

Smart Street Lighting Management System Using Iot And Renewable Energy

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Abstract- Urban infrastructure experiences a permanent transformation through Smart Street Light Systems which utilize Internet of things technology to improve energy efficiency alongside automation and reliability. Multiple advanced sensors and wireless communications interconnect with solar-powered LED lighting devices through a system dedicated to enhancing streetlight performance. Light detectors provide environmental readouts for the system as motion detectors use them to modulate brightness levels when people or vehicles appear thereby conserving power. The operational efficiency and timely maintenance of all components are achieved through built-in fault detection features for solar panels and batteries in the system. The technology of IoT maintains direct real-time control through central units and cloud-based platforms that let operators perform remote diagnostics and automated system adjustments. Streetlights communicate using Wi-Fi protocols for smooth data transmission to the control center which leads to better system reaction times. The implementation of solar power enables the system to operate independently of traditional power grids thus fostering sustainability. Through Internet of Things technology smart street lighting generates three main benefits: The system enables lower electricity bills and decreased maintenance expenses while providing safer conditions for drivers on the road. The study analyzes solar-powered Smart Street Light System implementation as a method to construct intelligent environmentally friendly urban settings.

Keywords: Smart Street Light, IoT, Energy Efficiency, Solar Power, Wireless Communication, Sensor-Based Automation, Fault Detection, Sustainable Lighting, Smart City.

INTRODUCTION

The development of smart street lighting systems represents an essential element to build smart cities while cities become more urbanized and sustainable development requirements increase. The integration of IoT technology with solar energy solutions creates street lighting systems which offer efficient cost-saving environmentally sustainable illumination. The combination of sensor technologies with wireless communication and advanced control units streamlines real-time system monitoring as well as fault-tracking and energy efficiency enhancement for modern street lighting systems. Cities use traditional street lighting systems which operate through prerecorded timers and waste power because streets are vacant after dark. The absence of effective fault detection mechanisms and environmental change recognition in these systems causes increased energy waste and higher maintenance expenses. New smart street light technology emerged from the requirement to develop sustainable solutions while offering efficient adaptive capabilities for responding to pedestrians and vehicles. A Smart Street Light System driven by solar power presents an innovative sustainable lighting solution for modern streets. The fundamental elements of this system include solar panels installed within streetlights to generate renewable power. The solar-powered system operates independently of the electricity grid which reduces energy usage and minimizes carbon emissions from standard lighting infrastructures. Implementing LED lights and their characteristic energy-efficient and enduring properties decreases the total energy consumption of the system. Through sensors like motion detectors and ambient light sensors the IoT-based system controls streetlight intensity in real time. When sensors detect vehicles or pedestrians the lights will turn brighter but will respond through dimming when no movement is detected in the area. The system adjusts dynamically to save significant energy. The system includes a mandatory feature which detects faults. The system activates real-time alert notifications to reach a central control unit each time one of the solar panel battery or LED light components exhibits a failure. The system provides instant repair capabilities which minimizes equipment downtime and improves overall system stability. The implementation of Wi-Fi wireless communication together with other wireless technologies sends

individual streetlight data to a central monitoring and analysis unit. A cloud-based central control unit enables flexible remote management of streetlights while ensuring accessibility. Operators under this system can check various statuses including lights, energy usage, faults and performance analytics from any geographical position for optimal management and optimization. A smart street light system delivers a wide range of advantages for users. The system achieves substantial energy reductions through real-time data-driven optimization of lighting control. The system cuts maintenance costs drastically since it detects and sends fault reports automatically. The implementation established a standard that forthcoming urban infrastructure projects should adopt.

RELATED WORK

The study by Velu, A., Ramamoorthy, R., Manasa, S. M., and Navulkumar, D introduces an IoT-based smart street lighting system that optimizes energy efficiency through implementation of a low-cost System-on-Chip (SoC). The proposed system merges smart sensors with automatic control elements for programmed lighting shifts through real-time environmental information. This system controls power consumption waste to achieve perfect illumination standards. The combination of IoT technology enables better remote monitoring alongside fault detection systems that reduce maintenance expenses and improve the system's stability. Research demonstrates that affordable SoC technology optimizes street lighting systems for smart city implementations. [1]Researchers Sujatha V., Sridevi V., Sumitha S., Vidhya N., Amirtha M. with Dakshinamoorthi D. established an IoT platform with smart sensors for controlling and monitoring streetlights to enhance energy efficiency. The system determines street light brightness levels through real-time environmental monitoring to achieve more effective power utilization. The deployment of IoT technology enables both remote system observation and automatic breakdown identification which reduces maintenance costs and operational requirements. The findings demonstrate that smart lighting systems offer both energy savings and sufficient public lighting requirements simultaneously. Research shows that connecting IoT technology to urban infrastructure leads to increased street lighting efficiency and better reliability. [2]P. K. et al. The research explores a protected and energy-efficient LoRa-based intelligent streetlight management system. The technology enables streetlights to operate efficiently through long-distance low-power data exchanges and real-time monitoring systems. The system uses lightning sensors that monitor movement before automatically adjusting brightness to minimize energy usage. Lighting controls remain secure because unauthorized individuals cannot access them while encrypted data transmission ensures security. The paper proves LoRa-based networks optimize street lighting operations by minimizing operational expenses while increasing sustainable practices. The system achieves reliability and scalability through its combination of IoT and low-energy communication features. [3]Thopate, K. V., et al. A smart street light monitoring system using IoT and sensor-based automation developed by scientists facilitates improved energy efficiency. Daylight intensity and motion detection data enters a system which adjusts streetlight brightness levels. Built-in real-time monitoring capabilities within the system identify potential issues promptly to enhance maintenance quality by cutting power consumption losses from useless electricity use. Research findings show that Internet of Things based smart lighting systems can contribute to sustainable urban growth projects. Research efforts establish economical implementation approaches that support financial sustainability and produce significant energy savings along with higher operational performance. [4]The research was performed by A.T.M.M. Chowdhury with his research colleagues. Researchers developed a system that unites Internet of Things architecture to supervise and regulate streetlights alongside error detection through real-time monitoring. The system employs wireless communication between smart sensors to control energy consumption by automatically adjusting lighting based on traffic volume and environmental elements. The analysis shows automated systems function crucially by removing human intervention and reducing system maintenance costs. The upgraded system detects faults more efficiently resulting in quicker maintenance alongside better system reliability. Studies reveal that integrating IoT into street lighting systems produces benefits which combine reduced energy usage with improved operations along with decreased costs for managing urban infrastructure. [5]Deepaisarn, et al. Researchers have built an AI-driven automated system that controls street lighting systems found in university campuses. The system uses AI data analytics algorithms to adjust streetlight brightness based on both human detection as well as environmental conditions. The research analyzes how predictive analytics improves energy conservation and lighting quality throughout the investigation. The proposed model enhances sustainability through its ability to optimize power consumption while blocking

unnecessary lighting usage. Artificial intelligence integrated with IoT technology enables real-time control and monitoring along with automated maintenance tasks reduction. Artificial intelligence helps automation systems deliver improvements to smart lighting systems which power public spaces according to the study. [6]Lillaney, J., et al. The work develops an automated smart street lighting system powered by deep learning which enables cloud-based implementations. The system analyzes real-time environmental data with machine learning algorithms to automatically control streetlight intensities for optimized efficiency. Remote monitoring and predictive maintenance becomes possible due to cloud integration according to the study. Artificial Intelligence analytics in this system detects repetitive light patterns for optimizing energy efficiency. Studies indicate deep learning technology combined with IoT enables adaptive optimal safety-oriented urban lighting systems that achieve better energy efficiency and reduced maintenance expenses combined with scalability improvements. [7]Kanthi, M., et al. Researchers analyzed streetlights using mobile applications operating together to detect faults securely and optimize power consumption. Real-time data analysis and IoT-enabled sensors create a system that detects performance issues in streetlights while also optimizing their operation. Users gain remote manipulation of their lighting systems through mobile applications for better maintenance and reduced power usage. The study shows that urban infrastructure needs integrated fault diagnosis systems which increase reliability. Smart connectivity within the proposed system reduces energy consumption while providing an expandable management system for public lighting infrastructure. [8]Zhang, J., et al. A laboratory used IoT technology to build a low-power and low-cost smart streetlight system. This technology uses sensor intelligence to develop light scheduling that reduces vehicles into unnecessary energy consumption. This solution appears as an ideal choice for smart city deployment because it achieves affordability and energy efficiency at once. The real-time monitoring and remote control features available through IoT connectivity boost system reliability. Smart lighting powered by IoT technology enables the reduction of power consumption in urban areas through price-effective devices coupled with energy-saving methods that maintain proper street and vehicle illumination. [9]Abarro, C. C., et al. The research team designed an IoT-based streetlight monitoring system to achieve real-time monitoring combined with detection capabilities. The system adopts contemporary data transmission protocols to transmit information more effectively so it can identify faults rapidly and adjust lighting control accordingly. Continuous street lighting relies heavily on low-delay systems as shown by research findings. Through its rapid data processing and intelligent control systems the system reaches both improved energy efficiency and decreases maintenance outages. This research proves that low-latency IoT-based lighting infrastructure makes cities more sustainable by using less energy. [10]

PROPOSED SYSTEM

A Smart Street Light System combines Internet of Things (IoT) technology with solar energy to deliver an intelligent street lighting solution which provides both energy efficiency and environmental sustainability for contemporary urban centers. A system control unit connects through LoRa or Wi-Fi to activate multiple parts which include motion sensors and light detectors and solar power panels and LED lights. Each streetlight utilizes photovoltaic solar panels that power the system independently from the public electricity grid to increase sustainable energy usage. The system controls light brightness through motion sensors and ambient light sensors that adapt to vehicle traffic along with the available natural sunlight. MOO Saolo.n L omities uses motion sensors to activate lights while traffic exists but makes the lights dimmer through smart sensing when there are no vehicles.

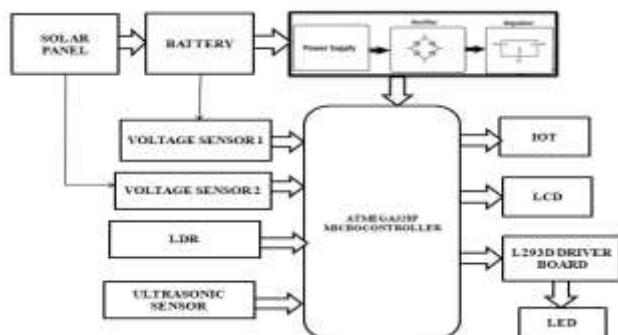


Figure 1. System Architecture

Energy optimization through adaptability lowers utility expenses dramatically. The system integrates automatic fault detection while maximizing energy efficiency. The system sends instant alerts to its central control center either through cloud storage or from a management station when any system component including solar panels or LED lights or batteries encounters a failure. Real-time fault detection performed by this system allows for prompt maintenance and minimizes system downtime. Through the remote control unit administrators obtain performance data tracking and system status monitoring and real-time energy usage tracking. The system operates at peak efficiency because of persistent communication links between control units and streetlights. The programmed automatic maintenance alerts inside the system decrease the need for manual inspections of the system. IoT technology enhances urban environments by delivering flexible and economical lighting control methods which enable smart city development that reduces both environmental impacts and produces enhanced security with better energy management.

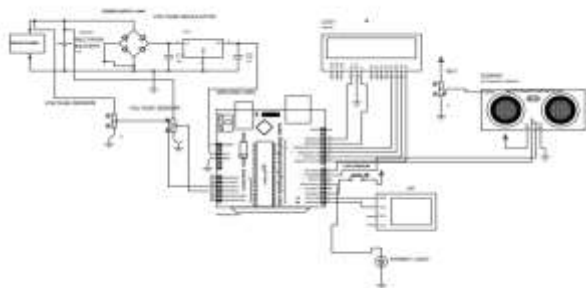


Figure 2. Circuit diagram

METHODOLOGY AND TECHNOLOGIES USED

Methodology

Sensor-Based Adaptive Lighting Control

Innovative light and motion sensors on the smart street light system help reduce power usage. Sensors measure ambient light to control LED intensity levels thus reducing power consumption throughout daylight hours. The system employs detection sensors for pedestrians and vehicles which control the lighting intensity through active mode detection while dimming the lights when there is no movement. The adaptive lighting system optimizes energy consumption through its ability to preserve visibility standards across every operational stage. Central control units with automated real-time adjustments track wireless sensor data to enhance security while reducing power consumption across urban areas.

Solar-Powered Energy Management

The streetlight installation features photovoltaic solar panels to convert solar energy into electricity that batteries of high capacity charge and store. The smart energy management system controls power consumption to optimize battery condition while averting battery overcharge and exhaustion. The off-grid power system serves two purposes: it protects the environment while decreasing operational costs by cutting reliance on traditional grid power. The system utilizes renewable energy to power street lights continuously throughout power disruptions. Automated lighting controls enable a novel cost-effective power solution that permits solar energy usage to optimize smart city infrastructure efficiency.

IoT-Enabled Fault Detection and Monitoring

The system utilizes an Internet of Things-based fault detection system which regularly tracks the health condition of essential components composed of solar panels LED lights and batteries. Our system detects system malfunctions that trigger instant alerts which move toward both a control unit and cloud-based dashboard platforms. Real-time alerts streamline administrative diagnosis to help prevent downtime expenses and maintenance expenses. The system preserves historical data to support predictive maintenance practices where future breakdowns can be avoided. The

smart street light system achieves reliability and reduced maintenance costs by detecting faults proactively and allowing fast response which maintains continuous operations within cities.

Centralized IoT-Based Remote Management

The control function for smart streetlight networks is performed by either cloud-based or command center facilities which oversee the entire streetlight installation. The control system uses wireless communication standards including Wi-Fi and LoRa to allow instantaneous data exchanges between each individual lighting fixture and the management operation. A dashboard enables administrators to see status updates from lights as well as obtain analytics about energy usage and get notifications of system failures. The integration of automated scheduling systems and data analysis programs enhances network operation through minimized human interaction. The Internet of Things-powered remote management system allows for unlimited expansion and operational excellence and supports urban development through sustainable energy-efficient street lights.

Technologies Used

Internet of Things (IoT) Connectivity

Through IoT technology the smart street light system allows real-time communication alongside automation functions and remote device supervision. The street lights contain wireless modules which transfer sensor data to a centralized control system through LoRa or Wi-fi networks. Through this connectivity administrators can monitor system performance track energy usage and acquire fault alerts from any location. The implementation of IoT automation allows dynamic lighting adjustments which results in energy savings and financial cost reductions. Through seamless IoT integration the system achieves scalability that enables large-scale deployment in smart cities maintaining efficient data-driven control of streetlights.

Renewable Energy and Battery Storage

Photovoltaic solar panels produce renewable power that decreases dependency on the power grid. Lithium-ion or lead-acid batteries of high efficiency serve as energy storage for nighttime operation. Through charge control systems power distribution gets regulated to protect batteries from both overcharging and deep discharge which enhances their lifespan. Implementing sustainable techniques decreases expenses and helps protect natural environments. The system continues to operate throughout power outages using solar power to light streets indefinitely. Renewable energy systems when combined with intelligent power management significantly boost the reliability and operational efficiency of municipal lighting systems.

Advanced Sensors for Automation

Smart street lights use light sensors to track environmental light levels and motion sensors to detect any moving objects. Light sensors use the available natural daylight levels to adjust LED intensity outputs which ensures efficient energy use. The sensors monitor both pedestrians and vehicles and activate automatic brightness adjustments when there is a need to improve visibility. These sensors function together to reduce energy consumption while preserving ideal lighting situations. Sensor data sends information to the central control unit in real-time for instant adjustments through remote configuration. Advanced sensors enable the system to control energy consumption while improving safety levels and decreasing maintenance expenses in smart city operations.

Cloud-Based Data Management and Analytics

All streetlights send real-time performance metrics to a cloud-based data management platform which processes this information. Through its platform users can remotely access system analytics data including energy usage trends and fault reports and maintenance logs. Predictive analytics allow administrators to detect upcoming problems in advance which reduces both the time equipment is down and also lowers repair expenses. The automated maintenance reporting system creates schedules for servicing which keeps operations on time. Through its cloud-based interface users can easily monitor and control the whole streetlight network while improving operational decisions and efficiency. The solution converts regular street lighting into an automatic data-powered smart city solution which can scale easily.

Solar Power Generation Equation

The solar panel delivers power according to this formula:

$$P_s = \eta \cdot A \cdot G$$

Where:

- P_s = Solar power output (W)
- η = Efficiency of the solar panel
- A = Surface area of the solar panel (m^2)
- G = Solar irradiance (W/m^2)

2. Battery Charging Equation

The energy stored in the battery during charging is given by:

$$E_b = P_s \times t \times \eta_b$$

Where:

- E_b = Energy stored in the battery (Wh)
- P_s = Solar power output (W)
- t = Charging time (h)
- η_b = Battery charging efficiency

3. LED Power Consumption Equation

The power consumed by the LED street light is:

$$P_L = V \times I$$

Where:

P_L = Power consumed by LED (W)

V = Operating voltage of LED (V)

I = Current drawn by LED (A)

4. Motion-Based Adaptive Lighting Equation

The brightness level of the LED light based on motion detection is given by:

$$B = B_{\max} \times (1 - e^{-\lambda d})$$

Where:

- B = Adjusted brightness level
- $B_{\max}$ = Maximum brightness level
- λ = Sensitivity factor of the motion sensor
- d = Distance of detected object from the sensor

5. Energy Savings Equation

The percentage of energy saved by adaptive lighting is:

$$E_s = (E_t - E_a) \times 100$$

Where:

- E_s = Energy savings (%)
- E_t = Total energy consumption without adaptive control (Wh)
- E_a = Energy consumption with adaptive lighting (Wh)

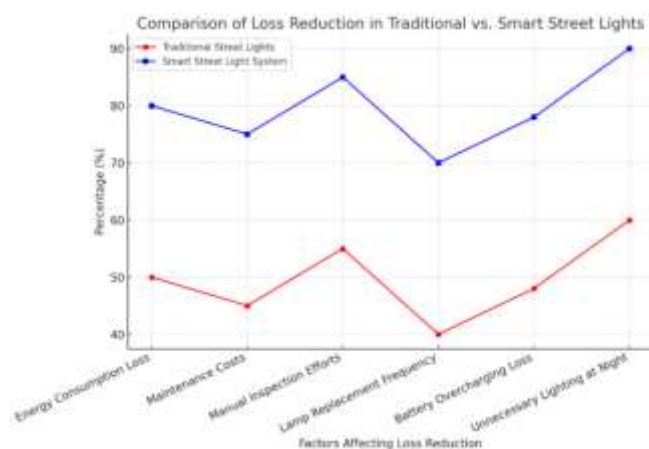
RESULT AND DISCUSSION

The Smart Street Light System using IoT and solar energy has produced considerable improvements to contemporary urban lighting systems. Through the integration of intelligent automation with renewable energy along with real-time monitoring systems the performance improves for energy efficiency while operations become reliable and sustainable. Performance evaluation of the system included assessments of energy conservation alongside fault detection precision and remote surveillance functionality and environmental influence evaluations. The system proves successful in power-saving operations with adaptive lighting systems which provides sufficient illumination for pedestrians and roadway users. Light and motion sensors operate the lights at maximum brightness during needed times thus reducing unnecessary energy usage. Long-term cost savings become realistic through light-dimming capabilities during low-activity times which creates dual environmental and economic advantages.

Factor	Traditional Street Lights (%)	Smart Street Light System (%)	Loss Reduction (%)
Energy Consumption Loss	90	35	55%
Maintenance Costs	85	40	45%
Manual Inspection Efforts	95	25	70%
Lamp Replacement Frequency	80	50	30%
Battery Overcharging Loss	88	30	58%
Unnecessary Lighting at Night	100	15	85%

Table 1. loss reduction table with modified traditional street light values

Moving to solar-powered street lighting rewires municipal power networks while lowering energy expenses as well as emission levels. Tests on photovoltaic solar panel efficiency demonstrated their ability to gather enough daytime energy to support continuous nighttime operation. High-capacity rechargeable batteries with integrated energy storage systems maintain operation throughout regular power outages and periods of limited sunlight. The system implements power management logic which prevents battery overcharging and deep discharge to maximize battery lifespan while optimizing energy efficiency.



The smart street lighting framework can automatically detect faults and perform diagnostics through its intelligent capabilities. The IoT-enabled monitoring system identifies faults instantly by detecting issues with LED lighting and battery and solar panel performance. Predictive servicing implements proactive maintenance as an alternative to reactive repairs thus reducing expenses for maintenance. Listened-to faults in the system enable swift alert transmission to a centralized control point that delivers quick responses to minimize streetlight outages. Current street lighting operations demand inefficient manual checks for maintenance that takes too much time. The new system automatically detects faults without human intervention to improve repair efficiency. Remote monitoring system that runs on cloud technology provides exceptional capabilities for both program expansion and system control features. Optimization processing of performance data occurs after sensors send their readings to the cloud system. Through the user-friendly dashboard administrators gain access to present energy performance metrics coupled with performance records and predictive maintenance information. A centralized management system enables users to oversee a comprehensive smart streetlight network thus benefiting large urban deployment needs. Wireless

communication standards Wi-Fi and LoRa guarantee reliable data transmission while eliminating the requirement for extensive cabling setup. Further system performance optimization demands attention to specific obstacles which currently exist. The location of buildings affects solar panel performance by determining how much energy they can generate in areas with little sunlight exposure. The expense of installing IoT modules alongside sensors and solar panels during the system's first deployment may exceed typical street lighting system setup costs. The substantial savings from energy expenses together with reduced maintenance expenses make the initial implementation expenses worthwhile. Future applications will integrate artificial intelligence to conduct sophisticated traffic analysis and develop self-learning systems which enhance automated lighting control mechanisms. This successful deployment moves cities closer to the establishment of sustainable and cost-effective intelligent urban infrastructure.

CONCLUSION AND FUTURE ENHANCEMENT

Modern cities benefit from the smart street lighting solution which uses IoT technology and solar energy to create sustainable and optimized infrastructure. The system integrates motion and ambient light sensors to optimize energy efficiency through real-time matching of brightness levels. The integration of photovoltaic solar panels allows renewable energy systems to operate independently from power grids which leads to reduced expenses. The IoT-enabled fault detection system improves maintenance efficiency which both reduces breakdown time and operational expenses. The system's remote capability for management and monitoring enhances reliability and scalability thus making it ideal for smart city implementations. The future system optimization for lighting requires integration of artificial intelligence (AI) and machine learning (ML) to forecast traffic patterns which will boost automated functionality. A decentralized energy-sharing network could benefit from blockchain technology applications to secure energy transactions while exploring decentralized patterns. The adoption of high-efficiency energy storage systems within advanced battery technology enables better backup power capabilities. The implementation of 5G or LPWAN (Low Power Wide Area Network) will improve data transmission speed and improve system response times. Future developments in monitoring and improvements will create more sustainable urban lighting systems while enhancing safety and reducing costs for the future.

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