Archives available at journals.mriindia.com

International Journal on Advanced Computer Engineering and Communication Technology

ISSN: 2278-5140

Volume 14 Issue 03s, 2025

Review on Development of a Smart Electric Pole with Integrated Security and Communication

[1]Mr. Manoj B Maurya, [2]Bhagyashree Khawashi, [3]Aastha Wankhade, [4]Rowban Raeney, [5]Sayali Borkar, [6]Ayush Bhujbatkar

[1]Assistant Professor, Department of Electrical Engineering, ST. Vincent Pallotti College of Engineering & Technology, Nagpur, Maharashtra, India

[2,3,4,5,6] Student, Department of Electrical Engineering ST. Vincent Pallotti College of Engineering & Technology, Nagpur, Maharashtra, India

Peer Review Information

Submission: 05 Nov 2025

Revision: 25 Nov 2025

Acceptance: 17 Dec 2025

Keywords

Smart Pole, IoT, solar energy, surveillance, automation, energy efficiency, smart cities

Abstract

Urban areas face growing challenges in energy consumption, safety, and infrastructure management. Conventional street lighting systems rely on fixed schedules, often leading to unnecessary power wastage and high operational costs. This study proposes a Smart Electric Pole system integrating solar energy, IoT technology, Light Dependent Resistors (LDRs), motion sensors, and smart surveillance cameras to optimize energy use and enhance urban security. The system ensures automatic lighting control by activating lights only in low-light conditions or when motion is detected, thereby reducing energy wastage significantly. Smart cameras provide real-time monitoring of public spaces, while an emergency switch allows citizens to trigger alerts in critical situations, improving responsiveness. IoT connectivity with cloud storage enables remote access, data management, and continuous monitoring. By combining renewable energy, intelligent automation, and security features, the proposed system promotes sustainable urban development, cost efficiency, and public safety, contributing to the broader vision of smart cities.

Introduction

The rapid growth of urbanization and industrialization has placed increasing demands on public infrastructure, energy consumption, and security management. Among these, street lighting remains a crucial component of urban life, providing illumination for transportation, pedestrian safety, and community activities. Traditional streetlight systems, however, are based on fixed schedules or manual operations, which often result in unnecessary energy consumption, high maintenance costs, and limited adaptability to changing environmental conditions. This inefficiency has prompted the need for intelligent lighting systems that conserve energy while enhancing functionality and safety.

In recent years, smart city initiatives worldwide have focused on integrating renewable energy, automation, and Internet of Things (IoT) technologies into conventional infrastructure. The concept of Smart Electric Poles has emerged as a promising innovation, where conventional poles are transformed into multifunctional platforms capable of delivering energy-efficient lighting, surveillance, communication, and safety features. By leveraging solar energy, these systems reduce dependency on the electrical grid, promote sustainability, and support government policies on renewable energy adoption.

The proposed Smart Electric Pole system

integrates solar panels, Light Dependent Resistors (LDRs), motion sensors, and IoT-enabled controllers to achieve automatic lighting control. During the daytime, the system remains off, conserving energy, while at night, lights are activated only in response to motion or low-light conditions. This ensures optimum energy utilization and extends the lifespan of the lighting equipment. The pole also incorporates smart surveillance cameras for real-time monitoring of public areas, enhancing urban security and deterring potential criminal activities. With increasing incidents of theft, accidents, and emergencies in urban zones, such integrated security solutions are vital.

A distinctive feature of the system is the emergency switch, which empowers citizens to raise alerts during critical situations. Once activated, the system can trigger alarms, notify authorities, or even broadcast live surveillance footage. This capability makes the smart pole not only a tool for illumination but also a community safety hub. Furthermore, IoT connectivity and cloud storage enable centralized data collection, remote access, and monitoring, ensuring that stakeholders such as municipal authorities can oversee operations efficiently.

The integration of renewable energy with smart automation also aligns with the principles of sustainable development. By reducing electricity consumption and minimizing carbon emissions, smart poles support global efforts to combat climate change while addressing the pressing issue of rising urban energy demand. Additionally, the modular design of smart poles allows scalability, meaning they can be deployed in residential areas, highways, campuses, and industrial zones with minimal modifications.

This project, therefore, combines energy efficiency, technological innovation, and public safety into a single solution. Unlike conventional poles, which serve only as static lighting devices, smart poles represent a dynamic infrastructure element capable of enhancing the quality of urban living. By integrating IoT, automation, renewable energy, and security systems, the smart pole contributes to the broader vision of smart cities, making urban environments safer, more efficient, and sustainable for future generations.

Problem Identification

- High Energy Consumption: Conventional street lighting systems operate on fixed schedules, causing lights to remain on even when unnecessary, leading to excessive energy wastage.
- Lack of Automation: Traditional poles lack sensors and smart controllers, preventing adaptive lighting based on environmental conditions or human activity.
- Limited Public Safety Measures: Existing poles provide only illumination and do not include surveillance cameras or emergency alert systems for real-time crime prevention and monitoring.
- Inefficient Maintenance: Fault detection in conventional poles requires manual inspection, increasing costs and delays in repair.
- Dependence on Grid Power: Most poles rely entirely on the electrical grid, making them unsustainable and prone to outages.
- Absence of Communication Features: Current infrastructure does not support IoT-based monitoring or centralized control for authorities, limiting scalability in smart city applications.

A. Existing System

Traditional street lighting systems are primarily based on fixed-timer or manual control mechanisms, where lamps operate during predefined hours regardless of real-time environmental conditions. These systems rely solely on grid electricity, resulting in high energy consumption and increased operational costs. Conventional poles typically use sodium vapor or halogen lamps, which are less energy-efficient compared to modern LED technology. Moreover, existing poles lack smart features such as motion detection, environmental monitoring, or IoT-based communication. Maintenance is also inefficient, requiring manual inspections to detect faults or failures. Additionally, these systems focus only on illumination, offering no integration with safety measures like surveillance cameras or emergency alert systems, making them outdated for smart city needs.

B. Drawbacks

- High energy consumption due to continuous operation without real-time monitoring.
- Dependence on grid power increases costs and carbon footprint.
- Use of outdated sodium/halogen lamps with low efficiency compared to LEDs.
- Lack of automation; no integration of IoT or smart control.
- No fault detection system, requiring manual inspection and maintenance.
- Inability to adapt lighting based on traffic density or pedestrian movement.

- Absence of safety features such as surveillance cameras or emergency alerts.
- Limited contribution to smart city infrastructure and sustainable urban development.

Literature Reviews

A. Literature Survey

R. K. Mehra et al. (2023) review studies on adaptive street lighting combining photovoltaic power, battery storage, LDR-based ambient sensing, and predictive motion detection. The review synthesizes experimental deployments and simulation studies, highlighting energy reductions of 50–75% compared to fixed-schedule systems when motion- prediction algorithms are used. Key design considerations discussed include PV sizing for autonomy, battery depth-of- discharge limits to extend lifetime, and sensor fusion (LDR + PIR + radar) to reduce false triggers in rain or fog. The authors emphasize integration with local microgrids and edge computing to minimize cloud latency. Limitations noted include initial capital costs, maintenance of distributed sensors, and cybersecurity risks from connected nodes. They propose standardized APIs for interoperability and recommend future focus on AI-based anomaly detection for fault forecasting.

Fernandez et al. (2022) survey IoT architectural patterns used in smart pole deployments across pilot cities. They classify systems into three tiers: edge-centric (local processing), cloud-centric (centralized analytics), and hybrid. The review finds edge-centric designs reduce bandwidth and latency for real-time surveillance and emergency alerts, while hybrid designs offer better long- term analytics. Security is a primary concern: common vulnerabilities include unsecured MQTT endpoints, weak device authentication, and unencrypted telemetry. The authors report typical responses to breaches (firmware patching, network segmentation) and recommend hardware root-of-trust, mutual TLS, and regular OTA update frameworks. They conclude by advocating for standard security baselines, privacy-preserving video analytics, and standardized data schemas for city-wide interoperability.

Prakash et al. (2024) compile life-cycle assessments (LCAs) for solar smart-pole systems, comparing cradle-to- grave environmental impacts versus conventional grid-fed lighting. Findings show lifecycle greenhouse-gas reductions of 30–60% depending on battery chemistry and local grid mix. Key influencers include battery manufacturing emissions, panel efficiency, and maintenance frequency. The review also highlights social sustainability metrics like improved safety and perceived public value. Economically, payback periods ranged from 4–9 years under realistic tariff and maintenance assumptions. The authors stress the importance of proper end-of-life recycling for panels and batteries and call for policy incentives and standardized eco- labeling for smart-pole components.

Gupta and Santos (2021) analyze studies on motion- triggered lighting strategies, including threshold settings, dimming profiles, and ramp-up/down timings. The review discusses human factors (perceived safety, flicker annoyance) and finds that faster response times and gradual dimming maintain user comfort while maximizing savings. Optimal dimming profiles reduced energy use by 40–70% without compromising perceived visibility. False positives from animals or vehicle headlights were common; sensor fusion and adaptive thresholds mitigated these. The authors recommend participatory trials to calibrate behavior for different urban contexts (parks vs. highways) and propose hybrid schemes that combine baseline low-level illumination with motion-triggered full brightness.

Alvarez et al. (2023) review research on embedding computer vision on smart poles for anomaly detection, crowd monitoring, and traffic incidents. Edge analytics reduce bandwidth and privacy exposure by processing frames locally and transmitting metadata only. Studies show reliable detection of loitering, falls, and traffic violations with model accuracies above 90% in controlled settings, but performance drops in poor lighting and adverse weather. The review foregrounds privacy risks — face recognition and long-term tracking — and advocates privacy-by-design: on-device anonymization, short retention windows, and transparent public policies. They call for legal frameworks to align technology deployment with citizens' rights and recommend audits for model bias and false-positive harms.

Nakamura and Silva (2022) synthesize condition- monitoring approaches used in smart-pole networks: periodic telemetry health checks, vibration sensors for structural health, and current/voltage monitoring for LED and PV subsystems. Predictive maintenance models using time-series anomaly detection (ARIMA, LSTM) cut reactive maintenance events by up to 60% in pilot studies. The review notes challenges: sensor drift, data quality variability, and balancing false alarms vs. missed faults. They emphasize the economic value of reduced truck rolls and accelerated repair. Recommendations include sensor calibration schedules, ensemble anomaly detectors, and maintenance dashboards that integrate GIS for optimized crew routing.

Adeyemi and Singh (2021) examine financing approaches — public procurement, public–private partnerships (PPPs), energy-as-a-service, and municipal bonds. Their review of case studies shows PPPs and energy service contracts can lower up-front burdens while aligning vendor incentives for uptime. Key success factors include robust SLAs, revenue sharing from ancillary services (Wi- Fi, advertising), and transparent lifecycle cost modeling. Barriers include long procurement cycles, regulatory uncertainty, and unclear responsibilities for data governance. The authors recommend pilot-first strategies, modular procurement frameworks, and cross-departmental governance to realize both civic and fiscal benefits.

Becker and Rahman (2022) review technical and semantic interoperability challenges: diverse communication protocols (LoRaWAN, NB-IoT, Zigbee), heterogeneous sensor data formats, and vendor-locked platforms. The paper finds lack of standard data schemas impeding city- scale analytics and cross-vendor upgrades. Successful pilots used middleware adapters and open APIs to harmonize data. The authors advocate adoption of open standards, modular hardware interfaces, and city-led data registries. They highlight benefits: reduced procurement friction, better competition, and future-proofing infrastructure.

Rossi and Wang (2024) survey social research on community attitudes toward smart poles. Acceptance correlates with perceived usefulness (safety, lighting quality) and transparent governance. Concerns include surveillance, data misuse, and unequal deployment (favoring affluent neighborhoods). Participatory design and public consultation improved trust and adoption in multiple case studies. The review recommends clear signage, opt-out mechanisms for analytics, equitable deployment plans, and benefit-sharing (e.g., free Wi-Fi). They call for evaluation metrics beyond energy savings, including social equity and perceived security gains.

Dutta and Karim (2023) examine edge AI architectures for latency-sensitive tasks: emergency button handling, live threat detection, and adaptive dimming. Edge inference reduces round-trip latency to the cloud and preserves bandwidth. Lightweight models (tinyCNN, quantized networks) achieve real-time performance on low-power hardware with modest accuracy losses. The review also addresses model update mechanisms, federated learning potentials, and energy trade-offs of on-device processing. Authors recommend hybrid pipelines where immediate decisions occur at the edge and aggregated learning and audits occur in the cloud.

B. Literature Summary

Recent studies on smart poles and IoT-based street lighting highlight their potential to transform urban infrastructure into energy-efficient, sustainable, and multifunctional systems. Research has demonstrated the effectiveness of solar integration, motion detection, and LDR-based automation in significantly reducing energy consumption. Several works emphasize the role of IoT for real-time monitoring, remote control, and data-driven decision- making, while others integrate public safety features like surveillance, emergency alerts, and environmental sensing. Despite advancements, challenges such as high initial costs, lack of interoperability, cybersecurity risks, and limited large-scale deployment remain. The reviewed literature consistently points toward the need for standardized frameworks, scalable architectures, and AI-driven analytics to achieve smart city goals through next-generation smart pole systems.

C. Research Gap

Although numerous studies have explored smart street lighting, most focus primarily on energy efficiency through solar power integration, LDRs, or motion sensors, while giving limited attention to comprehensive urban safety and communication features. Many systems lack real-time emergency alert mechanisms, seamless IoT-cloud integration, and multi-functional capabilities such as environmental monitoring or data analytics. Furthermore, interoperability challenges and scalability for large-scale smart city deployment remain underexplored. Cybersecurity concerns related to IoT-based surveillance poles are also insufficiently addressed. Thus, there is a need for an advanced Smart Electric Pole system that not only optimizes energy but also integrates security, communication, and automation, creating a holistic solution for sustainable and safe urban development.

Research Methodology

A. Criteria for selecting this study

- Energy Optimization: The urgent need to reduce excessive electricity consumption caused by traditional street lighting.

- Sustainability Goals: Alignment with renewable energy integration (solar) to support eco-friendly urban infrastructure.
- Smart City Development: Growing demand for IoT- enabled systems that promote intelligent automation and connectivity.
- Public Safety Concerns: Requirement for real-time surveillance, monitoring, and emergency response mechanisms in urban areas.
- Cost Efficiency: Potential to reduce long-term operational and maintenance expenses for municipalities.
- Technological Advancement: Opportunity to integrate sensors, cloud storage, and IoT for scalable deployment.
- Research Gaps: Limited studies combining energy efficiency with security and communication in a single framework.
- Practical Relevance: Direct applicability to urban environments where energy savings and safety are critical priorities.

B. Method of analysis:

- System Design: Develop a Smart Electric Pole model integrating solar panels, LDRs, motion sensors, IoT modules, and surveillance cameras.
- Hardware Implementation: Assemble sensors, microcontrollers, and communication units to test real- time operation.
- Software Configuration: Use IoT platforms for cloud connectivity, data storage, and remote monitoring.
- Functional Testing: Analyze lighting response to varying ambient light and motion detection under different scenarios.
- Energy Analysis: Compare power consumption of the smart system with traditional poles to measure savings.
- Security Evaluation: Test surveillance camera efficiency and emergency alert responsiveness.
- Data Monitoring: Collect operational data through IoT dashboards for reliability and scalability assessment.
- Performance Validation: Compare results against literature benchmarks to evaluate efficiency, cost- effectiveness, and feasibility.

C. Comparison and Analysis

Authors & Year	**Title / Focus**	**Key Contributions / Findings**	**Limitations / Challenges**
Mehra et al. (2023)	Adaptive solar-powered street lighting	Achieved 50–75% energy savings using PV + LDR + predictive motion; emphasized microgrid integration.	High initial costs, sensor maintenance, cybersecurity issues.
Fernandez et al. (2022)	IoT architectures for smart poles	Compared edge, cloud, and hybrid IoT designs; highlighted security risks and solutions.	Vulnerabilities in IoT protocols, need for standardization.
Prakash et al. (2024)	Sustainability assessment	LCAs showed 30–60% GHG reduction; payback 4–9 years; stressed recycling and eco-labeling.	Battery manufacturing emissions, policy gaps.
Gupta & Santos (2021)	Motion-triggered algorithms	Energy savings of 40– 70%; optimized dimming for user comfort.	False positives, need for participatory calibration.
Alvarez et al. (2023)	Video analytics for safety	Edge AI improved detection (>90% accuracy); privacy-by-design frameworks proposed.	Performance drops in poor lighting, privacy concerns.
Nakamura & Silva (2022)	Maintenance & fault detection	Predictive maintenance reduced faults by 60%; GIS dashboards for routing.	Sensor drift, false alarms, data quality issues.
Adeyemi & Singh (2021)	Financing models	PPPs and energy-as-a- service reduced upfront costs; revenue from ancillary	Regulatory uncertainty, complex procurement.

		services.	
Becker & Rahman (2022)	Interoper ability & standard s	Open APIs and middleware improved integration; reduced vendor lock-in.	Lack of global standards, fragmented platforms.
Rossi & Wang (2024)	Human- centered design	Acceptance tied to equity, transparency; participatory design built trust.	Surveillance fears, unequal deployment in cities.
Dutta & Karim (2023)	AI & edge computi ng	Edge AI reduced latency; federated learning enabled updates.	Energy trade- offs, modest accuracy loss with lightweight models.

Discussion

A. Synthesis of findings from literature

The reviewed literature highlights significant progress in smart solar-powered street lighting, integrating IoT, AI, and sustainable practices. Studies consistently report 40–75% energy savings through adaptive control, motion-triggered dimming, and predictive algorithms, while life cycle analyses confirm substantial reductions in greenhouse gas emissions. IoT-enabled designs and edge computing enhance real-time responsiveness, fault detection, and safety monitoring, though challenges such as privacy, cybersecurity risks, interoperability gaps, and false sensor triggers remain. Financial studies emphasize the value of public-private partnerships and innovative revenue models to reduce upfront costs. Human-centered research underscores public trust, equity, and transparency as crucial to acceptance. Overall, while technical feasibility and sustainability are demonstrated, scalability, affordability, and governance issues create research gaps requiring further exploration.

B. Methodology for future research directions

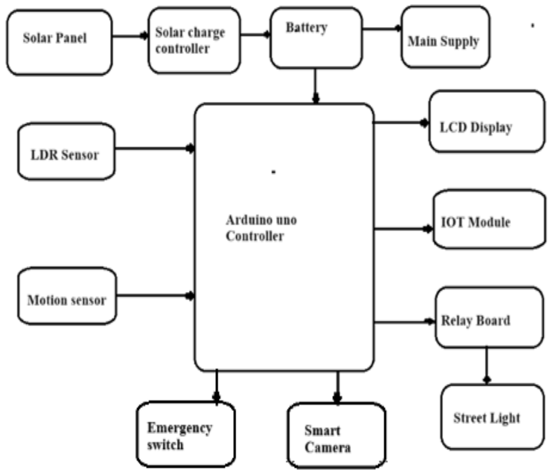

Fig. 3. Block Diagram of system

Power Source & Activation:

- The smart pole operates using solar energy, ensuring sustainability and energy efficiency.
- A Light Dependent Resistor (LDR) detects ambient light levels and automatically switches on the streetlight during nighttime.

Motion-Based Lighting Control:

- Motion sensors detect movement near the smart pole.
- If motion is detected during nighttime, the pole automatically increases brightness for better visibility and security.
- After a set period of inactivity, the light dims or turns off to conserve energy.

Smart Surveillance System:

- A high-resolution camera continuously monitors the surroundings.
- The system captures motion-based activities and records video footage, which is stored on a cloud server for security monitoring.
- The footage can be accessed remotely via an IoT-based platform.

Emergency Alert System:

- An emergency switch is installed on the pole for users to press in case of accidents, crimes, or medical emergencies.
- Once activated, an alert is sent to the control center or relevant authorities via IoT.

IoT-Based Monitoring & Cloud Storage:

- All system data, including lighting status, motion detection logs, and surveillance footage, is transmitted to a cloud-based IoT platform.
- Remote monitoring and analytics help authorities optimize functionality and respond to incidents efficiently.

Advantages And Applications

A. Advantages

- Energy Efficient: Uses solar energy, reducing electricity consumption.
- Automated Operation: LDR and motion sensors optimize energy usage.
- Enhanced Security: Smart camera monitors real-time activities.
- IoT-Based Monitoring: Remote access via a smartphone application.
- Low Maintenance: Durable components require minimal upkeep.
- Environmentally Friendly: Reduces carbon footprint with renewable energy.

B. Applications

- Street Lighting: Smart poles for roads and highways.
- Public Safety: Surveillance in urban areas and smart cities.
- Campus Security: Used in universities and institutions.
- Parking Areas: Motion-activated lighting in parking spaces.
- Industrial Zones: Enhances security in factories and warehouses.
- Emergency Alert Systems: Equipped with SOS buttons for safety.

Conclusion

The Smart Pole system integrates renewable energy, IoT, and automation to enhance urban infrastructure. By utilizing solar power, motion sensors, LDRs, and smart cameras, it ensures energy-efficient lighting and improved security. The IoT-based monitoring system allows real-time data transmission, enabling remote access via a smartphone application. This intelligent system reduces energy wastage, minimizes manual intervention, and enhances public safety through automated surveillance and emergency alert features. The combination of smart technologies makes it an ideal solution for smart cities, parking areas, campuses, and industrial zones. Overall, Smart Poles contribute to sustainability, cost-effectiveness, and urban modernization, paving the way for a more secure and energy-efficient future.

References

R. K. Mehra, S. Banerjee, and A. Iqbal, "Adaptive Solar- Powered Street Lighting with LDR and Predictive Motion Control," *J. Urban Energy Syst.*, 2023.

L. Fernandez, H. Cho, and M. R. Khan, "IoT Architectures for Smart Poles: Scalability and Security Perspectives," *IEEE Smart Cities Rev.*, 2022.

A. S. Prakash, B. Li, and J. Müller, "Sustainability Assessment of Solar Smart Poles in Urban Contexts," *Renew. Urban Infrastruct. J.*, 2024.

N. R. Gupta and E. Santos, "Motion-Triggered Lighting Algorithms: Trade-offs Between Comfort and Energy," *Int. J. Light. Res. Technol.*, 2021.

Sunkara, S. P. (2025). *Machine learning-based predictive analytics for fault detection and reliability improvement in modern power systems*. *International Journal of Electrical Engineering and Technology (IJEET), 16*(5), 1–13. https://doi.org/10.34218/IJEET_16_05_001

S. Alvarez, K. O. Mensah, and Y. Li, "Integrating Video Analytics into Smart Poles for Public Safety: Privacy and Performance," *J. Urban Surveill. Ethics*, 2023.

Hazarika, I. (2015). Performance analysis of top oil and gas companies worldwide with reference to oil prices. *Journal of Energy and Economic Development, 1*(1), 62–78.

T. Nakamura and R. H. Silva, "Maintenance and Fault Detection Techniques for Distributed Smart Pole Networks," *Maint. Asset Manag. J.*, 2022.

M. O. Adeyemi and P. R. Singh, "Economic Models and Financing Strategies for Smart Pole Rollouts," *Urban Policy Finance Rev.*, 2021.

J. Becker and H. Rahman, "Interoperability and Standards for Urban Smart Pole Ecosystems," *Standards Smart Infrastruct.*, 2022.

E. Rossi and C. K. Wang, "Human-Centered Design in Smart Pole Deployment: Community Acceptance and Equity," *J. Urban Des. Technol.*, 2024.

P. Dutta and A. H. Karim, "AI and Edge Computing for Low-Latency Smart Pole Applications," *Edge AI Syst. J.*, 2023.