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Smart Street Lighting System with Webserver Interface

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Abstract – *In urban environments, traditional streetlight systems face challenges such as limited remote management capabilities and the use of outdated lighting technologies, resulting in energy inefficiencies and operational constraints. This project focuses on addressing these challenges by developing a LED-powered street lighting system that integrates LoRa technology and a web server interface. The network architecture adopts a master-slave configuration, where the master server controls three 35 W LED luminaries, functioning as slave units, with the following specifications: 6500K Correlated Color Temperature (CCT), 4200 lumens, and an energy efficiency of 120 Lumens/Watt. LoRa technology facilitates low data rate transmission over a considerable distance, enabling efficient communication between the units. Through a web server, the master unit establishes an access point that is WiFi-enabled, allowing users to view and manually configure the smart street lighting system. The web server interface allows users to visualize and manually control the streetlights, providing information on the state of LED luminaires, temperature, humidity, and connectivity between the master and slave units. The slave units, controlled by NodeMCU ESP32, operate on a 12-hour cycling interval and can receive commands from users or the master unit. Distance testing, energy efficiency calculations, and automated switching tests—including a 13-hour night test to ensure the device functions effectively and identify defects for future development—are used to evaluate the system's performance. The distance test results show steady connections behind walls and in open areas up to specific distances. LED luminaires are a cost-effective option because energy efficiency comparisons demonstrate a significant reduction in power usage when compared to classic High-Pressure Sodium luminaires. It is advised to add cameras for real-time vision-based monitoring, expand coverage with additional master units, and incorporate data logging and brightness control functions. Furthermore, remote switching outside the access point of the master unit can be accomplished by integrating a cloud server with strong security measures.*

Keywords – *Smart Lighting System, LED-Powered Streetlights, Webserver Interface, Remote Switching, Monitoring, NodeMCU ESP32, LoRa module.*

INTRODUCTION

Streetlights play a vital role in urban environments, ensuring public safety and providing illumination for nighttime travel. Traditional streetlights, which typically use low-pressure and high-pressure sodium lamps, have historically relied on various energy sources, such as electricity, solar energy, or other sources of energy (Kumar et al., 2019).

In recent years, there has been a notable shift towards incorporating smart technologies into street lighting systems. With the evolution of smart streetlight technology, particularly the rise of Internet of Things (IoT) devices, cities are rethinking their approach to urban lighting. Lighting technologies enabled advanced functionalities and remote monitoring, providing heightened energy efficiency, better maintenance and monitoring capabilities, and enhanced control over its operation (Ramos et al., 2021). On the other hand, existing traditional streetlights, have posed significant limitations in terms of maintenance, energy efficiency, and overall operating performance. Frequent maintenance requirements and issues such as sensor failure, flickering lights, and unsynchronized on/off

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cycles cause significant power consumption (Chen and Liu, 2009). These challenges make them less suitable for the evolving requirements of modern cities. As a result, there is a growing trend to replace traditional street lights with light-emitting diode (LED) systems. The transition to LED technology is motivated by its superior performance characteristics, offering advantages in maintenance, dimming capabilities, and power efficiency (Staff, 2019).

In the Philippines, several cities, including General Santos City (GSC), have embraced the importance of optimizing safety, security, and urban functions, promoting the implementation of smart street lighting systems. GSC, concerned about the growing number of road accidents and street crimes due to inadequate lighting, has embarked on an initiative to introduce a smart street lighting system to address these concerns. Additionally, the city has actively been targeting to replace all existing Sodium lights with LED lamps to address electricity inadequacy since 2018 due to the limited supply of electricity in Mindanao Grid and reduce maintenance expenses (PNA, 2018).

However, despite adopting the use of LED luminaries, street lighting systems can still be susceptible to faults that could compromise safety and security. Thus, to mitigate these risks, it is essential to implement a preventive measure in the current street lighting system that involves transitioning to LED luminaries and incorporating a smart lighting system with automatic switching capabilities (Leccese, 2013).

In this study, the research aims to develop a smart street-lighting system leveraging IoT technology, enabling remote switching, and replacing outdated technologies with energy-efficient LED luminaires. This initiative aims to enhance safety, security, and energy efficiency, providing a sustainable and adaptable lighting solution.

OBJECTIVES OF THE STUDY

This study is developed to tackle challenges inherent in traditional streetlight systems with the primary goal of addressing limitations in remote management capabilities and outdated lighting technologies. Specifically, it aims to 1) create a master-slave network configuration utilizing LoRa technology to ensure connectivity and control between individual streetlight units, 2) design a web server interface capable of remotely switching the luminaires for convenient and effective lighting system management, and 3) incorporate energy-efficient LED luminaires as the main lighting source for improved lighting quality and energy consumption.

MATERIALS AND METHODS

Research Design

Figure 1 provides an overview of the project's methodology. It begins with problem identification, where the project team engages with target stakeholders to identify issues. Subsequently, they develop a system to address the identified problem. The next step involves producing the necessary hardware, specifically the master and slave units, followed by their integration. Finally, rigorous testing is conducted to ensure the system's overall functionality, both in terms of hardware and software.

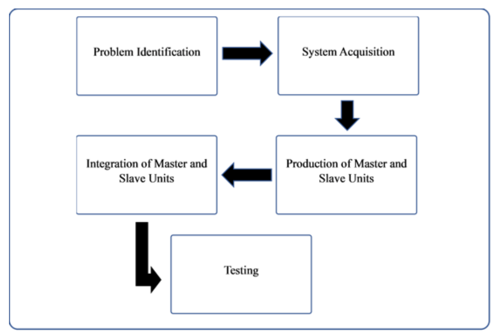

Fig. 1. Procedure flowchart for the development of the Smart Streetlight with Web Server Interface

Network Architecture

The network architecture for the smart street lighting system is illustrated in Figure 2. This network is established using a master-slave configuration, where the primary server assumes the role of the master, and the unit responsible for directly managing the three LED luminaires is designated as a slave unit. Data synchronization between these master and slave units occurs through a network facilitated by the LoRa gateway. The choice of LoRa technology is motivated by its capacity for low-data-rate transmission over substantial distances. LoRa operates at low frequencies, ensuring minimal transmission power consumption and imposing no duty cycle restrictions. These attributes are crucial to accommodate the operational cycling patterns of the street lighting system.

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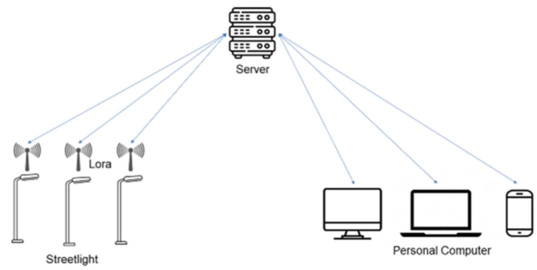

Fig. 2. Master-Slave network configuration facilitated using LoRa

The integration of master and slave units into a network is facilitated using LoRa technology. The master unit establishes an access point (AP) that users can access as a Wireless Fidelity (WiFi) network. This arrangement enables users to visualize and manually configure the smart street lighting system. However, it's important to note that data sent to the web server via a Domain Name System (DNS) at 192.168.1.1 can only be accessed within the network. This restriction is in place to ensure both manual safety and the system's effective operation.

Web Server Interface

The web server interface visualizes the state of the streetlights and allows manual remote control. This was developed on a private network to enable remote monitoring. The integral system of the master and slave units is accessed through an access point provided by the master unit. The user can interact with the master unit to obtain system information and remotely control the luminaries of the system. The information available from the master unit will include the status of the LED luminaries, temperature, humidity, and the established connectivity between the master and slave units.

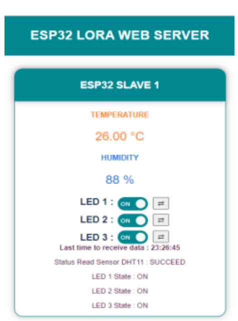

Fig. 3. Web Server User Interface

Streetlight Details

The system used three (3) 35 W LED luminaries with the following specifications: 6500K Correlated Color Temperature (CCT), 4200 lumens, and an energy efficiency of 120 Lumens/Watt. The streetlight is designed for installation at the standard height of eight feet, typically found in conventional streetlamp posts (DOE, 2017). It uses alternating current (AC) power from distributing companies, specifically SOCOTECO II. The streetlight system follows a 12-hour interval between on and off states, from 1800 PST and 0600 PST.

Master and Slave Unit Assembly

The slave units have integrated control using only one microcontroller unit (MCU), the NodeMCU ESP32. It has a 12-hour cycling interval between 1800 PST and 0600 PST; the lights will go on and off, respectively. One MCU could control the LED luminaries at a particular block or street. However, the connection between the luminaries is different so each LED light can be controlled separately. Aside from the automated control, the slave unit could also receive commands from the users via the web server, and upon receiving a command from the master, it would also send the state of the LED luminaries, which are on and off. The components were connected to the NodeMCU ESP32 board as shown in Figure 4 and interfaced with the SX1278 LoRa module supplied with 3.3 volts of DC power. The LED driver was also connected to the microcontroller unit, which controls the LEDs. At the same time, the LED driver is also connected to an AC power source, which is the main power source of the LED.

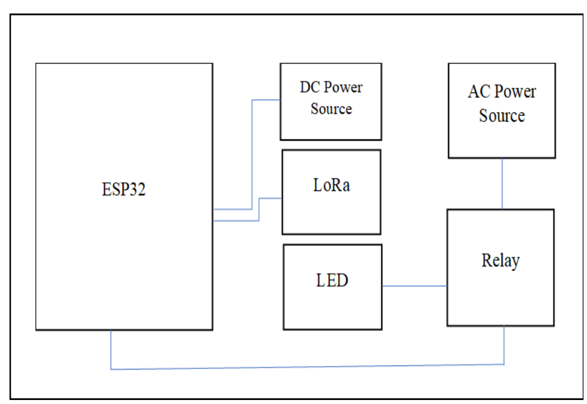

Fig. 4. Schematic Diagram of the Master and Slave Units

The master unit serves as the brain of the entire street lighting system. It hosts the IoT platform and allows communication between slave units. The master

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unit also provided access, device management, and application and service analysis using a module for unified access to the smart street lighting system.

The master and slave units are integrated into the same private network.

Testing

To assess the system's functionality and ensure that all objectives are met, a series of tests were conducted.

Distance Test in an Open Field: This test is designed to determine the maximum distance the network can reliably cover before experiencing a loss of connection. It seeks to maximize the system's connectivity under optimal conditions.

Distance Test Behind Obstacles: In this test, the network's performance will be evaluated when the master unit is positioned behind obstacles such as walls or inside buildings. The objective is to assess the network's ability to maintain a stable connection under less favorable conditions. These tests are instrumental in gauging the system's resilience and reliability across various real-world scenarios. They provide critical insights into its performance and ensure its readiness for deployment.

Mathematical Equations and Computations

To facilitate the tests, the formula for calculating kilowatthours (kWh) will be employed. This formula will be complemented with both real-world and forward-looking assumptions, including the expected duration for which a streetlight will remain powered on. The formula for calculating kilowatthours within a specific timeframe is given as:

$$kWh = \frac{W*h}{1000} \qquad (1)$$

Where, W represents the power rating, and h signifies the number of hours the streetlight operates daily. This formula aids in estimating energy consumption, contributing to a comprehensive assessment of the system's performance. An additional equation to be employed is the one for computing luminous efficiency:

$$luminous\ efficiency = \frac{lumens}{power\ rating} \qquad (2)$$

In this equation," Lumens" represents the luminary's output luminance, while" Power Rating" signifies the amount of power the luminary could potentially consume within an hour.

Results and Discussion

System Features

The system features are as follows: Powered by LED luminaries, Web-server monitoring, and, Automatic and Manual Remote Switching.

The Smart Street Lighting System with Webserver Interface uses efficient LED luminaries for lighting which produces ahigh amount of lumen at a relatively low power. To be precise, the LED that was used is a 35W with 4200 lumens output and a correlated color temperature is 6500 K. By far, the proponents concluded that the lighting of the system is good.

According to the DOE, luminaries must have at least a luminous efficiency of 100 lumens per watt, 4000 K correlated color temperature, and 4000 lumens (DOE, 2017). To solve for the luminous efficiency, simply divide lumens over watt which is (4200 lumens)/(35 watts) and the answer would be 120 lumens/watts. See Equation 2. Meanwhile, the correlated color temperature refers to the color temperature of the light that the luminaire produces. For example, a 4000 K CCT's (Correlated Color Temperature) output is orange light while 6500 is white light.

The system would have a clock-based automatic switching capability. The luminaries will be powered on and off at 6 pm and 6 am, respectively. The state of the LED could be seen on the web server. However, that is limited only to the state at which the system perceives and if lost due to some reasons, example: it was stolen or defective, it is not included. Along with the monitoring of the LED states, the web server could provide convenience to let the users manually turn on or off the luminaries in case of emergencies.

Distance Test

During the test, the luminaries were removed to provide convenience during the testing phase. The master and the slave units were connected to a dc power source to make sure that either of them could be moved for distance test.

Distance Test in an Open Area: From one meter to one hundred meters, the connection was stable. But when it reached the distance of one hundred one meters, the connection was lost. The maximum height of the master and the slave during the test is six feet. See Table 1 for more details. The result of the test made the

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proponents conclude if the height of the distance test was correct or not because as what was written on the datasheet of the LoRa module, the maximum distance should reach about five kilometers.

Table 1. Results of the distance test on the luminaires conducted in open space to determine the stability of the LoRa connection and the maximum distance it can handle

Distance (m)	Connection
27	Stable
29	Stable
34	Stable
40	Stable
47	Stable
58	Stable
70	Stable
100	Stable
101	Lost

Distance Test Behind the Wall: Starting at one meter until fifty-one meters, the connection is stable. However, at fifty-two meters, the connection is lost. There is no syncing of data between the two units. The master unit is twenty-six feet off the ground while the slave unit is 4 feet off the ground. This time, the distance was halved. But it is rather understandable since there is a wall blocking the signal. However, the distance compared to what was claimed in the datasheet of the LoRa is still unreasonable. Nevertheless, this is due to the height at which the units were placed. The higher the height, the wider the coverage. Results are shown in Table 2.

Table 2. Results of the distance test on the luminaires conducted behind the wall to determine the stability of the LoRa connection despite signal blockage and the maximum distance it can penetrate.

Distance (m)	Connection
7	Stable
8	Stable
10	Stable
12	Stable
18	Stable
27	Stable
38	Stable
51	Stable
52	Lost

Power Efficiency

Table 3 shows the projected power consumption of LED (Light Emitting Diode) and HPS (High-Powered Sodium) luminaires. It could be seen that the consumption of HPS is twice higher than the LED. Note that the two luminaires, although they have different power ratings, are producing the same amount of lumens, 4200 lm. If their luminous efficiency were to be calculated, the HPS, with the power rating of 70W and producing 4200lm, has an efficiency of 60lm/W. Compared to the LED, which is 120lm/W, the gap is big. Meanwhile, the data in the projected power consumption was from solving the kilowatt-hour used. The product of the power rating and the number of hours divided by 1000 to convert it to kW and then multiplied to the number of hours that the LED was used. See Equation 1.

Table 3. Power consumption comparison of light-emitting diode (LED) and high-powered sodium (HPS) luminaires tested at 12, 24, 168 and 740 hours.

Power Rating	12 hours	24 hours	168 hours	720 hours
70W HPS	0.84 kWh	1.68 kWh	11.76 kWh	50.4 kWh
35W LED	0.42 kWh	0.84 kWh	5.88 kWh	25.2 kWh

CONCLUSION AND RECOMMENDATION

From the tests and discussions, the Smart Street Lighting System with Webserver Interface is concluded as working properly and as intended. By deploying LED-powered streetlights with remote on/off switching and monitoring capabilities, the project successfully addresses the challenge of excessive power consumption due to outdated luminaires. Utilizing the NodeMCU ESP32 microcontroller unit in a master-slave network configuration via the LoRa module enables efficient remote control and monitoring, thereby enhancing both energy efficiency and operational convenience.

However, there is still plenty of room for improvement. More slave units and master units could be added to the network along with sensors such as LDR, and ultrasonic sensors to incorporate luminance control. Cameras could also be installed for better real-time vision-based monitoring. The system's recommendations for scalability and enhancement further underscore its potential for future development. Incorporating data

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logging, luminance control, real-time vision-based monitoring through cameras, and the addition of master units and luminaries can enhance the system's functionality. Moreover, employing a secure cloud server is advised to expand remote switching capabilities beyond the access point provided by the master unit. Ultimately, the Smart Street Lighting System with Webserver Interface is poised for integration into smart cities through a decentralized network, promising a sustainable and technologically advanced urban lighting solution.

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