Implementation of IoT-Based Public Street Lighting System Using Solar Energy and LoRa Technology

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Abstract. In this modern era, renewable energy sources are crucial for reducing dependence on limited fossil fuels and the ever-increasing cost of electricity generation. One of the most effective ways to reduce electricity consumption and high operational costs in public street lighting systems is to use solar power as the primary power source. Solar Power Plants (PLTS) have become an environmentally friendly and efficient solution to meet energy needs in various sectors. Public street lighting plays a crucial role in improving the safety and comfort of road users at night. However, maintenance of street lighting systems often faces problems such as damage to some streetlamps that is not quickly detected. This can lead to prolonged inoperability of streetlamps and create discomfort for road users and even increase the risk of accidents. Therefore, this study aims to design and develop a solar-powered public street lighting system utilizing LoRa technology, based on the Internet of Things. This study uses an experimental method. This monitoring system comprises an LDR sensor to detect light intensity, a LoRa module for long-distance communication, and a microcontroller to process and transmit data to a central server. Data from the sensor is used to determine whether the streetlight is on or off and then sent to the control centre for analysis. Based on the study's results, LoRa technology can be utilized for wireless communication between street lighting points, resulting in low power consumption. The condition of street lighting can be monitored remotely in real-time on a website via the internet.

1 Introduction

In this modern era, renewable energy sources are crucial for reducing dependence on limited fossil fuels and the ever-increasing cost of electricity generation. One of the most effective ways to reduce electricity consumption and high operational costs in public street lighting systems is to use solar power as the primary power source. Solar Power Plants (PLTS) have become an environmentally friendly and efficient solution to meet energy needs in various sectors (1), (2). Public street lighting plays a crucial role in urban infrastructure, improving the safety and comfort of road users. Properly functioning streetlights can reduce the risk of traffic accidents, improve environmental safety, and support economic activity at night. However, maintenance of streetlight systems often faces challenges, such as undetected

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failures in some streetlights. This can lead to prolonged streetlight outages, inconvenience for road users, and even increase the risk of accidents. Along with the development of technology, the concept of the Internet of Things (IoT) has emerged as an innovative solution in various fields, including public street lighting systems (3). The Internet of Things enables devices to communicate with each other and exchange data over the internet, allowing for more effective and efficient real-time monitoring and control. In (4), Arduino can be used as a smart street light controller. A system designed to save energy, preventing energy waste caused by streetlights that automatically turn on at dusk and turn off at dawn. By utilizing infrared sensors, the system activates LED lights when it detects a car or obstacle. Some lights are on, while others are off. The lights turn on when an obstacle is detected or when a car approaches. The lights will turn off after the car or obstacle moves. In (5), (6), (7), (8), a smart street lighting system utilizing Internet of Things (IoT) technology is presented. The sophisticated system is designed to integrate various devices, such as sensors and cameras, to optimize and automate streetlights. It provided an efficient and cost-effective solution. The streetlights can be monitored and controlled by using an IoT sensor (9). It allowed for dynamic adjustments of lighting levels based on traffic patterns and weather conditions. In (10), Street lights can be controlled when a vehicle is detected. The system will dim the streetlights if there are no vehicles or pedestrians present. The energy wastage can be reduced. The fault detection of smart solar street light batteries/panels can be monitored based on IoT (11). This system is designed to know the status of Street Lights. The system can send alert messages to authorized people's mobile numbers. In (12) and (13), the solar tracker IoT-based lighting control system is presented. This smart system controls the light dimmer and operates the solar tracker simultaneously. By following the path of the sun, the solar tracker receives sunlight more effectively than traditional solar panels. One communication technology that supports the implementation of the Internet of Things (IoT) is Long Range (LoRa), which offers a wide communication range with low power consumption, and even no internet (14), (15). LoRa is a wireless communication technology designed for Internet of Things (IoT) applications that require a wide range and low power without an internet connection for data transmission. In the application of LoRa technology is used in photovoltaic system monitoring. This technology is very suitable for monitoring streetlights because it can transmit data over long distances without requiring complex network infrastructure. By using Long Range (LoRa), each street light can be equipped with sensors that monitor its operational conditions, such as 'ON' or 'OFF' status, energy consumption, and damage detection. Data collected by these sensors is then sent to a control centre, which we happen to use in this study, based on a microcontroller via the Long Range (LoRa) network. The data is examined to determine the necessary maintenance actions. Implementing an Internet of Things (IoT)-based streetlight monitoring system with Long Range (LoRa) communication has several key benefits. First, this system enables early detection of streetlight damage, allowing for quick repairs before it causes further disruption. Second, real-time data collection enables more efficient energy management, as streetlights can be set to turn on only when needed or their light intensity can be adjusted based on environmental conditions. Third, this system can reduce operational and maintenance costs, as monitoring and control are automated, eliminating the need for time-consuming and costly manual inspections. The implementation of this system also has a positive impact on the environment. With more efficient energy management, electricity consumption can be reduced, which in turn reduces carbon emissions and the environmental footprint. This is in line with global efforts to achieve sustainability and reduce the negative impacts of climate change, namely 'World Zero Emission'. However, the implementation of an Internet of Things (IoT)-based streetlight monitoring system with Long Range (LoRa) communication also faces several challenges. One of the concerns is data security, as this system involves transmitting data over a wireless network that is vulnerable to cyberattacks. Therefore, adequate security measures are needed to protect data integrity and confidentiality. Furthermore, integration with existing infrastructure also requires careful planning and investment. This study will discuss the design of a solar-powered public street lighting system using LoRa technology and IoT.

2 Methods

The method used in this research is experimental, involving a literature study on theories, datasheets, and research results related to public street lighting systems, system design, and system implementation, encompassing both hardware and software aspects. The main components of this public street lighting system use solar panels, solar charger controllers, batteries, and LED lights. The components of the Public Street Lighting monitoring system consist of an ESP32 microcontroller, Arduino Nano, current and voltage sensors, light sensors, relays, and LoRa modules. The design of a solar street lighting system based on LoRa technology and the Internet of Things (IoT) is illustrated in Figure 1. The block diagram of the control system is shown in Figure 2.

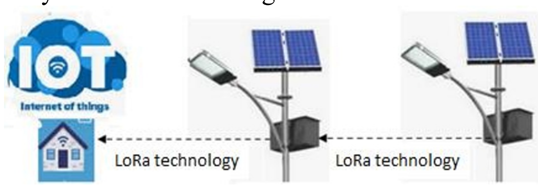

Fig. 1. The Design of Solar Street Lighting Monitoring System

As shown in Figure 2, the LDR sensor and current sensor are used as input signals to the Arduino Nano controller. The Light Dependent Resistor (LDR) sensor detects whether the streetlight is on or off based on the measured light intensity. The current sensor is used to measure the power and energy consumption of the lamp. Data from the sensor will be processed by the ESP32 microcontroller to be sent to the control centre via the Long Range (LoRa) module installed at each light point. The data will then be sent to the cloud for processing and analysis via the internet.

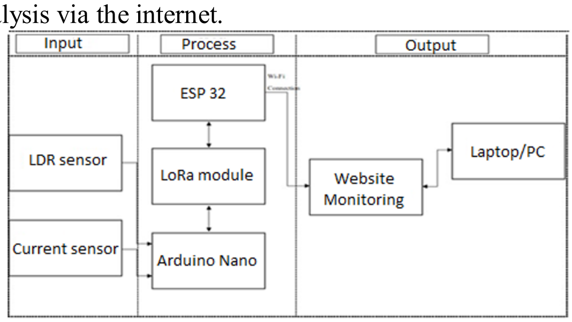

Fig. 2. Block Diagram of Control System

The lamp's operational conditions can be monitored remotely via a website on a laptop or mobile phone. The schematic diagram system is shown in Figures 3 and 4.

3 Results and Discussion

The system consists of an Arduino Nano, a Wi-Fi ESP32 microcontroller, a LoRa SX1278 Module, current and voltage sensors, light sensors, and a Solar panel used to charge the battery. The light will turn ON only at night by sensing the solar voltage. The battery gets charged from the solar panel and supplies power to the system. The experimental prototype of the system is shown in Figures 5 and 6.

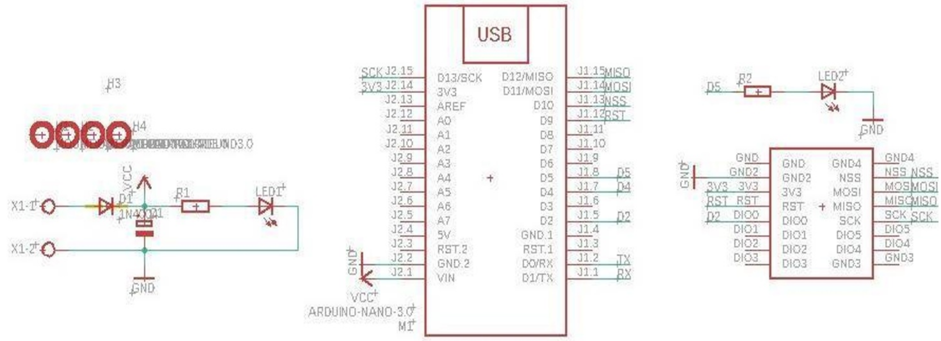

Fig. 3. Transmitter Schematic Design

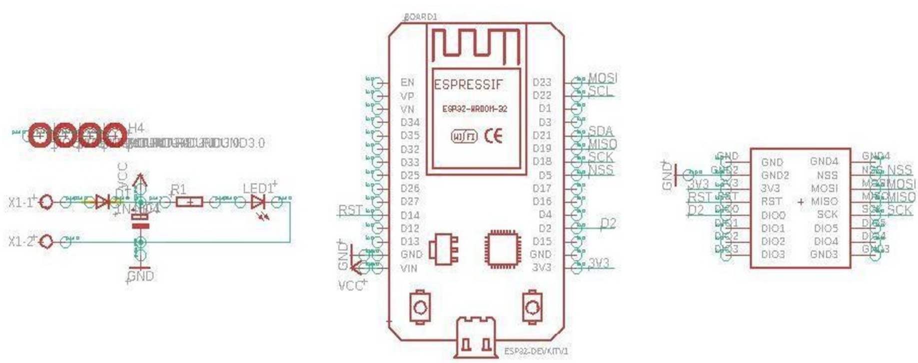

Fig. 4. Receiver Schematic Design

Testing the electrical energy transfer from the solar panel to the battery was conducted to determine whether the battery was charging properly. The solar panel test results data are shown in Table 1.

Fig. 5. Prototype of the system

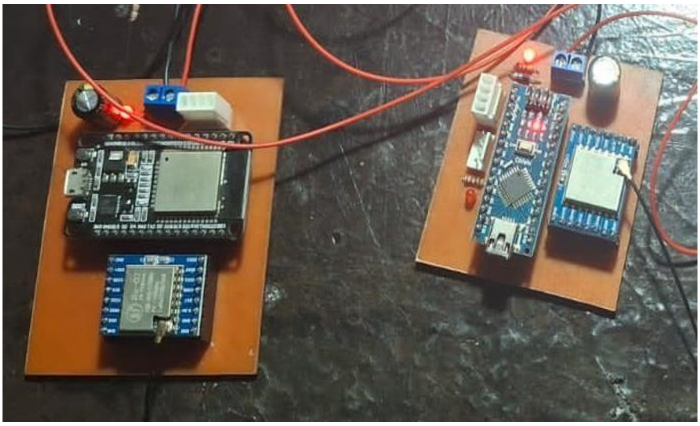

Fig. 6. Electronics circuit

Table 1. Solar Panel Test Results

Time (WIB)	Sunlight Intensity (Lux)	Voltage (Vdc)	Current (A)	Power (W)
10.00	6019	12,87	0,46	5,92
11.07	8935	13,24	0,67	8,87
12.03	8682	13,22	0,65	8,58
13.00	9805	13,33	0,88	11,59
14.00	8330	13,00	0,64	8,32
15.30	5892	12,67	0,44	5,57
17.00	2193	12,10	0,18	2,17
18.00	0	0	0	0

Based on the results of battery charging tests on the PLTS system in Table 1, it was found that the intensity of sunlight has a significant influence on the amount of power generated by solar panels. Measurements were carried out from 10:00 to 18:00 WIB. The highest intensity occurred at 13:00 WIB, with a value of 9805 Lux, producing a maximum power of 11.59 W, a voltage of 13.33 V, and a current of 0.88 A. Conversely, at 17:00 WIB, when the intensity dropped to 2193 Lux, the power also decreased drastically to 2.17 W, until it did not produce any power at all at 18:00 WIB because there was no sunlight (0 Lux). Overall, the most optimal time for the battery charging process is in the range of 11:07–13:00 WIB when the sunlight intensity is high, and the panels work efficiently. At the same time, after 15:30 WIB, the efficiency decreases as the light intensity decreases. It shows that the PLTS system is very dependent on lighting conditions as its energy source. The current and voltage sensors are used to measure battery voltage. The results of the comparison of battery voltage measurements using an avometer and current and voltage sensors are shown in Figure 7. The sensor data shows that the voltage values are close to the avometer, with a difference of 0.07 V to 0.36 V. The smallest voltage difference occurs at the fourth point (0.07 V), and the largest at the second and sixth points (0.36 V). The graph shows a consistent and similar measurement pattern between the two devices. This proves that the current and voltage sensors are quite accurate and reliable for real-time voltage monitoring.

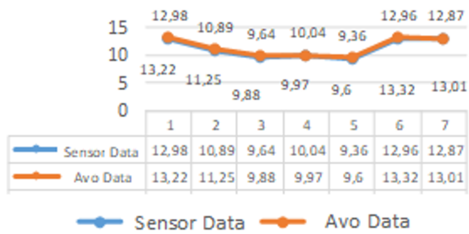

Figure 7. Battery voltage test results

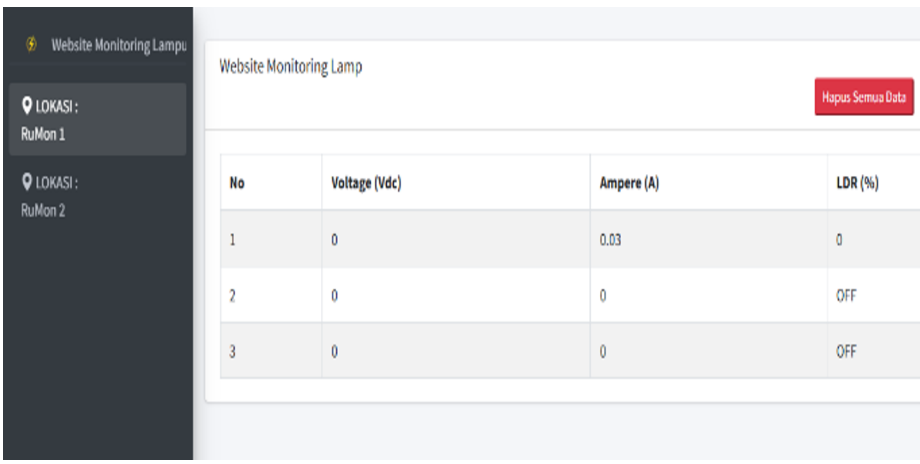

Figure 8. Website Monitoring Lamp

The LoRa Module testing is carried out to ensure that the LoRa Module can function properly in sending and receiving data between LoRa Modules in the appropriate form from the start of the transmission. The ESP32 microcontroller will process this data and then display it on the monitoring website. In LoRa testing, data is sent from the Transmitter to the Receiver using frequency communication. This process involves adjusting the frequency between the LoRa Modules through the internal LoRa network, which enables communication between them according to the Arduino program created. The Arduino IDE is useful for integrating Arduino with the LoRa Module, both the LoRa Transmitter Module and the LoRa Receiver Module. The program used for this test is a basic program that is useful for verifying whether the LoRa Module can send and receive data properly between the LoRa Transmitter Module and the LoRa Receiver Module. This test aims to ensure that data can be transmitted between the LoRa Modules in the appropriate form, smoothly, and in real-time. Testing the light and current sensors demonstrated accurate results in detecting light status and measuring active energy. The integrated system testing was conducted in two environments, the home environment and the Jakarta State University building, with a test point distance of up to 250 m. At distances of 70m in the home environment, the system does not function well due to many obstructions, such as trees and buildings. The lamp condition, voltage, and current data were not displayed successfully. The receiver was only connected to Wi-Fi and the server, but communication between LoRa devices failed due to signal obstructions. At distances of 100m, 130m, and 180m, the system performed well, displaying real-time voltage, current, and lamp status data, especially in straight lines and areas without obstacles. The transmitter and receiver successfully connected via LoRa, and the receiver connected to Wi-Fi and the server. However, at a test point 250m away, the system failed to respond due to the long distance and numerous signal obstructions. These results indicate that the system's effectiveness is highly dependent on environmental conditions and the distance between devices. Based on the test results, Arduino Nano and ESP32 successfully received and sent data via the LoRa module, and the data can be displayed on the website. When the light is off, the display on the website is 'OFF'. The light is on, the display is 'ON' along with the active voltage and current. The website monitoring system is shown in Figure 8.

4 Conclusion

A solar-powered street lighting system using LoRa-based IoT technology has been successfully developed. This system can monitor streetlight conditions and energy consumption in real-time, both with and without an internet connection. Arduino collects data from light sensor, current, and voltage sensors, then sends it to the ESP32 via the LoRa module. The ESP32 sends the data to the Web server via Wi-Fi, allowing it to be displayed on the Website Monitoring.

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