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Design And Construction of Public Street Lighting System Based on Internet of Things

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ABSTRACT
This study examines the design and implementation of an Internet of Things-based Public Street Lighting system that integrates WLAN communication and high-quality system design to improve real-time performance, energy efficiency, and dini detection. The architecture system uses an ESP32 microcontroller for control, a LoRa E220 for wide-band data transmission, and a WLAN for local communication. The MQTT protocol is used to transfer data between nodes, gateways, and dashboards that are connected by Node-RED. The results of WLAN testing show that the transmission time between 10 and 20 seconds in a 1000-meter range, and even under non-line of sight conditions, can be achieved. The systematic design process and the results of various work tasks are discussed, providing insight into the scalability and effectiveness of the system in reducing energy consumption and increasing operational efficiency.

INTRODUCTION

Roads are essential elements in both urban and rural areas, serving as connectors between locations. Street lighting at night is crucial for the safety of road users and pedestrians. Lack of adequate lighting can lead to higher rates of accidents, crime, and theft, making people feel unsafe and reluctant to use the roads at night. Street lighting systems (PJU) are employed to enhance nighttime traffic safety and comfort, helping drivers see the road better (Tansri et al., 2020). The main goal is to provide sufficient lighting to reduce accidents and criminal activity. However, managing PJU efficiently is often challenging, especially when it comes to monitoring and controlling street lights scattered across various locations (Hidayatullah et al., 2022).

Currently, PJU uses conventional lights to save energy (Amri et al., 2018). However, the large number of installed street lights operating at maximum brightness throughout the night still leads to energy wastage (Buwana et al., 2017). One of the main issues is suboptimal energy efficiency, as conventional street lights are often left on at full brightness all night without any adaptive mechanism based on environmental conditions or real needs. This results in significant energy wastage.

The current monitoring and control of PJU is inefficient, relying on reports from road users or routine inspections by field officers, which is time-consuming and costly, often leading to delayed detection of issues. Previous studies have developed solutions for monitoring and controlling PJU. The study by Yudhi et al. (2024) implemented LoRa and ESP32 for an automated LPJU system, while the study by Taufik et al. (2021) developed an IoT-based monitoring system using the MQTT protocol and LoRa.

However, these studies have limitations, such as suboptimal use of LoRa modules and the lack of PIR sensors for motion detection. The latest research addresses these shortcomings by using the more accurate ZMCT103C current sensor, a 2000 Watt dimmer for lighting control, and the LoRa E220-900T30D for more reliable long-distance communication. The system is also capable of monitoring lamp status, detecting abnormal conditions, and controlling lighting with greater precision.

LITERATURE REVIEW

2.1 Public Street Lighting

Public Street Lighting is an essential facility that provides sufficient light, reduces the risk of accidents, and combats crime on the road. According to the National Standardization Agency (BSN SNI 7391:2008), street lighting in urban areas has several functions, namely creating contrast between objects and road surfaces, assisting navigation for road users, increasing the safety and comfort of road users (especially at night), supporting environmental security, and beautifying the road environment (Muhammad Yusril et al., 2021)

2.2 Internet of Things

The Internet of Things (IoT) is a technological innovation that has the potential to be one of the major changes in the future. The IoT concept aims to utilize continuous internet connectivity to integrate physical and virtual objects. By utilizing the ability to capture data 8 and communicate. IoT allows physical objects in the real world to interact with each other via networks and the internet. (Sasmito, G.W. and Wijayanto, S., 2020)

2.3 Raspberry Pi

Raspberry Pi is a single-board computer the size of a credit card. This Raspberry Pi is able to function like a regular computer and runs the Raspbian operating system with an ARM11 processor with a speed of 10700MHz. There are two types of Raspberry Pi, namely type A and B, which differ in memory capacity: type A has 256MB while type B has 512MB. Data storage on this device uses an SD card instead of a hard disk. Raspberry Pi is also equipped with two USB ports, an HDMI connector, and an ethernet port. For power, RaspPi requires a voltage of 5V with a minimum current of 700 mA for type B and 500mA for type A. (Kurniawan & Fani, 2017)

2.4 ESP-32

The ESP32 microcontroller is an integrated SoC (System on Chip) microcontroller equipped with WiFi 802.11 b/g/n, Bluetooth version 4.2, and various peripherals. ESP32 is a fairly complete chip, there is a processor, storage and access to GPIO (General Purpose Input Output). ESP32 can be used as a replacement circuit on Arduino, ESP32 has the ability to support direct connection to WI-FI (Agus Wagyana, 2019)

2.5 LoRa

LoRa (Long Range) is a wireless communication system for IoT, offering long-distance communication (> 15 km in remote areas) and low power (5-10 years). (I. P. Sari and T. Hariyanto, 2020). LoRa has a long range, low power consumption, low data rates, and secure data transmission. LoRa can be used for public, private, or hybrid networks so that it can achieve a greater range than cellular networks. LoRa technology can be easily integrated with existing networks and can be applied to low-cost, battery-operated Internet of Things (IoT). (M. Liandana, 2019)

2.6 Relay

Relay is an electronic component that functions to disconnect or connect electricity indirectly. Relays are also commonly referred to as electromechanical or electromechanical components consisting of two main parts, namely coils or electromagnets and switch contacts or mechanical. Relay components use electromagnetic principles as switch contact drivers, so that by using a small or low power electric current, it can conduct electric currents that have higher voltages. (Hudan et al., 2019)

2.7 PIR

PIR sensors are devices used to detect infrared radiation. This sensor is passive, meaning it does not emit infrared light but only receives radiation from the surrounding environment. As the name implies, "Passive", this sensor only responds to energy from passive infrared radiation possessed by objects being detected, which are usually the human body. (Alfazri, 2015).

2.8 Photosensitive Light Intensity Sensor

Photosensitive Light Intensity Sensor is a three-pin module that measures light intensity using an LDR and an LM393 voltage comparator. This sensor produces a digital output that can be read by a microcontroller. The output value will be HIGH if the light intensity is below the threshold specified by the user via the trimpot. This module is equipped with two indicator LEDs, one to indicate the power supply and the other lights up when the light intensity is lower than the threshold. (T. Suryana, 2021)

2.9 Current Hall Effect ZMCT103C Sensor

The hall effect phenomenon was discovered in 1879. A certain amplifier is needed to transform the current signal into a voltage signal. (Chang, Lin, & Chen, 2004). The hall effect sensor will produce a voltage that is proportional to the strength of the magnetic field received by the sensor. This hall effect sensor consists of a silicon layer that functions to flow electric current. With this method, the current that is passed will be read on the voltage magnitude function in the form of a sinusoidal wave. (L. Umanand S.R. Bhat, 1992). Zeming Company's output current sensor is ZMCT103C consists of a fully integrated hall effect current sensor IC circuit that provides a low noise and highly accurate output voltage signal, proportional to the measured AC or DC current. Used in a variety of applications, including automotive inverters and electronic power steering (EPS) systems, inverters for industrial consumers.

2.10 Dimmer Light AC 2000W

Dimmer is an electronic circuit that modifies the form of a pure AC signal into a chopped signal so that the output power can be adjusted. This cutting of the AC signal is useful as a light dimmer, slowing down the motor, regulating heating and others. (P. M.-O. and Instrument, 2018)

2.11 Incandescent Lamps

Incandescent lamps work by incandescence, namely the current flowing to the filament when the incandescent lamp is turned on. The current flowing through the wire will cause the connecting wire to change. As a result, free electrons will appear, which move from the negative pole (-) to the positive pole (+) and constantly hit the atoms in the filament. The energy generated by the impact will cause the atoms to vibrate. As a result, each electron in the atom vibrates causing the atom to expand to a higher temperature. When the energy has returned to its normal level, an electron will release excess energy in the form of photons. Photos in this case cannot be seen with the naked eye. However, if the temperature is up to 2,200°C, the light will look like the incandescent lamp that we use every day. (B. Priyandono, 2013)

2.12 MQTT

The Message Queue Telemetry Protocol (MQTT) protocol is a protocol that is often used in IoT applications (Rochman et al., 2017). MQTT is a lightweight protocol, sending messages with a small header of 2 bytes. MQTT works using the publish/subscribe concept. The device that carries out the publish process is called the publisher, while the one that carries out the subscribe process is called the subscriber. MQTT is publish/subscribe based with a message broker as a bridge between publisher and subscriber (Bandyopadhyay, 2013).

2.13 Node-RED

Node-RED is a tool for building Internet of Things (IoT) applications with a focus on simplifying the 'wiring together' of code blocks performing tasks. Provides a browser-based editor that makes it easy to connect flows using various Nodes in the palette that can be applied to the process time in one click. Node-RED consists of a node-based runtime. (M. Tim J, 2016)

METHOD

3.1 System Design

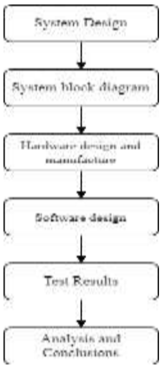

Fig. 1 Design Systems

The image illustrates the design process of a street lighting system (PJU) that consists of several sequential stages. It begins with system design, where the basic concepts and system specifications are formulated. Next, a system block diagram and flowchart are created to visualize the flow of data and processes within the system. The following stage is the hardware design and development, involving the creation of physical components such as sensors and nodes. After that, software is designed to develop the software that will control and manage the street lighting system. Once the hardware and software are ready, the system is tested during the testing phase to ensure all components function properly. Finally, the test results are analyzed, and conclusions are drawn during the analysis and conclusion phase, evaluating the overall performance of the system.

3.2 Block Diagram

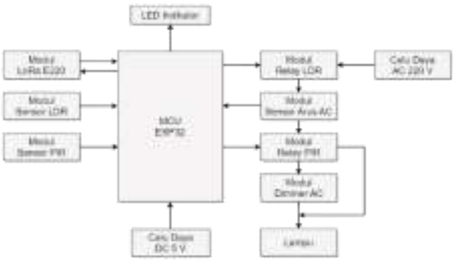

Fig. 2 Block Diagram Node

The street lighting system (PJU) consists of two main parts: the node, which sends data, and the gateway, which receives data. The node collects information from the LDR sensor, which detects light intensity, and the PIR sensor, which detects human or vehicle movement. This data is processed by the ESP32 microcontroller, acting as the main processing unit. Based on the received data, the ESP32 controls the streetlights through relay and dimmer modules, allowing the lights to turn on or off automatically and adjust brightness for energy efficiency.
The LoRa E220 module enables long-distance communication between the node and the control center, particularly in areas with limited network coverage. A 5V DC power supply is used to power electronic components like sensors and the MCU, while a 220V AC power supply is used for devices requiring higher voltage, including the streetlights. The system

is also equipped with relay modules and current sensors to measure and control the electrical flow, ensuring the devices operate safely.
Overall, the system operates efficiently through the interaction of input components (sensors), processing (ESP32), and output (light control and relay). LED indicators provide visual feedback on system status, while all components receive stable power from the appropriate power supplies.

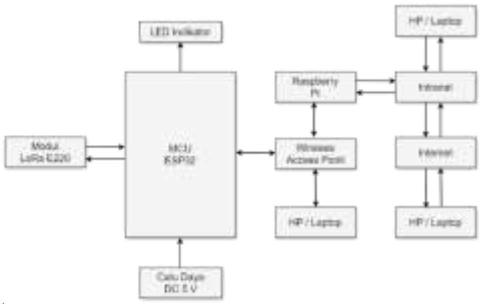

Fig. 3 Block Diagram Gateway

The gateway system block diagram in PJU illustrates the architecture connecting the main components. The LoRa E220 module supports long-range wireless communication with nodes, while the ESP32 MCU functions as the primary controller, processing data and managing outputs. The Raspberry Pi acts as a mini-server, connecting the system to the intranet and internet, and sending data to the cloud. A wireless access point enables wireless connectivity, and the LED indicator shows the system's status. The intranet and internet provide local and remote access to the system, allowing operators to monitor and control street lighting from devices like smartphones or laptops.

3.3 Hardware and Software Design

The hardware design of the LoRa and IoT-based street lighting system involves key components such as PIR sensors, LDR sensors, ESP32, dimmers, and lamps. With a structured design, data from the sensors can be processed by the ESP32 to adjust lamp brightness via the dimmer, helping to save energy and extend lamp lifespan. This system also enables remote monitoring and control of street lights, enhancing energy efficiency, as well as ensuring safety and comfort for road users.

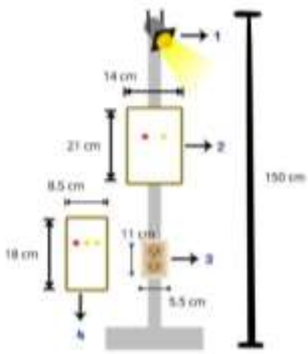

Fig. 4 Hardware Design

Meanwhile, the software design in this project aims to create an integrated and efficient IoT system by utilizing technologies such as Node-RED, MQTT, E-byte LoRa, and Raspberry Pi.

RESULT

4.1 Testing Network Connection to Raspberry using WLAN

The connection test to the Raspberry Pi via the WLAN network using IP 10.30.4.11 aims to assess the stability and speed of the local connection. Ping results show that each ICMP packet has a payload size of 32 bytes, with 64 hops remaining (TTL=64), indicating minimal router traversal. This test is vital to ensure the Raspberry Pi operates effectively as the system's control center, with the results covering key aspects such as data transmission speed, packet loss, and overall connection quality, which are essential for the system's daily performance.

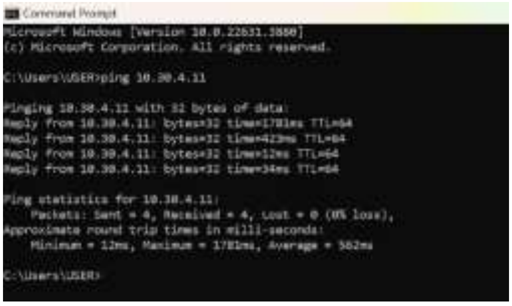

Fig. 5 Testing Network Connection to Raspberry using LAN

4.2 Testing Data Delivery on Dashboard Through WLAN Network

The test was conducted to measure the data transmission time displayed on the dashboard over a WLAN network using a laptop. The testing involved observing changes in values on the dashboard, including changes in node device statuses such as light status, light control, and dimmer control. The test was performed three times on both node 1 and node 2.

A. Node 1

Table 1
Data Delivery Time On Dashboard

Node 1 Data Delivery Time on Dashboard	
24.86 s	23.57 s
19.32 s	11.00 s
25.74 s	13.35 s

B. Node 2

Table 2
Data Delivery Time On Dashboard

Node 2 Data Delivery Time on Dashboard	
36.01 s	20.55 s
31.46 s	22.96 s
36.28 s	20.72 s

DISCUSSION

The use of WLAN for real-time communication is essential to ensure that the system can operate efficiently in an urban environment. WLAN was chosen because of its relatively high data transfer rate in local range, as opposed to LoRa, which is used for long-distance communication with lower bandwidth. The Ping results in Figure 1 show that each ICMP packet has a payload size of 32 bytes, with 64 hops remaining (TTL=64), indicating minimal router traversal. This testing is essential to ensure that the Raspberry Pi operates effectively as the central control of the system, with results covering key aspects such as data transmission rate, packet loss, and overall connection quality, which are critical to daily system performance.

The data transmission time testing displayed on the dashboard over the WLAN network was conducted on two nodes, namely node 1 and node 2, with the results summarized in Table 1 and Table 2. For node 1, although the programmed data transmission time was set to 10 seconds, the test results showed significant variations, ranging from 11.00 seconds to 24.86 seconds. While some tests recorded times closer to the programmed time, the variation remained considerable. The longer-than-expected transmission times indicate a delay in data delivery through the WLAN network. Possible causes for this delay could include network quality, signal interference, or device performance.

Similarly, the test results for node 2, summarized in Table 2, revealed that even though the programmed data transmission time was set to 20 seconds, the recorded times varied from 20.55 seconds to 36.01 seconds. As with node 1, some tests showed results closer to the programmed time, but the variation remained significant. This also indicates a delay in data transmission, where factors such as WLAN network stability and device conditions may contribute to the variation in transmission times.

CONCLUSION

This study tested the stability of the WLAN connection on Raspberry Pi within an IoT-based street lighting system, focusing on data transmission times. The results showed significant variations, with transmission times ranging from 11 to 24.86 seconds for node 1 and from 20.55 to 36.01 seconds for node 2. These delays were caused by factors such as network quality, signal interference, and device performance, indicating that the system still faces challenges in achieving real-time data transmission efficiency. Recommendations from the study include improving the WLAN network to reduce interference and enhance stability, optimizing both hardware and software to ensure transmission times are closer to the expected duration, and considering alternative network technologies or additional communication protocols to improve efficiency and reduce time variations. Further testing is also advised under various environmental conditions to ensure the system performs optimally in diverse real-world scenarios.

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