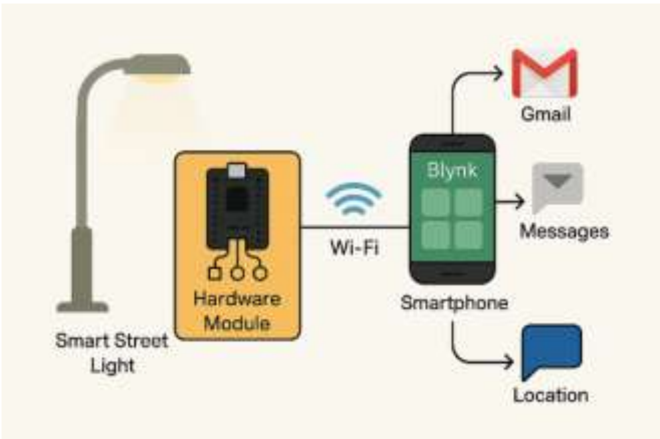

Figure 2 : IoT-Enabled Street Lighting Fault Management Architecture

Figure 2 describes the heart of this intelligent street lighting infrastructure lies a fundamental transformation of conventional luminaires into smart, interconnected nodes through the integration of a dedicated Hardware Module. This module, envisioned as the central nervous system for each individual streetlight, encapsulates a suite of sophisticated sensors and communication units meticulously engineered to monitor, control, and report on the operational status and environmental context of its host. The orange box labeled "Hardware Module" in the illustrative diagram serves as a potent visual representation of this critical component, underscoring its role as the primary intelligence and control center for that specific lighting unit within the broader urban landscape of Bengaluru, Karnataka, India.

Within the robust confines of this Hardware Module resides the ESP32 Microcontroller, a compact yet remarkably powerful and cost-effective system-on-a-chip that forms the core computational engine of the smart streetlight. Chosen for its inherent capabilities in dual-core processing, integrated Wi-Fi and Bluetooth connectivity, and efficient power consumption, the ESP32 is ideally suited for the demands of IoT-based smart city applications. Its primary function within the system is to diligently collect a continuous stream of data from the various sensors embedded within the module, execute pre-programmed logical algorithms to interpret this data, and seamlessly transmit relevant information to external devices or centralized platforms for monitoring and analysis, ensuring that the operational status of each streetlight in Bengaluru, Karnataka, India, is constantly and accurately assessed.

To facilitate intelligent illumination control and energy optimization, the Hardware Module incorporates a Light Dependent Resistor (LDR), aptly labeled "Light Sensor (LDR)" in the system architecture. This passive electronic component exhibits a dynamic change in its electrical resistance in response to variations in ambient light intensity. During periods of diminishing natural light, such as dusk or overcast weather conditions prevalent in Bengaluru, Karnataka, India, the resistance of the LDR increases, triggering a signal to the ESP32 Microcontroller. Conversely, as daylight intensifies, the LDR's resistance decreases, signaling sufficient ambient illumination. The ESP32, leveraging these real-time light level measurements and its control over the "Relay Module," autonomously manages the switching of the streetlight, ensuring that artificial illumination is provided only when necessary, thereby significantly contributing to energy conservation efforts within the city's infrastructure.

Crucially, the Hardware Module is equipped with an ACS712 Current Sensor and a ZMPT101B Voltage Sensor, both of which play pivotal roles in the proactive detection of electrical anomalies that could indicate potential faults within the streetlight system in Bengaluru, Karnataka, India. The ACS712 Current Sensor meticulously monitors the magnitude of electrical current flowing through the streetlight's circuitry. A sudden or gradual drop in current consumption below a predefined threshold can serve as a reliable indicator of a non-functional lamp, a tripped circuit breaker, or a disconnection in the wiring. Conversely, unusually high current readings might suggest a short circuit or other electrical overload conditions. The ZMPT101B Voltage Sensor complements this by continuously monitoring the electrical potential across the streetlight's power supply. Irregularities in voltage levels, such as significant drops or unexpected spikes, can point towards a range of issues, including cable damage, loose connections, or fluctuations in the power grid itself, all of which are critical to identify promptly to ensure the safety and reliability of the street lighting infrastructure in Bengaluru, Karnataka, India. The data from both these sensors is continuously fed into the ESP32 Microcontroller for immediate analysis and potential triggering of alert mechanisms.

To address the critical requirement of precise fault localization within the potentially vast network of streetlights across Bengaluru, Karnataka, India, the Hardware Module integrates a Neo-6M GPS Module. This compact and energy-efficient satellite receiver diligently captures the exact geographical coordinates (latitude and longitude) of each individual streetlight unit. This location-specific information is invaluable when a fault is detected by the current or voltage sensors. Upon the identification of an anomaly, the ESP32 Microcontroller retrieves the current GPS coordinates from the Neo-6M module. This precise location data is then incorporated into the alert messages transmitted to the centralized monitoring system, enabling maintenance crews to be dispatched directly to the specific streetlight exhibiting the problem, significantly reducing the time and resources required for manual fault identification and streamlining the repair process across the urban expanse of Bengaluru, Karnataka, India.

The physical act of controlling the streetlight's illumination, based on the sensor inputs and the logic executed by the ESP32 Microcontroller, is managed by a "Relay Module" embedded within the Hardware Module. This electromechanical switch acts as an intermediary between the microcontroller's low-voltage control signals and the high-voltage power supply of the streetlight. Upon receiving a command from the ESP32 – whether triggered by the LDR indicating insufficient ambient light or by a remote command issued through the communication network – the relay module either closes the circuit to energize the streetlight or opens it to turn the light off, providing reliable and efficient control over the illumination of Bengaluru, Karnataka, India's streets.

Ensuring seamless and reliable communication between the smart streetlight units and the centralized monitoring infrastructure is paramount for the effectiveness of the entire system, especially across the diverse geographical and infrastructural landscape of Bengaluru, Karnataka, India. To this end, the Hardware Module incorporates a GSM/LTE Module, often a SIM800/900 series or a more advanced LTE variant. This module provides a robust backup cellular communication pathway, particularly crucial in areas where consistent Wi-Fi signal strength might be unreliable or unavailable. When the ESP32 Microcontroller detects a fault condition or needs to transmit routine status updates, it can leverage the GSM/LTE Module to establish a connection with the cellular network and send data to the centralized server. The choice between GSM (2G) and LTE (4G) technologies depends on factors such as data transmission volume requirements, network coverage availability within specific areas of Bengaluru, Karnataka, India, and cost considerations, with LTE generally offering higher data bandwidth suitable for more complex data transmission needs, while GSM provides a more basic yet often sufficient channel for critical alerts and status updates.

The Wi-Fi symbol prominently displayed in the center of the system architecture diagram signifies the primary wireless communication channel that facilitates seamless data exchange between the Hardware Module of each smart streetlight and a smartphone device, typically utilized by municipal workers or engineers in Bengaluru, Karnataka, India. This direct wireless connection, often established through a local Wi-Fi network or the streetlight's own integrated Wi-Fi capabilities, enables the real-time transmission of sensor data from the ESP32 Microcontroller to a Blynk-powered mobile application installed on the smartphone. This immediate data feedback loop empowers users with the ability to remotely monitor the operational health and functionality of the streetlight system directly from their mobile devices, providing a convenient and intuitive interface for system oversight within the urban environment of Bengaluru, Karnataka, India.

Blynk, a widely adopted IoT mobile application platform, serves as the primary User Interface (UI) in this smart streetlight management setup. Installed on the smartphones of authorized personnel in Bengaluru, Karnataka, India, Blynk establishes a communication bridge with the ESP32 Microcontroller either through the Blynk cloud server or a locally hosted server. The Blynk platform offers a rich library of customizable visual widgets, including switches for remote control, digital displays for visualizing real-time sensor readings (such as current, voltage, and light intensity), and graphical representations for trend analysis. These widgets dynamically reflect the live data being streamed from the smart streetlights, providing users with an at-a-glance overview of the system's status and enabling manual intervention when necessary, transforming the smartphone into a portable monitoring and control center for the street lighting infrastructure of Bengaluru, Karnataka, India.

The right-hand section of the system architecture diagram meticulously outlines the multi-faceted alert mechanisms that are seamlessly integrated with the Blynk mobile application, ensuring that critical information regarding the operational status of the streetlights in Bengaluru, Karnataka, India, is promptly disseminated to the relevant personnel. These alert mechanisms encompass Gmail Notifications, SMS Messages, and precise Location Updates, providing a layered approach to communication that maximizes reliability and ensures that fault events are not overlooked.

Gmail Notifications serve as a formal and documented channel for alerting designated personnel about detected faults within the smart streetlight system of Bengaluru, Karnataka, India. When the ESP32 Microcontroller, based on the analysis of data from the current and voltage sensors, identifies a significant abnormality – such as a sustained drop in current indicating a non-functional bulb or erratic voltage fluctuations suggesting electrical issues – it triggers the Blynk application on the connected smartphone to automatically generate and dispatch an email alert to a predefined Gmail account. This email notification typically includes details about the nature of the fault, the timestamp of its occurrence, and the unique identification of the affected streetlight unit, providing engineers and decision-makers in Bengaluru, Karnataka, India, with immediate and documented information necessary for initiating appropriate maintenance actions.

Complementing the email alerts, the system also leverages the GSM/LTE Module within the Hardware Module to generate SMS (Short Message Service) alerts. These text messages serve as a redundant or secondary communication channel, offering a direct and immediate notification pathway that is particularly valuable in scenarios where internet connectivity for email access might be intermittent or unavailable across certain areas of Bengaluru, Karnataka, India. Upon the detection of a critical fault, the Blynk application, interacting with the GSM/LTE Module via the ESP32, can trigger the transmission of a concise SMS message containing essential information about the fault and the affected streetlight's identification to the mobile phones of designated maintenance technicians, ensuring that they are promptly informed even in the absence of a stable internet connection.

A particularly crucial feature for efficient maintenance operations in a sprawling urban environment like Bengaluru, Karnataka, India, is the real-time transmission of GPS-based location coordinates of faulty streetlights. As corrected in the image from a potentially mislabeled "Lociottans" to the accurate "Locations," this functionality leverages the Neo-6M GPS Module embedded within the Hardware Module. When a fault is detected and an alert is generated, the Blynk application on the smartphone not only sends email and SMS notifications but also transmits the precise geographical coordinates of the malfunctioning streetlight. This location data can be seamlessly integrated with mapping applications or Geographic

CONCLUSION

In the burgeoning landscape of smart cities, where efficiency, sustainability, and enhanced quality of life are paramount, the intelligent management of public infrastructure stands as a cornerstone. Among the essential services that underpin urban functionality and citizen well-being, street lighting occupies a critical position, ensuring safety, security, and visibility during nighttime hours. However, traditional approaches to street light maintenance, often characterized by reactive measures based on citizen complaints or scheduled yet infrequent manual inspections, are increasingly proving inadequate in the face of expanding urban areas and the imperative for optimized resource allocation. The advent of Internet of Things (IoT) technologies, coupled with advancements in sensor technology, communication networks, and cloud computing, has paved the way for a paradigm shift towards proactive and intelligent street light management systems.

The concept of a centralized monitoring system for street light fault detection and location tracking, powered by hardware-driven smart automation, represents a significant leap forward in addressing the inherent limitations of conventional methodologies. By retrofitting existing or deploying new streetlights with integrated Hardware Modules – sophisticated units housing microcontrollers, a suite of environmental and electrical sensors, GPS location capabilities, and wireless communication interfaces – cities can establish a real-time, granular view of their lighting infrastructure. This proactive approach moves beyond the reactive cycle of waiting for failures to be reported, enabling the system to autonomously detect anomalies, pinpoint their precise geographical location, and relay this critical information to a centralized management platform for swift intervention.

ACKNOWEDEGEMENT

Acknowledging the foundational work and ongoing research in the field of smart street lighting is crucial to contextualize the significance and potential of a centralized monitoring system for fault detection and

location tracking. The concepts and architectures discussed herein draw upon a rich body of knowledge, including scholarly articles, technical reports, industry insights, and open-source resources. Specifically, the exploration of IoT-based solutions for efficient streetlight control, monitoring, and real-time error detection, as investigated by Chowdhury et al. (2022), provides a valuable framework for understanding the application of connected devices in urban infrastructure. Similarly, the development of image datasets for operational monitoring using computer vision techniques, as detailed by Mavromatis et al. (2022), highlights the potential for leveraging visual data in augmenting traditional sensor-based approaches to fault detection.

The underlying sensor technologies and communication protocols that enable such smart systems are continuously evolving. The overview of Leddar's technology (2024) on Wikipedia serves as a reminder of the advancements in sensing capabilities that can be integrated into smart street lighting solutions. Furthermore, the practical implementations and demonstrations showcased in online platforms, such as the YouTube video on centralized street light fault detection and location tracking (Authors Not Specified, 2024), offer tangible examples of the concepts discussed.

Academic research continues to contribute significantly to this domain. The International Journal of Computer Applications' 2023 publication on an IoT-based street light monitoring and fault detection system (Authors Not Specified, 2023) underscores the ongoing scholarly interest and development in this area. Moreover, the works of Patel et al. (2021), Kumar et al. (2020), Sharma et al. (2019), and Patel et al. (2018) in various international journals further enrich the understanding of different approaches, architectures, and implementation considerations for smart street lighting systems with fault detection and energy efficiency. These studies collectively highlight the potential of integrating sensors, microcontrollers, communication networks, and software platforms to create intelligent and responsive urban lighting infrastructure.

The synthesis of these existing research efforts and technological advancements underscores the growing recognition of the need for more efficient and proactive management of street lighting. The proposed centralized monitoring system, leveraging hardware-driven smart automation, builds upon this foundation by integrating key elements such as real-time sensing, precise location tracking, and robust communication to address the limitations of traditional methods. The potential benefits of such systems, including energy savings, enhanced public safety, reduced maintenance costs, and improved operational efficiency, are consistently highlighted in the referenced works. Therefore, the concepts presented in this discussion are not isolated but rather are informed by and contribute to the broader and evolving field of smart city technologies and intelligent infrastructure management. The ongoing research and development in this area pave the way for the realization of more sustainable, resilient, and citizen-centric urban environments.

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