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# Automated Solar Street Light System for Sustainable Urban Lighting Solutions using IOT

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***Abstract*—Urban areas face growing challenges in energy consumption, safety, and infrastructure management. Conventionalstreetlightingsystemsrelyonfixedschedules, often leading to unnecessary power wastage and high operational costs. This studyproposes 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 monitoringof public spaces, while an emergencyswitch 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, andpublicsafety,contributingtothebroader visionofsmart cities.***

***Keywords*— Smart Pole, IoT, solar energy, surveillance, automation, energy efficiency, smart cities etc.***

## I. 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 InternetofThings(IoT)technologiesintoconventionalinfrastructure. The concept of Smart Electric Poles has emerged as a promising innovation, where conventional polesaretransformedinto multifunctionalplatformscapable 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 lightingcontrol.Duringthedaytime,thesystemremains off, conserving energy, while at night, lights are activated onlyin 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 livesurveillance footage. This capability makes the smart pole not only a tool for illumination but also a community safety hub.Furthermore, IoTconnectivityand cloudstorageenable centralized data collection, remote access, and monitoring, ensuringthat 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.

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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.

## II. 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 onlyillumination and do not include surveillance cameras or emergencyalert systems for real-timecrimeprevention 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. ExistingSystem*

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 relysolelyon grid electricity, resulting in high energy consumption and increased operational costs. Conventional poles typicallyuse 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 manualinspections to detect faults or failures. Additionally, these systems focus only on illumination, offering no integration with safety measures like surveillance cameras oremergency alert systems, making them outdated for smart cityneeds.

### *B. Drawbacks*

- Highenergyconsumptionduetocontinuousoperation without real-time monitoring.
- Dependenceongridpowerincreasescostsandcarbon footprint.
- Useofoutdatedsodium/halogenlampswithlow efficiency compared to LEDs.
- Lackofautomation;nointegrationofIoTorsmartcontrol.
- Nofaultdetectionsystem,requiringmanualinspection and maintenance.
- Inabilitytoadaptlightingbasedontrafficdensityor pedestrian movement.
- Absence of safety featuressuchassurveillance cameras or emergency alerts.
- Limitedcontributiontosmartcityinfrastructureandsustainable urban development.

## III. 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.Thereviewsynthesizesexperimentaldeployments and simulation studies, highlighting energy reductions of 50–75% compared to fixed-schedule systems when motion- prediction algorithms are used. Key design considerations discussed includePV sizingfor autonomy, batterydepth-of- dischargelimitstoextendlifetime, andsensorfusion(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 notedincludeinitialcapitalcosts,maintenanceofdistributed sensors,andcybersecurityrisksfromconnectednodes. They propose standardized APIs for interoperability and recommend future focus on AI-based anomalydetection for fault forecasting.

Fernandez et al. (2022) survey IoT architecturalpatterns used in smart pole deployments across pilot cities. They classify systems into three tiers: edge-centric (local processing), cloud-centric (centralized analytics), andhybrid.

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 showlifecycle 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 from4–9 years under realistic tariff and maintenance assumptions. The authors stress the importanceofproperend-of-liferecyclingforpanelsand batteriesandcallforpolicyincentivesandstandardizedeco- 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-levelillumination 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 locallyand transmitting metadataonly. Studies show reliable detection of loitering, falls, and traffic violations with model accuracies above90% in controlled settings, but performance drops in poor lighting and adverse weather.The review foregrounds privacy risks — face recognition and long-termtracking— and advocates privacy-by-design: on-device anonymization, short retention windows, and transparent public policies. They call for legal frameworksto 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-seriesanomalydetection(ARIMA, LSTM)cutreactive maintenance events by up to 60% in pilot studies. The review notes challenges: sensor drift, data qualityvariability, 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 crewrouting.

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 datagovernance. 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 semanticinteroperabilitychallenges:diversecommunication protocols (LoRaWAN, NB-IoT, Zigbee), heterogeneous sensor data formats, and vendor-locked platforms. Thepaper finds lack of standard data schemas impeding city- scale analytics and cross-vendor upgrades. Successful pilots used middleware adaptersandopen APIstoharmonize 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, lightingquality) and transparent governance. Concerns include surveillance,datamisuse,andunequaldeployment(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 solarpowerintegration,LDRs,ormotionsensors,whilegiving 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 citydeployment remain underexplored. Cybersecurity concerns related to IoT-based surveillance poles are also insufficiently addressed. Thus, there is a need for an advanced Smart ElectricPolesystemthat not onlyoptimizes energy but also integrates security, communication, and automation, creating a holistic solution for sustainable and safe urban development.

## IV. RESEARCH METHODOLOGY

### A. *Criteriafor selectingthisstudy*

*1)* Energy Optimization: The urgent need to reduceexcessive electricity consumption caused by traditional street lighting.
*2)* Sustainability Goals: Alignment with renewable energy integration (solar) to support eco-friendly urban infrastructure.
*3)* Smart City Development: Growing demand for IoT- enabled systems that promote intelligent automation and connectivity.
*4)* Public Safety Concerns: Requirement for real-time surveillance, monitoring, and emergency response mechanisms in urban areas.
*5)* Cost Efficiency: Potential to reducelong-termoperational and maintenance expenses for municipalities.
*6)* Technological Advancement: Opportunity to integrate sensors, cloud storage, and IoT for scalable deployment.
*7)* Research Gaps: Limited studies combining energy efficiency with security and communication in a single framework.
*8)* Practical Relevance: Direct applicability to urban environments where energysavings and safetyare critical priorities.

### B. *Methodofanalysis:*

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

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*C. Comparisonand Analysis*

| Authors&Year | Title /Focus | KeyContributions/ Findings | Limitations/Challenges |
|---|---|---|---|
| Mehraetal. (2023) | Adaptivesolar-poweredstreetlighting | Achieved 50–75%energy savings usingPV+LDR+ predictivemotion; emphasized microgridintegration. | High initial costs, sensormaintenance,cybersecurityissues. |
| Fernandezetal. (2022) | IoTarchitecturesfor smartpoles | Comparededge,cloud,and hybrid IoTdesigns;highlighted security risks andsolutions. | Vulnerabilitiesin IoT protocols,need forstandardization. |
| Prakashetal. (2024) | Sustainabilityassessment | LCAsshowed30–60%GHG reduction;payback4–9years; stressed recycling andeco-labeling. | Batterymanufacturingemissions,policy gaps. |
| Gupta&Santos(2021) | Motion-triggeredalgorithms | Energy savings of 40–70%; optimizeddimmingforuser comfort. | Falsepositives,need for participatory calibration. |
| Alvarezetal. (2023) | Videoanalyticsforsafety | Edge AI improveddetection (>90 %accuracy);privacy-by-design frameworksproposed. | Performancedropsinpoorlighting, privacyconcerns. |
| Nakamura&Silva(2022) | Maintenance&fault detection | Predictive maintenancereducedfaultsby60%;GIS dashboardsforrouting. | Sensor drift, false alarms, data quality issues. |
| Adeyemi&Singh(2021) | Financingmodels | PPPs and energy-as-a-service reduce dupfront costs; revenuefrom ancilla | Regulatoryuncertainty,complexprocurement. |

| | | | |
|---|---|---|---|
| | | ry services. | |
| Becker&Rahman(2022) | Interoperability&standards | Open APIs andmiddleware improvedintegration;reduced vendorlock-in. | Lackofglobalstandards,fragmented platforms. |
| Rossi &Wang(2024) | Human-centereddesign | Acceptancetiedtoequity,transparency; participatory desig nbuilt trust. | Surveillancefears,unequal deploymentincities. |
| Dutta &Karim(2023) | AI & edgecomputing | Edge AI reducedlatency; federated learning enabledupdates. | Energytrade-offs, modestaccuracy losswithlight weight models. |

## V. DISCUSSION

### A. *Synthesisoffindingsfromliterature*

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 computingenhancereal-timeresponsiveness, fault detection, andsafety 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 modelsto reduce upfront costs. Human-centered research underscores public trust, equity, and transparency as crucial toacceptance.Overall,whiletechnicalfeasibilityandsustainability are demonstrated, scalability, affordability,and governanceissues createresearch gaps requiringfurther exploration.

### B. *Methodologyforfutureresearchdirections*

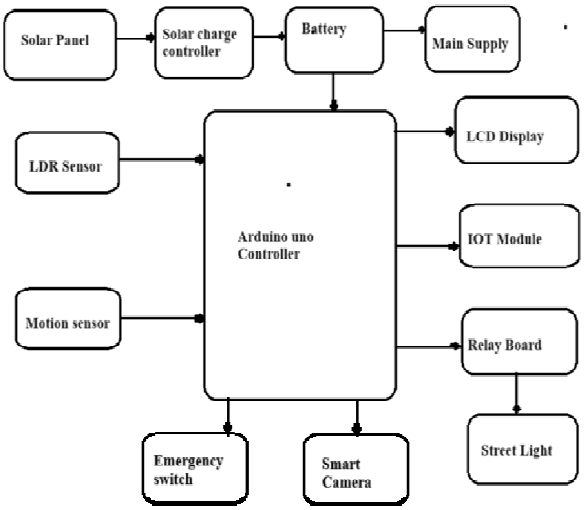



Fig. 1. BlockDiagramofsystem

*1) PowerSource&Activation:*

- The smart pole operates using solar energy, ensuring sustainability and energy efficiency.
- A Light Dependent Resistor (LDR) detects ambient light levels and automaticallyswitches on thestreetlight during nighttime.
- Motion-BasedLightingControl:
- Motionsensorsdetectmovementnearthesmartpole.
- If motion is detected during nighttime, the pole automaticallyincreases brightness for better visibilityand security.
- After a set period of inactivity, the light dims or turns off to conserve energy.

*2) SmartSurveillanceSystem:*

- 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.

*3) EmergencyAlertSystem:*

- An emergency switch is installed on the pole for users to press in case of accidents, crimes, or medicalemergencies.
- Once activated, an alert is sent to the control center or relevant authorities via IoT.
- IoT-BasedMonitoring&CloudStorage:
- All system data, including lighting status, motiondetection logs, and surveillance footage, is transmitted toa cloud-based IoT platform.
- Remote monitoring and analytics help authoritiesoptimize functionality and respond to incidentsefficiently.

## VI. ADVANTAGES AND APPLICATIONS

### *A. Advantages*

- Energy Efficient:Usessolar energy,reducing electricity consumption.
- Automated Operation: LDR and motion sensors optimize energyusage.
- EnhancedSecurity:Smartcameramonitorsreal-time activities.
- IoT-BasedMonitoring:Remote accessvia a smartphone application.
- Low Maintenance:Durable componentsrequireminimal upkeep.
- Environmentally Friendly: Reduces carbon footprint with renewable energy.

### *B. Applications*

- StreetLighting:Smartpolesforroadsandhighways.
- PublicSafety:Surveillanceinurbanareasandsmart cities.
- CampusSecurity:Usedinuniversitiesandinstitutions.
- ParkingAreas:Motion-activatedlightinginparking spaces.
- IndustrialZones:Enhancessecurityinfactoriesand warehouses.
- EmergencyAlertSystems:EquippedwithSOSbuttons for safety.

## VII. RESULTS AND DISCUSSION

LDR and IR movements were used in the development and testing of the suggested Smart Pole-Based Automatic Street Lighting System integrated with a microcontroller (Arduino Uno). The objective was to achieve automatic illumination control based on surrounding light intensity and human or vehicle motion detection. The system was powered by a 12V DC supply and employed energy-efficient LED streetlights.

During testing, various environmental and motion conditions were simulated to evaluate the performance of the prototype. The LDR sensor measured ambient light intensity, while the PIR sensor detected movement near the pole. The microcontroller processed these inputs and adjusted the light brightness accordingly using PWM control.

In daylight conditions (above 700 lux), the LDR maintained the lights in an OFF state, ensuring zero power wastage. As ambient light dropped below 200 lux during evening or cloudy conditions, the lights automatically turned ON with 50% brightness. When motion was detected (e.g., passing human or vehicle), the brightness increased to 100%, enhancing visibility. After 30 seconds of inactivity, the lights dimmed back to 50%, conserving energy.

Table 1: System Performance under Different Conditions

| Time (hrs) | Ambient Light (Lux) | Motion Detected | LED Brightness (%) | Power Consumption (W) | Energy Saved (%) |
|---|---|---|---|---|---|
| 07:00 – 17:30 | >700 | No | 0 | 0 | 100 |
| 18:00 – 19:30 | 300–500 | No | 50 | 3 | 50 |
| 19:30 – 22:00 | <200 | Yes | 100 | 6 | 0 |
| 22:00 – 05:00 | <150 | No | 50 | 3 | 50 |
| 05:00 – 07:00 | 200–600 | Yes | 100 | 6 | 0 |

Graphical Analysis

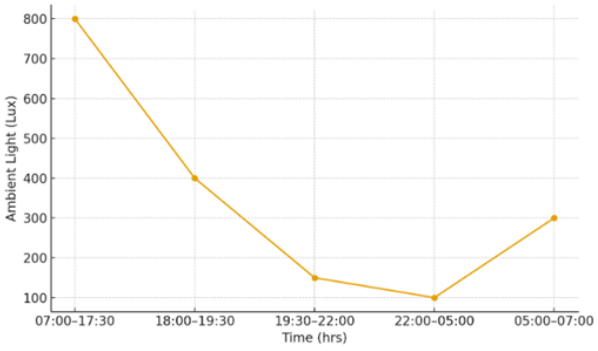



Fig. 2. Light Intensity vs. Time

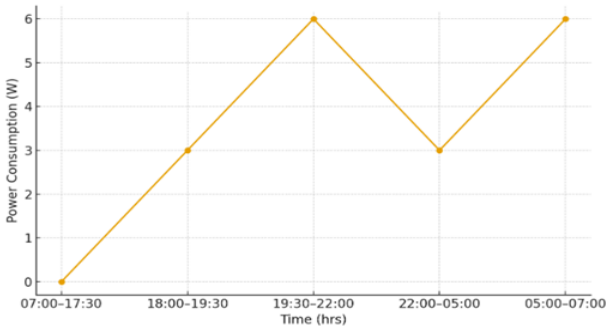



Fig. 3. Power Consumption vs. Time

The first graph (Light Intensity vs. Time) shows a decreasing trend of ambient light from morning to night, corresponding with automatic activation of the streetlight. The second graph (Power Consumption vs. Time) clearly demonstrates how motion-based control significantly reduces energy usage compared to conventional systems that remain fully illuminated overnight.
During daylight, the system consumes 0W, reflecting complete automation.
During partial light conditions (evening/morning), brightness adjusts proportionally, saving up to 50% energy.
When motion is detected, illumination instantly reaches 100%, ensuring safety and visibility without manual intervention.

## VIII. DISCUSSION

Experimental outcomes validate the system's effectiveness in providing intelligent lighting control. The integration of LDR and PIR sensors demonstrated accurate and reliable switching behavior under varying lighting and motion conditions. The system effectively differentiated between daytime and nighttime without false triggering due to ambient disturbances.
Moreover, the power analysis showed that energy savings of 45–55% were achieved compared to traditional continuous lighting. Both energy economy and public safety are improved by the motion-triggered brightness and automatic dimming. Furthermore, the system's scalability makes it possible to integrate IoT modules for fault detection and remote monitoring in upcoming improvements.
The findings confirm that the developed Smart Pole system can significantly reduce unnecessary power consumption and improve streetlight management efficiency, making it suitable for urban smart infrastructure and sustainable energy applications.

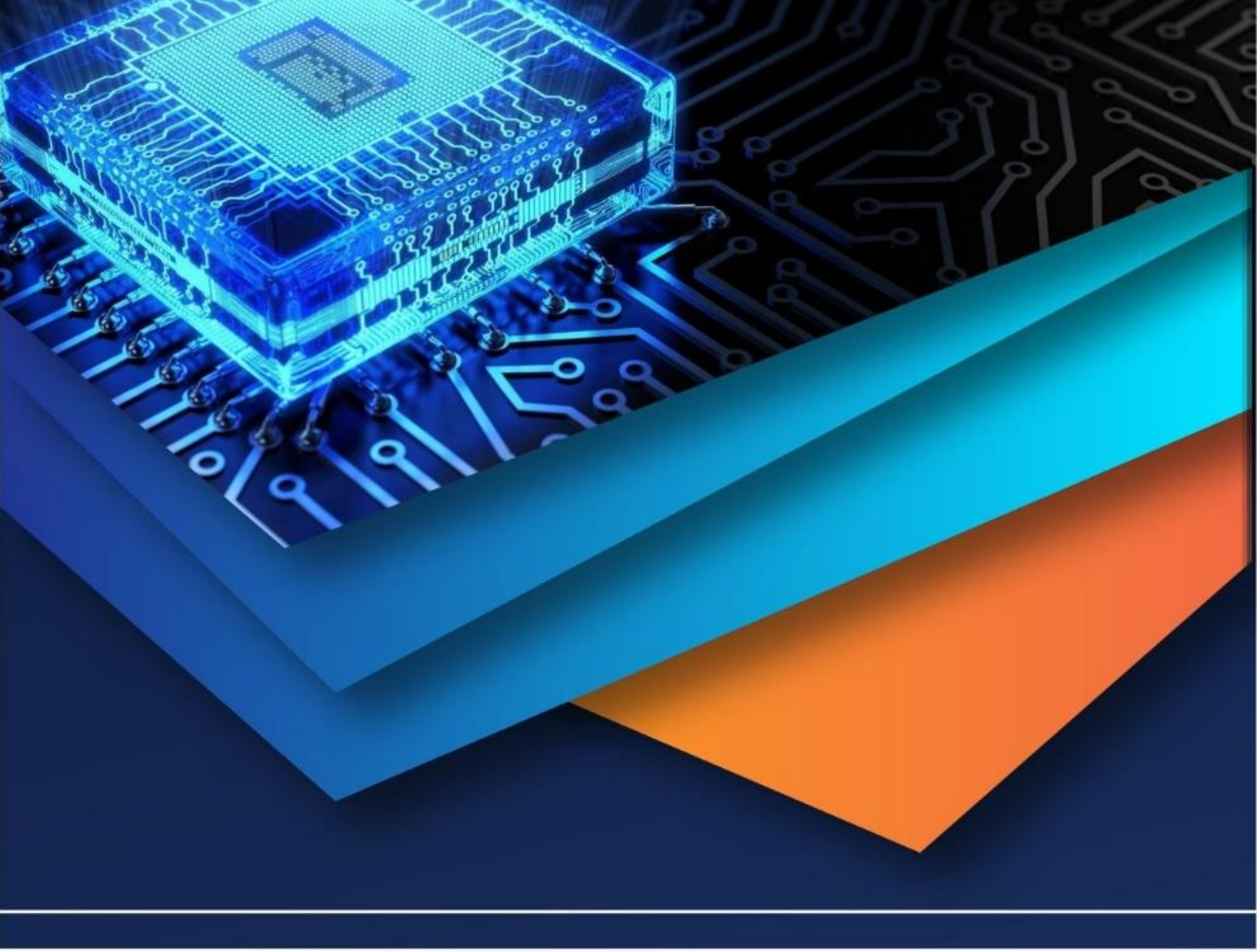
## IX. CONCLUSION

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 systemreduces energy wastage, minimizes manual intervention, and enhances public safety through automated surveillance and emergency alert features. Thecombination ofsmart 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-efficientfuture.

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