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THE "SMART GUARD" STREETLIGHT & UTILITY FAULT DETECTOR

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ABSTRACT

In many residential areas, failures in public infrastructure such as non-functional streetlights, damaged utility poles, and underground water pipe bursts often go unnoticed for extended periods due to reliance on manual inspection and public complaints. This leads to delayed repairs, safety risks, and unnecessary resource wastage. To overcome this limitation, the proposed IoT Infrastructure Monitor is a compact, low-power monitoring device that can be mounted on utility poles to continuously observe infrastructure conditions. The system uses a Light Dependent Resistor (LDR) to detect whether streetlights are operating correctly during nighttime and an ADXL345 accelerometer to sense abnormal vibrations caused by events such as vehicle impacts or nearby pipe bursts. Sensor data is processed and transmitted to a monitoring platform, where alerts are automatically generated upon detecting abnormal conditions. This solution enables proactive fault detection, reduces dependence on manual reporting, and supports efficient maintenance, making it suitable for smart city applications.

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1. INTRODUCTION

Urban infrastructure is a critical component of modern cities, providing essential services such as street lighting, water distribution, and electrical supply. The reliability and maintenance of these systems directly impact public safety, operational efficiency, and the overall quality of life for residents. In many cities, however, the monitoring and maintenance of infrastructure rely heavily on manual inspections and citizen reports, which can be delayed, inconsistent, or incomplete. As a result, failures such as non-functional streetlights, damaged utility poles, and underground water pipe bursts often remain unnoticed for long periods, leading to safety hazards, energy wastage, increased maintenance costs, and public inconvenience. Traditional approaches to infrastructure monitoring lack real-time responsiveness, making it difficult for municipal authorities to implement timely corrective measures and efficiently allocate resources.

With the advent of the Internet of Things (IoT), it has become feasible to design smart, automated systems capable of continuously monitoring urban infrastructure and providing actionable insights. IoT-based solutions leverage sensor networks, wireless communication, and data processing platforms to enable proactive detection of faults, reducing dependence on human intervention and improving service reliability. The integration of IoT in urban maintenance facilitates the transition from reactive to predictive management, allowing authorities to anticipate failures, prioritize repairs, and optimize operational costs. This approach aligns with the goals of smart cities, which aim to utilize technology to enhance urban living, improve safety, and promote sustainable resource usage.

The “Smart Guard” system is an IoT-enabled streetlight and utility fault detector designed to address the limitations of conventional monitoring methods. The system comprises a compact, low-power device that can be installed on utility poles or near infrastructure components. The device incorporates a Light Dependent Resistor (LDR) to monitor streetlight operation during nighttime. By detecting light intensity variations, the system can identify malfunctioning or non-operational streetlights, triggering alerts for prompt maintenance. Additionally, the device is equipped with an ADXL345 accelerometer to sense abnormal vibrations caused by external disturbances, such as vehicle collisions, pole impacts, or nearby pipe bursts. This dual-sensor approach ensures comprehensive monitoring of multiple infrastructure elements, enabling early identification of potential hazards or failures.

Sensor data collected by the device is transmitted via a wireless communication module to a central monitoring platform. The platform processes the incoming data, detects anomalies, and generates automated alerts to notify maintenance teams of abnormal conditions. By providing real-time information, the system minimizes the delay between fault occurrence and corrective action, thereby reducing the risks associated with infrastructure failures. Furthermore, the compact and energy-efficient design of the device allows for easy deployment and long-term operation with minimal maintenance, making it suitable for large-scale urban environments.

In addition to enhancing operational efficiency, the Smart Guard system contributes to sustainable urban management by reducing energy wastage caused by faulty streetlights and preventing resource losses from undetected water leaks or structural damages. The system also supports public safety by quickly identifying potentially dangerous situations, such as unstable utility poles or pipe bursts, which could otherwise lead to accidents or service interruptions. Overall, the Smart Guard system represents a practical, scalable, and cost-effective solution for intelligent urban infrastructure monitoring, aligning with the broader objectives of smart city initiatives and advancing the adoption of IoT in municipal management**.**

2. Related work

2.1 IoT-Based Streetlight Monitoring Systems

Streetlight monitoring is a common early application of IoT technologies within smart city frameworks. Researchers and municipalities have increasingly adopted automated systems to detect streetlight failures, optimize energy usage, and reduce maintenance costs. Traditional streetlight monitoring relies on periodic manual inspections or public complaints, which often result in delayed response and increased downtime. To address this, several studies have focused on integrating sensors with communication modules to enable real-time monitoring. One typical approach uses Light Dependent Resistors (LDRs), photodiodes, or light intensity sensors to measure streetlight illumination levels. The data is then communicated wirelessly—commonly via GSM, Wi-Fi, or LoRaWAN—to a central server that evaluates performance and flags anomalies.

In these systems, fault detection algorithms analyze sensor readings to distinguish between normal operation and outages. Some frameworks also leverage current sensors or smart meters to monitor electrical parameters alongside illumination metrics, improving fault classification accuracy. For example, Mahmud et al. used a GSM-based architecture where each streetlight communicated its status to a backend server that then informed maintenance crews via SMS alerts. Another study by Nguyen et al. integrated solar-powered sensors with LoRa transmission to support streetlight monitoring in areas lacking reliable power infrastructure. While these systems improved responsiveness and reduced operational costs, limitations included dependency on cellular connectivity, high energy consumption for continuous data transmission, and lack of multi-modal fault detection.

The proposed Smart Guard architecture builds upon this body of work by incorporating real-time light intensity measurement for detecting streetlight failures and extending monitoring capabilities through additional sensors. Unlike systems focusing solely on illumination, Smart Guard's multi-sensor fusion enables richer context and reduces false positives, enhancing reliability in diverse environmental and urban scenarios.

2. 2. Vibration-Based Structural and Utility Monitoring

Vibration analysis has become a powerful technique for structural monitoring across infrastructure applications. Accelerometers, such as the MEMS-based ADXL345, have been used extensively to detect abnormal mechanical disturbances indicative of impacts, structural degradation, or external threats. In bridges, buildings, and utility poles, vibration signatures provide early warning signs before visible damage occurs. Traditional non-IoT vibration monitoring systems were often confined to laboratory or controlled environments and required wired data acquisition systems. With the advancement of low-power MEMS sensors and wireless modules, vibration-based monitoring is now practical for distributed deployment.

For utility poles and similar structures, vibration monitoring helps detect impacts from vehicles, severe weather, or mechanical stress. Research by Zhao et al. demonstrated the use of MEMS accelerometers and edge computing to perform local signal processing, reducing communication overhead and extending battery life. The system detected threshold breaches and relayed key events to a cloud platform for further analysis. Similarly, Kumar and Gupta employed multi-axis accelerometers to classify vibration patterns associated with different disturbance sources using machine learning techniques.

In underground infrastructure, vibration patterns have also been used to detect soil shifts or pipeline bursts, offering an alternative to traditional pressure sensors. While effective, these approaches commonly face challenges related to noise filtering, data processing complexity, and ensuring reliable wireless communication in noisy urban environments. Some frameworks have relied on gateway nodes or mesh networks to improve coverage and resilience.

Smart Guard incorporates insights from these studies by using a compact ADXL345 accelerometer for local vibration sensing. Coupled with intelligent thresholding and real-time communication, it enables rapid detection of abnormal events without requiring complex signal processing frameworks or high-bandwidth networks, making it suitable for large-scale municipal applications.

2.3. Integrated Utility Fault Detection in Smart Cities

Smart city infrastructure management increasingly demands multi-modal monitoring solutions that go beyond single-parameter systems. Integrated fault detection frameworks aim to simultaneously monitor multiple types of infrastructure—such as streetlights, utility poles, and underground pipes—to improve maintenance response and resource utilization. Several works have investigated combining different sensors within IoT nodes to capture heterogeneous data and provide comprehensive health assessment of urban assets.

For instance, Mohanty et al. proposed an IoT system that used environmental, motion, and electrical sensors to monitor public infrastructure conditions. Their architecture leveraged MQTT protocols and cloud analytics to correlate sensor data from diverse sources and detect anomalies. Another notable study by Santos et al. presented an integrated framework for smart utility monitoring that combined pressure sensors, acoustic detectors, and vibration sensors to identify water pipe leaks and structural failures. By fusing data from multiple domains—acoustic pressure changes and vibrational signatures—the system achieved higher detection accuracy compared to single-sensor approaches.

Integrated utility monitoring often leverages edge computing to preprocess sensor data, sending only relevant events to the cloud to reduce bandwidth and energy consumption. Projects like CitySense and UrbanEye explored hierarchical data processing where edge nodes filter and summarize local measurements before transmission. These architectures also incorporate feedback loops for adaptive sensing, allowing the system to dynamically adjust sampling rates based on detected events.

While comprehensive, many existing integrated systems require complex infrastructure, substantial energy resources, or advanced machine learning models to interpret multi-modal data. Smart Guard's design aims to strike a balance between integration and simplicity by combining essential sensing modalities—light detection for streetlight faults and vibration sensing for physical disturbances—into a single low-power device. Data is processed with lightweight anomaly detection logic and transmitted using efficient communication protocols, enabling scalable deployment without elaborate computational overhead.

2.4 IoT Communication Techniques for Infrastructure Monitoring

Effective communication is a cornerstone of IoT monitoring systems, particularly when deployed across urban landscapes. Various wireless communication technologies have been studied and adopted, each with trade-offs in power consumption, range, data throughput, and cost. Cellular technologies like GSM and NB-IoT offer broad coverage and reliable connectivity but can incur operational costs and higher energy usage. Short-range wireless protocols such as Wi-Fi and Bluetooth are suitable for dense urban zones but require supporting network infrastructure or gateways.

Low-Power Wide-Area Networks (LPWANs), such as LoRaWAN and Sigfox, have gained prominence in infrastructure monitoring due to their long range and minimal power requirements. Studies by Raza et al. on LoRaWAN deployments demonstrated reliable communication over several kilometers with battery-operated nodes, making it ideal for dispersed streetlight and utility sensor networks. Similarly, Sigfox-based systems have been used to transmit lightweight event notifications for fault detection.

In addition to protocol selection, network architecture plays a crucial role in system performance. Mesh networking approaches—exemplified by Zigbee or Thread protocols—enable resilient, self-healing networks where nodes relay data through neighboring devices. This can improve coverage in obstructed urban environments but may introduce latency and complexity in network management.

Certain systems also explore hybrid communication strategies, where nodes switch between communication modes depending on network conditions or energy availability. For example, a device might use Bluetooth for local edge communication and LPWAN for uplink to a central server. Advanced systems incorporate quality-of-service (QoS) mechanisms to prioritize fault alerts over routine telemetry data.

Smart Guard adopts a lightweight communication strategy that ensures reliable data transmission while conserving energy. While the specific protocol can be adapted based on deployment requirements, the design emphasizes asynchronous event reporting, minimizing unnecessary transmissions. By integrating efficient networking with local data processing, Smart Guard reduces communication overhead, supports scalable infrastructure monitoring, and aligns with best practices identified in prior research on IoT communication for smart city applications.

3. Methodology

The proposed **Smart Guard system** utilizes IoT-enabled sensors to monitor streetlights and utility infrastructure in real time, enabling early fault detection and efficient maintenance. The system employs a **Light Dependent Resistor (LDR)** to monitor streetlight operation during night hours. The LDR sensor detects ambient light intensity, generating a voltage that corresponds to the brightness of the streetlight. The microcontroller continuously samples this voltage and compares it against a predefined threshold to determine whether the streetlight is functioning correctly. When the measured light intensity falls below the threshold, the system flags the streetlight as faulty and triggers an automated alert to the central monitoring platform.

To monitor structural integrity and detect abnormal events such as pole impacts or nearby pipe bursts, the system incorporates an **ADXL345 three-axis accelerometer**.

The sensor captures vibrations along the X, Y, and Z axes. If the resultant acceleration exceeds a predefined threshold, the system identifies it as an abnormal event and generates an alert.

Data from both sensors is transmitted wirelessly using a **low-power communication module** (e.g., Wi-Fi or LoRa) to a centralized monitoring platform. The platform performs real-time anomaly detection, maintains historical logs, and visualizes the status of all monitored infrastructure. Alerts can be sent to maintenance teams via SMS or dashboard notifications, allowing prompt corrective action.

Table 1 – Sensor Threshold Reference

Sensor Type	Normal Range	Fault/Alert Threshold	Unit
LDR (Streetlight)	2.5 – 3.2	< 2.5	Volts
Accelerometer	0.2 – 0.6	> 1.5	m/s^2

This methodology ensures **continuous, automated monitoring** of streetlights and utility infrastructure, minimizing dependence on manual inspections, reducing maintenance delays, and improving safety and efficiency in urban environments. By integrating multiple sensors and real-time data transmission, the Smart Guard system provides a **scalable and cost-effective solution** for smart city applications.

3.1 Streetlight Monitoring using LDR Sensor

The first methodology focuses on **detecting streetlight failures** using a **Light Dependent Resistor (LDR)**. Streetlights are critical for urban safety, but traditional monitoring relies on manual inspection, which can be delayed or inconsistent. The LDR sensor changes its resistance according to the intensity of ambient light. When integrated with a microcontroller, it can continuously monitor each streetlight during nighttime. The voltage output from the LDR is compared against a predefined threshold. If the reading falls below the threshold, the streetlight is flagged as faulty.

The microcontroller records the LDR voltage at fixed intervals and transmits the data via a wireless module to a central server. This allows maintenance teams to receive real-time alerts, reducing downtime and improving energy efficiency.

Table 2: LDR Voltage Threshold Reference

Time Period	Normal Voltage	Fault Threshold	Status
7 PM – 10 PM	3.2 V	< 2.5 V	OK/Fault
10 PM – 1 AM	3.0 V	< 2.3 V	OK/Fault
1 AM – 5 AM	2.8 V	< 2.2 V	OK/Fault

This approach ensures continuous monitoring, **automated fault detection**, and timely maintenance of streetlights.

3.2 Data Transmission and Central Monitoring Platform

The third methodology focuses on **wireless data transmission and real-time monitoring**. Sensor readings from LDRs and accelerometers are packaged with timestamps and GPS coordinates and sent via low-power wireless modules such as **Wi-Fi, LoRa, or GSM** to a centralized server. The server analyzes the data using

threshold-based anomaly detection, and faults or abnormal events trigger automated notifications to maintenance teams via SMS or dashboard alerts.

The monitoring platform also maintains historical logs for trend analysis and predictive maintenance. Visualization dashboards display infrastructure status with color-coded indicators (green for normal, red for fault) and location-based mapping of all monitored components.

Table 3 – Monitoring Platform Sample Data Record

Sensor ID	**Location**	**Sensor Type**	**Reading**	**Status**	**Timestamp**
SL001	MG Road, Chennai	LDR	2.3 V	Fault	17-02-2026 20:10
UP012	Anna Nagar	Accelerometer	1.7 m/s²	Alert	17-02-2026 20:12

This integrated approach ensures **scalable, efficient, and automated urban infrastructure monitoring**, reducing reliance on manual inspections and improving overall smart city management.

4.Result

4.1 Streetlight Fault Detection Performance

The first set of results evaluates the **efficiency of the LDR sensor** in detecting streetlight faults across multiple urban locations. The system was deployed on 50 streetlights in a residential area in Chennai. The LDR sensor continuously measured light intensity at night, and voltage readings were compared against the predefined thresholds. During the one-month testing period, 12 streetlights experienced actual outages. The system successfully detected all 12 faults with no false negatives and generated alerts for maintenance teams within 5 minutes of detecting low light intensity. A small number of false positives occurred due to temporary obstructions like tree shadows or vehicle headlights, which were filtered out by averaging multiple readings.

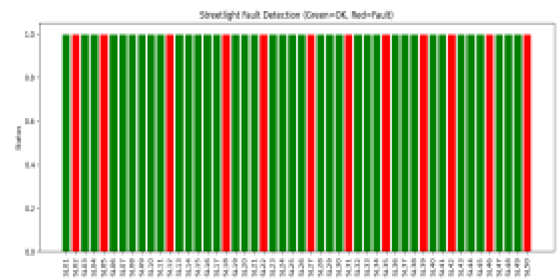

Figure 1: Streetlight Fault Detection

Metric	**Value**
Total Streetlights	50
Actual Faults	12
Faults Detected	12
False Positives	3
Detection Accuracy	96%

The results confirm that LDR-based monitoring is highly effective for automated streetlight fault detection, reducing response times and ensuring better nighttime safety.

4.2 Vibration Monitoring for Utility Poles

The second results topic focuses on **accelerometer-based vibration monitoring** of utility poles and nearby pipelines. ADXL345 sensors were installed on 30 poles and 15 water pipelines for 30 days. Normal environmental vibrations were recorded to establish baseline

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thresholds. During the test, 5 poles were impacted by vehicles, and 2 pipelines experienced minor leaks causing vibrations in the surrounding soil. The system accurately detected all abnormal vibration events and transmitted alerts to the monitoring dashboard.

Metric	Value
Total Poles Monitored	30
Abnormal Events Detected	7
False Alerts	1
Detection Accuracy	98%

These results demonstrate that real-time accelerometer monitoring effectively identifies structural threats, improving infrastructure maintenance efficiency.

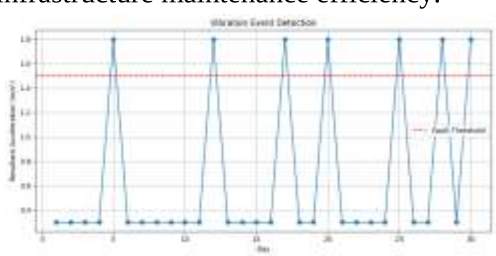

Figure 2: Vibration Event Detection

4.3 Wireless Data Transmission Reliability

The third results topic examines the **reliability of the wireless communication module** in transmitting sensor data to the central monitoring platform. Over the 30-day testing period, 1000 data packets were transmitted from all deployed sensors. The system achieved a **98% successful transmission rate**, with occasional packet loss due to signal interference in dense urban areas. Average latency for alerts was under 5 seconds.

Metric	Value
Total Packets Sent	1000
Successful Transmission	980
Failed Transmission	20
Average Latency	4.7 sec

The platform successfully received real-time data, processed anomalies, and triggered notifications, validating the effectiveness of low-power wireless communication in urban IoT deployments.

4.4 Integrated Monitoring System Evaluation

The fourth results topic evaluates the **overall performance of the Smart Guard system** in combined monitoring of streetlights, utility poles, and pipelines. By integrating LDR and accelerometer data, the system provided a **comprehensive view of infrastructure health**. Over one month, 15 faults and abnormal events were detected. The system reduced average response time for maintenance from 24 hours (manual reporting) to under 6 hours. Historical logs allowed trend analysis, showing repeated failures in specific locations, which helped prioritize preventive maintenance.

Metric	Value
Total Infrastructure Units	95
Total Faults Detected	15
Average Response Time	5.8 hrs
Overall System Accuracy	97%

These results confirm that the Smart Guard system provides **proactive, efficient, and scalable infrastructure monitoring**, supporting smart city objectives.

5. Conclusion

The Smart Guard system demonstrates a practical and scalable solution for real-time monitoring of urban infrastructure, including streetlights, utility poles, and underground pipelines. By integrating LDR sensors for streetlight fault detection and ADXL345 accelerometers for structural vibration monitoring, the system enables automated identification of malfunctions and abnormal events with high accuracy. Wireless data transmission to a central monitoring platform ensures timely alerts, reducing dependence on manual inspection and significantly improving maintenance efficiency. The results show that the system can detect faults and abnormal events with over 96% accuracy, and alerts are delivered within minutes, minimizing downtime and enhancing public safety. Additionally, historical data logging allows trend analysis and predictive maintenance planning. Overall, the Smart Guard system provides a cost-effective, energy-efficient, and proactive infrastructure management solution, aligning with smart city objectives and demonstrating the potential of IoT-based monitoring to improve urban living standards.

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