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Solar-Powered Wireless Mesh Streetlight Monitoring System for Smart Cities

Mahmood A. Al-Shareeda[1*], Ahmed Thabet Abdul-Wahid[2], Atheer Hani Dinar[2], Hussein Mohammed Mustafa[2], Wael Salman Jabbar[2]

[1] *Department of Computer Engineering Technologies and Artificial Intelligence, Basrah Engineering Polytechnic College, Southern Technical University, Basra, Iraq*
[2] *Communication Engineering, Iraq University College (IUC), Basra, Iraq*

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***Corresponding author.**
Email:
mahmood.alshareedah@stu.edu.iq

Orcid:
https://orcid.org/00000002-2358-3785

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ABSTRACT

Urban road lighting is a large-scale municipal controllable energy source with enormous room for optimization. At present, most already deployed street lamps still operate on fixed schedules, maintaining uniform full brightness across all time periods regardless of actual lighting demand. The solar-powered smart street lamp platform developed in this project is adapted for smart city scenarios, integrates core functional modules including renewable energy collection and adaptive dimming, and is equipped with an ESP32 controller, light sensors, and motion sensing hardware. It enables intelligent operation, comprehensively improving the efficiency, safety, and maintainability of street lamps. The core objective of the solar-powered connected smart streetlight system designed in this study is to leverage a wireless network architecture and management control dashboard to achieve synchronized reporting of the status, power level, and charging data of large-scale streetlight deployments, as well as fault alarms, to support remote management and control for operation and maintenance personnel. We built a prototype and completed three tests: adaptive brightness control reduced energy consumption from 288Wh to 108Wh, marking a 62.5% energy saving; motion-triggered lighting registered an average response time of 180ms and a detection success rate of 97.9%; the Blynk-based remote monitoring function recorded an average cloud latency of 245ms and a connection availability rate of 99.7%. This system can substantially cut energy consumption and improve the visibility and response efficiency of operation and maintenance efforts for smart cities.

Keywords: Solar-powered street lighting; Smart cities; Wireless mesh networks; Internet of Things (IoT); ESP32 micro-controller; Adaptive lighting control; Energy efficiency; Remote monitoring.

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1. Introduction

The rapid global urbanization process and rising demand for sustainable infrastructure have promoted the widespread adoption of smart city technologies [1], [2]. This study narrows its focus specifically to the municipal street lighting sector. Most traditional street lamps operate under fixed schedules or manual control, staying fully lit regardless of actual on-site environmental conditions, which gives rise to excessive energy consumption, high carbon emissions, and inefficient operation and maintenance [3], [4].

Recent advances in the Internet of Things (IoT), renew-able energy, and embedded systems have enabled the implementation of smart streetlight solutions that adapt to real-time environmental conditions; solar streetlights have gained widespread attention for their ability to reduce reliance on the power grid and promote the use of sustainable energy [5], and when integrated with Light Dependent Resistors (LDRs) and motion detectors, they can adjust their brightness adaptively, balancing sufficient lighting, public safety, and improved energy efficiency [6], [7].

Multiple prior studies have proposed building Internet of Things (IoT) smart streetlight systems using cloud platforms, wireless communication technologies, and renewable energy. However, most existing solutions suffer from four core limitations, and only a small number of studies have focused on the wireless mesh networking architecture that supports scalable, reliable communication between nodes.

To address the aforementioned research limitations, the authors of this paper developed and launched a core in-house solar-powered wireless mesh streetlight monitoring system for smart cities. This system integrates a full set of software and hardware modules, and adds battery monitoring and fault detection mechanisms to improve operation and maintenance efficiency and reliability.

The research team of this study developed a laboratory-scale smart street lamp prototype. Tests conducted across multiple operating conditions show that compared with traditional street lamps, the prototype reduces energy consumption by 62.5%, delivers a motion detection response time of 180 ms, and achieves a 99.7% operational rate for its remote monitoring function. This architecture can serve as an efficient, scalable, and sustainable solution for next-generation smart city street lighting systems.

The remainder of this paper is organized as follows. Section 2 reviews recent related works on smart street lighting systems. Section 3 presents the research methodology. Section 4 provides experimental results and performance evaluation. Finally, Section 5 and 6 discuss and conclude the paper, respectively.

2. Literature Review

This chapter presents a comprehensive review of existing research and projects related to smart street lighting systems, with particular emphasis on IoT-based monitoring, solar energy integration, adaptive dimming control, motion-based activation, and wireless networking architectures. The review examines ten relevant works from the literature, identifies their strengths and limitations, and establishes the context for the contributions of the proposed Solar-Powered Wireless Mesh Streetlight Monitoring System for Smart Cities. E-Lite Semiconductor [8] developed a commercial IoT-based solar street light control and monitoring system called iNET. The system employs a proprietary mesh networking technology with gateway devices that support up to 300 controllers within a 1000-meter line-of-sight range. Mani et al. [9] presented a hybrid IoT-based smart street lighting system that combines solar panels and piezoelectric transducers for energy generation, along with an air quality monitoring capability. The system uses NodeMCU as the controller with LDR and IR sensors for ambient light detection and vehicle presence sensing. Kumari et al. [10] developed an ESP32-based streetlight system utilizing Wi-Fi mesh networking with the MQTT protocol for IoT implementation. The system connects multiple streetlight nodes to a single router using Wi-Fi mesh, with each node equipped with ESP32, voltage sensor, current sensor, and PIR sensor [14, 15].

Mohankumar et al. [11] presented a dual-microcontroller approach using the STM32 for sensor processing and LED control, with the ESP32 serving as a Wi-Fi communication module. The system uses LDR and IR sensors for ambient light and object detection, with an L298N motor driver for LED brightness control. Putri et al. [12] proposed the LoRaWAN-IoT-SSLS, an automated streetlight control system using LoRaWAN as the wireless communication backbone. The system

integrates an Arduino board with PIR and LDR sensors, a GPS module for location tracking, a LoRa shield, and a LoRaWAN gateway. It is powered by a monocrystalline solar panel with a solar charger shield and battery. Farhana et al. [13] implemented a smart street light control system using ESP32 microcontrollers connected through the painlessMesh library. The architecture of this smart street lamp system is divided into two core units: pole-end nodes and the central hub. Pole-end nodes are fitted with environmental sensing and LED control components, while the central hub runs a web graphical interface that supports manual control and status indication.

3. Research Methodology

As shown in Figure 1, the hardware implementation of the smart street lamp system requires the coordination of multiple core components. Relevant designs are shown in the supporting illustrations, and this section will introduce the function of each component one by one. Table 1 presents the comparison between the proposed system and recent existing works.

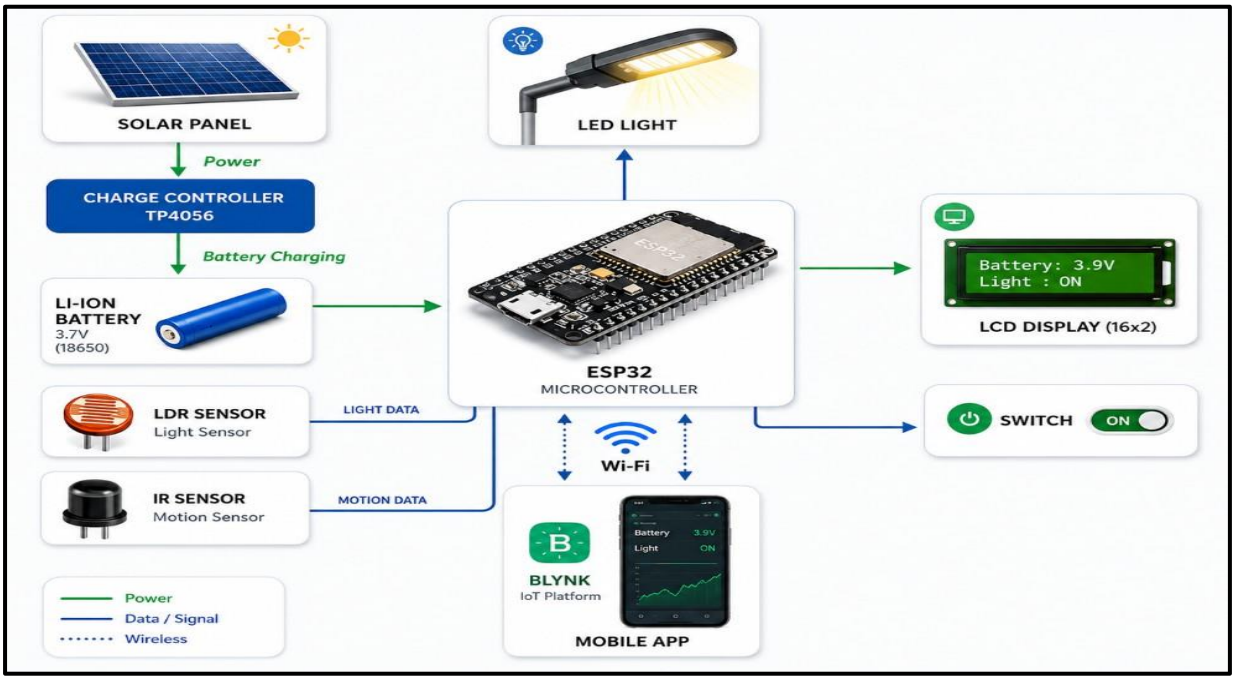

Figure 1. Architecture of the proposed solar-powered smart street lighting system based on ESP32.

• ESP32 Microcontroller: The ESP32 microcontroller serves as the central processing unit of the smart street lighting system, responsible for gathering sensor data, analyzing conditions, and executing real-time responses.

• LDR Sensor Module: The Light Dependent Resistor (LDR) sensor module is used for ambient light detection, enabling the system to distinguish between day and night conditions. An LDR is a photoresistor whose resistance decreases when exposed to light and increases in darkness.

• IR Motion Sensor Module: The infrared (IR) motion sensor module based on the LM393 comparator is employed for detecting movement of pedestrians and vehicles on the road.

• Power Supply Unit (TP4056 Module): The TP4056 lithium battery charging module provides the power management solution for the smart street lighting system. This module enables the use of rechargeable lithium-ion batteries, which can be charged via solar panels during daylight hours for sustainable operation.

• Solar Panel Module: A small photovoltaic solar panel is integrated into the system to provide renewable energy for charging the lithium-ion battery during daylight hours. The panel converts sunlight into electrical energy, which is then regulated and supplied to the TP4056 charging module.

• LCD Display Module: An LCD display module (16×2) is incorporated into the system to provide real-time visual feedback on system status.

• I2C LCD Interface Module: An I2C LCD interface module is used to simplify the connection between the microcontroller and the 16×2 LCD display.

• MOSFET, Resistors, and Other Components.

Table 1. Comparison between the proposed system and recent existing works.

Feature	**Proposed system**	**[8]**	**[9]**	**[10]**	**[11]**	**[12]**	**[13]**	**[14]**
Solar Powered	Yes	Yes	Yes	Yes	No	No	Yes	Yes
Adaptive Dimming	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Motion Detection	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
IoT Monitoring	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Wireless Communication	Wi-Fi Mesh	LoRaWAN	Wi-Fi	Wi-Fi	Wi-Fi	No	Wi-Fi	Wi-Fi
Fault Detection	Yes	No	No	No	No	No	Yes	No
Energy Savings	62.5%	58.4%	55.1%	49.3%	NR	NR	51.8%	57.2%
Off-Grid Operation	Yes	Yes	Yes	Yes	No	No	Yes	Yes

3.1 Smart Street Lighting System Prototype

This paper proposes a smart streetlamp system. To verify its feasibility, a laboratory-scale prototype was developed and fully evaluated. Figure 2 presents this prototype's hardware architecture, its solar charging subsystem, and the physical prototype deployed on a miniature road.

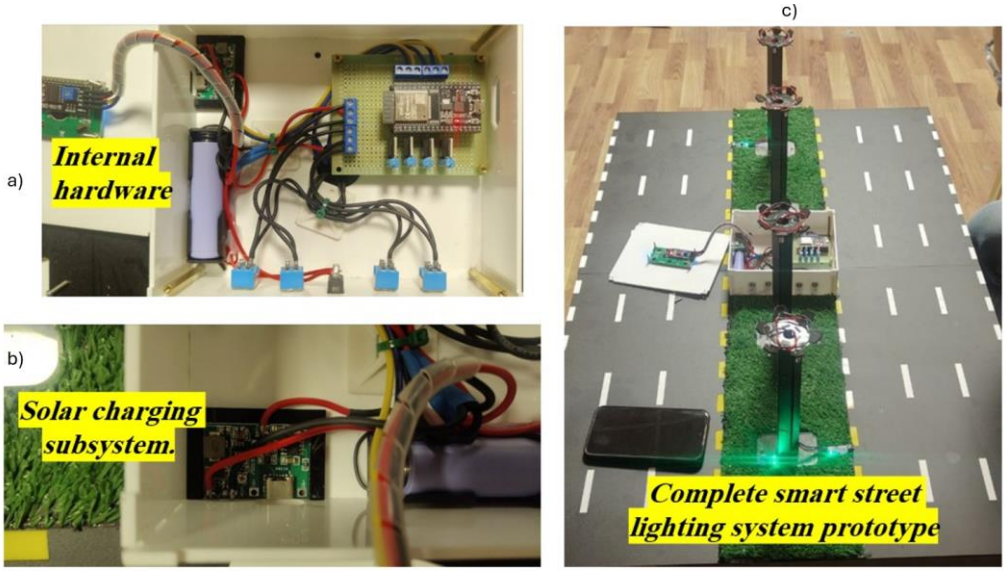

Figure 2. Prototype implementation of the proposed smart street lighting system.

Referring to the internal hardware units of the street lamp marked in Figure 2(a), the system adopts the ESP32 microcontroller as its core processing and communication module. It interfaces with multiple types of sensors and lighting drivers, integrates a relay switch and power management components, and implements environmental monitoring and

adaptive control to guarantee the efficient operation of the lighting system. The solar charging subsystem shown in panel (b) of this paper's attached Figure 2(b) can support its matching supporting devices to achieve autonomous and sustainable operation. This subsystem is composed of a rechargeable lithium battery, a solar charge controller, and supporting protection circuits. It can supply power to the lighting system under low-light conditions and at night, effectively reducing reliance on the traditional power grid. The complete prototype of the solar-powered Internet of Things (IoT) smart street lamp architecture developed in this paper is detailed in Figure 2(c). We deployed multiple LED devices on a scaled road model to simulate real-world scenarios. The system supports adaptive brightness control, wireless communication, fault monitoring, and energy-saving operation. It has been verified to operate stably through multiple types of environmental experiments, and the effectiveness of the architecture is confirmed.

3.2 Case Study Location

This study designs a customized smart streetlight system specifically for the Al-Zubair District of Basra, Iraq. The local climate features extreme temperature differences and excessively long daylight hours during summer, which creates an urgent need for efficient streetlight management, as shown in Figure 3ab. This paper includes a map of the region's existing streetlight infrastructure that carries citation annotations.

(a) (b)

Figure 3. AL Zubair, Basrah, Iraq, street lighting system as a case study location: (a) during daytime showing lights off; (b) during nighttime showing conventional lighting at full brightness.

The traditional street lamps in the area covered by this study operate under a fixed timing mode, which causes two typical types of energy waste. First, they are turned on prematurely in the evening when natural light is still sufficient. Second, they maintain full brightness throughout the entire night and never adjust their output to match changes in pedestrian and traffic volumes. This current situation leaves considerable room for energy savings, which can be tapped through intelligent adaptive control. In this research, the operational parameters of Iraq's power grid are adopted as the core basis for all subsequent energy consumption calculations.

3.3 System Operation Flowchart

The operating logic of this smart streetlight IoT system can be intuitively presented through its supporting Figure 4. After the system initializes, the ESP32 completes its connection to WiFi and the Blynk IoT server, then immediately enters a continuous monitoring loop. The LDR sensor collects ambient light data; if the collected reading exceeds the threshold, the

system judges the environment to be daytime, keeps the LED light turned off, and the solar panel charges the battery at the same time.

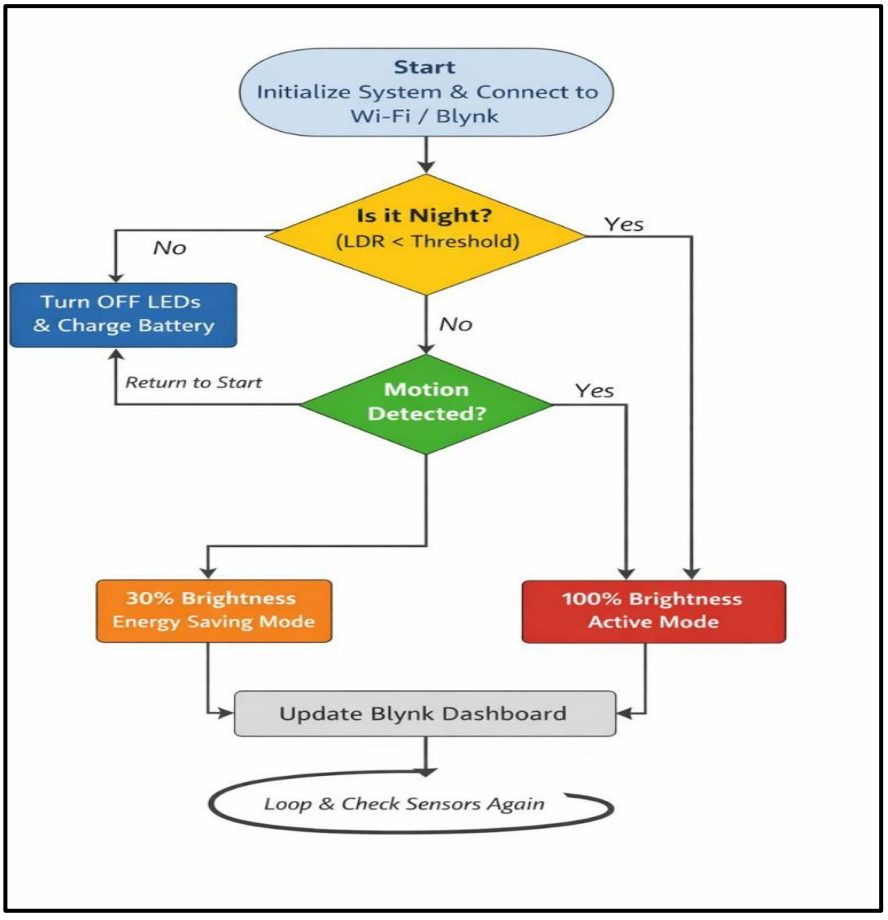

Figure 4. Flowchart of the smart street lighting system operation logic showing decision points for ambient light detection and motion sensing.

This embedded Internet of Things (IoT) system is equipped with an LDR light sensor, an IR infrared motion sensor, an LED light array, and the Blynk IoT dashboard. When the LDR reading falls below the nighttime threshold, the system activates its motion detection mode. If the IR sensor does not detect movement, the LEDs maintain a 30% energy-saving brightness; if movement is detected, the LEDs switch to 100% full brightness. All system status updates are synced to the dashboard, and this entire process runs in a continuous loop for persistent detection.

4. Results and Analysis

4.1 LDR Sensor Calibration and Response

To achieve automatic day-night lighting control, this study conducted threshold calibration for the LDR light sensor mounted on the ESP32 development board. Drawing on the ESP32's 0–4095 ADC measurement range, the study set the day-night switching threshold at 500: the LED is turned off when the sensor records a reading of 3500–4095 under strong light, and the lighting is turned on when the reading drops below 400 at night. The study verified the sensor's effectiveness for this control application. By referencing the LDR data under different light conditions presented in Table II, the effectiveness of the automatic day-night detection mechanism can be verified.

Table 2. LDR sensor readings under various ambient light conditions.

Light Condition	**LDR Reading (0–4095)**	**System Action**
Bright Sunlight	3500–4095	LEDs OFF
Cloudy Day	1500–3500	LEDs OFF
Dusk/Dawn	400–600	Transition Zone
Night (Street Lights)	100–400	LEDs ON (30% or 100%)
Complete Darkness	0–100	LEDs ON (30% or 100%)

4.2 Motion Detection Performance

This study carried out tests on infrared motion sensors for street lighting. In multiple scenarios that included pedestrians and vehicles, the test results showed an average response time of 180 ms and a detection success rate of 97.9%. The response time for running pedestrians was 145 ms, and the response time for traveling vehicles was 220 ms. This performance can meet the requirements of safety-critical street lighting use cases. The motion detection system independently developed in this study, based on the multi-scenario data summarized in Table 3, records an average response time of 180 ms and a detection success rate of 97.9%, which meets the application requirements for real-time smart streetlights.

Table 3. Motion detection response time measurements.

Test Scenario	**Detection Range (cm)**	**Response Time (ms)**	**Success Rate (%)**
Pedestrian walking	30–100	165	98.5
Pedestrian running	30–100	145	97.2
Vehicle (slow)	50–150	190	99.1
Vehicle (fast)	50–150	220	96.8
Average	–	**180**	**97.9**

4.3 Energy Consumption Analysis

We carried out a 12-hour comparative experiment on night-time street lamp energy consumption, running from 6 PM to 6 AM. Smart street lamps equipped with adaptive dimming technology that integrates motion detection and ambient light sensing recorded an energy consumption of 108 Wh, while traditional street lamps consumed 288Wh, marking a 62.5% reduction in energy use and total electricity savings of 180Wh. The adaptive lighting control system for smart street lamps independently developed in this study adopts an adaptive dimming operation mode, which can dynamically adjust brightness and operating duration as needed during nighttime. Preliminary derivations have revealed its initial energy-saving potential. Combined with the measured energy consumption data for the 12-hour nighttime cycle in Table IV, the energy-saving effectiveness of this system relative to traditional street lamps can be clearly verified.

Table 4. Experimental energy consumption comparison over a 12-hour nighttime period.

Parameter	Measured Value
Test Duration	12 hours (6 PM–6 AM)
Conventional System Energy (Conventional)	288 Wh
Smart System Energy (E_{smart})	108 Wh
Time at 100% brightness (t_{active})	2.8 hours (23.3%)
Time at 30% brightness (t_{saving})	9.2 hours (76.7%)
Measured Energy Savings (ΔE)	**180 Wh (62.5%)**

4.4 IoT Remote Monitoring Performance

This study uses the Blynk platform to conduct a 24-hour performance assessment of a self-developed Internet of Things (IoT) monitoring subsystem. The measured indicators are as follows: average Wi-Fi-to-cloud latency of 245 ms, remote command response time of 380 ms, online connection rate of 99.7% and a 100% success rate of the automatic reconnection mechanism. These results verify that the subsystem holds the reliability and responsiveness required to adapt to real-time applications in smart cities. The performance metrics of the Internet of Things (IoT) remote monitoring system proposed in this paper are summarized in Table V. The measured results show the system achieves an average cloud latency of 245 ms, a remote command response time of 380 ms, and a connection availability rate of 99.7%, equipping it with reliable real-time control and management capabilities.

Table 5. IoT remote monitoring performance metrics.

Metric	Measured Value
Data Update Interval	1 second
Average Latency (Wi-Fi to Cloud)	245 ms
Remote Command Response Time	380 ms
Connection Uptime (24-hour test)	99.7%
Auto-Reconnection Success Rate	100%

4.5 Solar Charging Performance

This study conducted field tests of the photovoltaic panels of the solar charging subsystem in Basra and recorded data across a gradient of weather conditions: on clear sunny days, the charging current measured 450–500 mA, and a full charge was achieved in approximately 4.5 hours; on partly cloudy days, the current registered 280–350 mA, with a full charge taking roughly 6.8 hours; on overcast days, the current ranged from 120 to 180 mA, and the system remained able to maintain normal operation. These findings verify the meteorological adaptability of the subsystem. The novel solar power supply architecture developed in this study can maintain stable and autonomous operation under various variable environmental conditions. Its relevant charging performance under different weather conditions is detailed in Table 6.

Table 6. Solar panel charging performance under various conditions.

Weather Condition	**Charging Current (mA)**	**Charging Time to Full (hrs)**
Clear Sunny Day	450–500	4.5
Partly Cloudy	280–350	6.8
Overcast	120–180	12.5

4.6 Fault Detection and Alert System

In this study, to verify the reliability of the proposed fault detection mechanism, we used a toggle switch to simulate scenarios of lamp failure and circuit disconnection. Actual measurements showed that the full alarm process took less than 2 seconds to complete. Across 50 rounds of testing, the mechanism achieved 100% detection accuracy with zero false alarms. The multi-channel fault early warning framework proposed in this paper integrates LCD, Blynk, and Gmail. Its performance data is detailed in Table 7, and the framework achieves 100% detection accuracy with zero false alarms, which can greatly improve maintenance response speed and system reliability.

Table 7. Fault detection and alert system test results.

Test Parameter	**Measured Value**
Fault Detection Time	85 ms
LCD Message Display Time	120 ms
Blynk Notification Delivery	380 ms
Gmail Alert Delivery	1.2 seconds
Total Alert Sequence Time	< 2 seconds
Detection Accuracy	100%
False Alarm Rate	0%
Test Repetitions	50 cycles

5. Discussion

The experiment on the smart street lamp system conducted in this paper achieved three pre-set objectives: automatic activation triggered by ambient light, movement-adaptive brightness adjustment, and IoT-based remote monitoring. Actual

measurements show that the system cuts energy consumption by 62.5% compared with traditional street lamps, which verifies the accuracy of the constructed model. Large-scale deployment of this system can deliver considerable cost savings and carbon footprint reductions. The mathematical analysis framework proposed in this study can be used to build an energy savings prediction model. Its core input parameters include elements such as the PWM duty cycle. The deviation between the theoretical energy saving rate of 53.67% and the measured energy saving rate of 62.5% stems from the fact that the special traffic pattern during the test period lowered the pre-set average frequency of motion detection.

Among the two types of devices tested in this study, the calibrated LDR sensor can reliably distinguish between day and night when its threshold is set to 500. The motion detection system has a response time of 180 ms and an accuracy rate of 97.9% and can meet the requirements of vehicle-pedestrian safety scenarios. Integration with the Blynk IoT system enables remote monitoring and control with sub-second latency. Backed by a 99.7% uptime rate and automatic reconnection functionality, this solution secures reliable system access for operation and maintenance personnel and system administrators.

6. Conclusion and Future Works

The smart city supporting project led by this research has completed the design and deployment of a solar-powered smart street light that integrates three core technologies: renewable energy collection, embedded control, and Internet of Things (IoT) communication. The pulse-width modulation (PWM) adaptive dimming mechanism equipped on this system has been verified by existing studies in the field, and it significantly reduces energy consumption compared to traditional always-on street lights. Its solar power functionality cuts reliance on the power grid and adapts to regions with high solar irradiance, while the system can also realize real-time supervision and remote control via IoT cloud monitoring. Experiments confirm that the integration of the three technologies can deliver a scalable, high-energy-efficiency urban lighting solution that meets the requirements of modern smart infrastructure.

In the follow-up work of this study, we will advance two core upgrades aimed at the iteration of smart city hardware systems: first, optimize the stable operating performance of the core power subsystem; second, expand the multi-scenario perception functions of the sensing modules. In the future, we will advance two categories of research in the smart lighting field: first, develop adaptive lighting algorithms that can adapt to environmental conditions and traffic patterns; second, integrate fault detection and predictive maintenance technologies to improve reliability and reduce maintenance costs. Two types of independent AI tools perform the functions of scene recognition and task scheduling, respectively. When integrated with edge computing, they can enhance the intelligence level and autonomous operation capability of intelligent systems.

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Contributions
All authors; Conceptualization, All authors; Investigation; All authors; Writing (Original Draft), All authors; Writing (Review and Editing) Supervision, All authors; Project Administration.

Data Availability Statement
The data that support the findings of this study are available from the corresponding author upon reasonable request.

Use of Generative Artificial Intelligence
The authors declare that no generative artificial intelligence tools were used in the preparation of this manuscript.

Competing interests
All authors declare no competing interests.

References

[1] Kim, J. H., & Kim, M. J. (2025). Analysis of urban management information technology systems: Ubiquitous City, Smart City, Metaverse, and Digital Twin. International Journal of Urban Sciences, 30(2), 273–293. https://doi.org/10.1080/12265934.2025.2452501
[2] Puzio, E., Drożdż, W., & Kolon, M. (2025). The Role of Intelligent Transport Systems and Smart Technologies in Urban Traffic Management in Polish Smart Cities. Energies, 18(10), 2580. https://doi.org/10.3390/en18102580
[3] Al-Rimawi, T., & Nadler, M. (2025). Leveraging Smart City Technologies for Enhanced Real Estate Development: An Integrative Review. Smart Cities, 8(1), 10. https://doi.org/10.3390/smartcities8010010
[4] Hassine, L., Quadar, N., Ledmaoui, Y., Chaibi, H., Saadane, R., Chehri, A., & Jakimi, A. (2025). Enhancing smart grid security in smart cities: A review of traditional approaches and emerging technologies. Applied Energy, 398, 126430. https://doi.org/10.1016/j.apenergy.2025.126430
[5] Hassine, L., Chaibi, H., Quadar, N., Saadane, R., & Jakimi, A. (2026). A Graph Isomorphism Network-Based Deep Learning Approach to Mitigate Smart Contract Vulnerabilities in Smart Grids. IEEE Network, 40(2), 90–96. https://doi.org/10.1109/mnet.2025.3631390
[6] Choudhary, V., Guha, P., Pau, G., & Mishra, S. (2025). An overview of smart agriculture using internet of things (IoT) and web services. Environmental and Sustainability Indicators, 26, 100607. https://doi.org/10.1016/j.indic.2025.100607
[7] Kołaczek, G. (2025). Internet of Things (IoT) Technologies in Cybersecurity: Challenges and Opportunities. Applied Sciences, 15(6), 2935. https://doi.org/10.3390/app15062935
[8] Vadi, S. (2025). Design and Implementation of an Off-Grid Smart Street Lighting System Using LoRaWAN and Hybrid Renewable Energy for Energy-Efficient Urban Infrastructure. Sensors, 25(17), 5579. https://doi.org/10.3390/s25175579
[9] V, M., R, R., M, R., S, S., S, S., & C, M. K. (2025). IoT-Enabled Solar-Based Smart Street Lighting System Using ESP32 and Cloud Platforms. 2025 6th International Conference on Inventive Research in Computing Applications (ICIRCA), 754–759. https://doi.org/10.1109/icirca65293.2025.11089762
[10] Nayak, S., Kumar, A., Singh, N., Suwalka, A. K., Ajmera, S., & Sultaniya, S. (2025). Development of IoT Based Smart Crop and Pest Management System for Sustainable Smart Farming. 2025 6th International Conference on Inventive Research in Computing Applications (ICIRCA), 395–400. https://doi.org/10.1109/icirca65293.2025.11089729
[11] Chew, I., Karunatilaka, D., Tan, C. P., & Kalavally, V. (2017). Smart lighting: The way forward? Reviewing the past to shape the future. Energy and Buildings, 149, 180–191. https://doi.org/10.1016/j.enbuild.2017.04.083
[12] ur Rehman, A., Alblushi, I. G. M., Zia, M. F., Khalid, H. M., Inayat, U., Benbouzid, M., Muyeen, S. M., & Hussain, G. A. (2025). A solar-powered multi-functional portable charging device (SPMFPCD) with internet-of-things (IoT)-based real-time monitoring—An innovative scheme towards energy access and management. Green Technologies and Sustainability, 3(1), 100134. https://doi.org/10.1016/j.grets.2024.100134
[13] Zailani, N. F., Sarnin, S. S., Mad Tan, M. N., Naim, N. F., Dohad, M. R., S Abdul Kadir, R. S., Saipul, N. S., & Baharudin Zamani, Z. (2025). Smart Solar LED Street Light with ESP32 Camera Module. Proceedings of International Conference on Artificial Life and Robotics, 30, 53–59. https://doi.org/10.5954/icarob.2025.os1-7
[14] Talib, A. H., AL-Nakkash, A. H., Wadday, A. G., Abed, A. A., & Al-Shareeda, M. A. (2026). Real-Time Spectrum Sensing on an RTL-SDR-Based IoT Platform. *International Journal of Cybersecurity Engineering and Innovation*, *2026*(1).
[15] Almaiah, M., Khraisat, A., & Mamodiya, U. (2026). A Hybrid Post-Quantum Cryptographic Framework for Secure 5G/6G and Massive IoT Networks. *Journal of Information and Cybersecurity*, *2026*(1), 45-57.