Monitoring and Controlling Ground D Toilet Area Lighting at Bedengan Tourism Park Malang Using Wireless Sensor Network

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***Abstract*— Electric lighting in Taman Wisata Bedengan Malang has a crucial role in supporting visitor comfort, especially at night. To overcome this problem, this research proposes a monitoring and management system for power, voltage, and security of public street lighting equipment based on wireless sensor network (WSN) with additional energy support from solar panels. The purpose of this research is to design and implement a WSN-based street lighting system, where the lights will dim automatically when no one passes by and turn on fully when someone passes by. This system uses ESP32 components, Arduino LGT8F328P, LoRa module type E220-900T22D, PIR sensor, PZEM 004-T, AC Dimmer, and Real Time Clock (RTC). The research aims to design and make WSN-based public street lighting where the lights will dim if no one passes by, and will turn on 100% when someone passes by. This research uses ESP32, Arduino LGT8F328P, LoRa module type E220-900T22D, PIR, PZEM, AC Dimmer, and Real Time Clock. The results show that the PZEM sensor has a reading accuracy of 99.995%. The maximum distance of data transmission by the LoRa module reaches 160 meters. Charging by the solar panel for 6 hours is able to reach the full capacity of the battery of 100 Ah, with a battery life of 386 hours (discharge of 0.2588 Ah). System throughput was recorded at 825 Kb/s, with packet loss of 0.996% and average delay of 0.585 seconds. The measurement difference between the PZEM sensor and the avometer is 0.995%. In addition, testing the system through the website using the QoS method resulted in a throughput of 82.5%, packet loss of 0.996%, and average delay of 0.585 seconds. The lighting system can operate in two modes, namely manual and automatic modes.**

Keywords*— *LoRa, Microcontroller, PIR Sensor, PZEM 004-T, Street Lighting, Wireless Sensor Network.

I. INTRODUCTION

There is research that has made a street light monitoring system using the ESP 32 Microcontroller and Telegram BOT Fire, the results of his research are, if one of the lights is damaged, it will provide information on damage or malfunction via text message to the BOT Telegram responsible person who has been registered in the system. However, more than one LDR sensor is needed to make the lights turn on automatically. This tool can be easily connected anywhere as long as there is Wi-Fi. Where we know in this sophisticated era the internet is something that is very difficult to separate from everyday life [1].

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Along with the development of computer and network applications, many are using it in various fields, one of which is the Wireless Sensor Network (WSN) [4]. Currently, WSN has experienced a significant increase in popularity over the past few years due to its various applications such as environmental monitoring, healthcare systems, automation, and military operations [5][6]. WSN can function autonomously or coordinate with other devices to perform complex tasks using LoRa as the means of transmitting the data [7]. LoRa (Long Range) has emerged as the dominating advanced solution in connecting connectivity between Internet of Things (IoT) devices today. LoRa's uniqueness lies in its ability to provide very wide and efficient wireless connectivity for a wide variety of IoT devices. LoRa has become a key element in the transformation to an increasingly connected and intelligent society [8]. Application of a waiting line–based system in an urban public service environment, which supports the relevance of implementing technology-driven monitoring and control systems to improve efficiency and management in

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public facilities, such as the lighting system in the Ground D toilet area at Bedengan Tourism Park [9].

Referring to previous research, this research aims to make it easier for tourist park managers to control and monitor lights [10][11]. This lamp is solar powered by implementing a street lighting monitoring system in the toilet area in front of Ground D while creating a data logger from the street lighting itself using LoRa module communication type E220-900T22D. Where there are 2 nodes in this system, namely the sensor node and the master node [12]. Both nodes have several components such as the ESP32 microcontroller, LoRa module, and there are several sensors, namely the PIR sensor to detect people [13], the AC Dimmer adjusts the brightness of the lights to 100% if someone passes by and adjusts the brightness to 30% when people have moved away from the lights for energy savings so that the brightness of the lights is not always 100%, PZEM 004-T to measure the voltage and current flowing in the load, and RTC to detect the time the lights are on and off [14][15]. Later, there will be notifications on the web if the lights experience interference.

II. METHOD

A. Research Stages

The stages of research are made to detail each stage of making the tool until testing the sensors paired in this system to match the power requirements of street lighting based on efforts to save electricity in this study, the following are the stages in this study as shown in Figure 1.

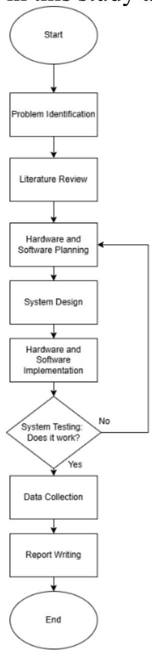

Figure 1. Flowchart of research stages

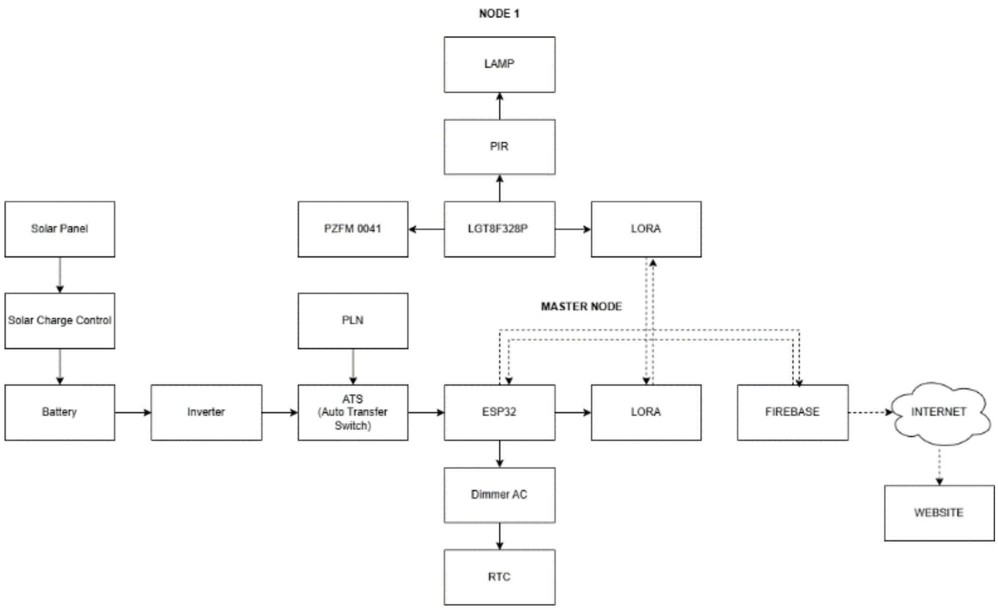

Figure 2. Block diagram

B. Block Diagram

The block diagram illustrates the overall architecture of the proposed street lighting monitoring and control system based on a Wireless Sensor Network (WSN). This diagram provides a clear overview of how each hardware component interacts and how data flows within the system, starting from energy generation to data transmission and control. The system consists of a solar power supply, sensing units, a microcontroller as the main processing unit, communication modules, and a monitoring platform. By using a block diagram, the relationship between power management, data acquisition, wireless communication, and control mechanisms can be clearly understood before proceeding to system implementation.

The following is an explanation of Figure 2:

1. Solar Panels and Energy Conversion
- Solar Panels: Sunlight is captured by solar panels, which consist of photovoltaic cells that convert light into direct current (DC) electricity.
2. Storage and Charging

- Battery: The DC electrical energy generated from solar panels is stored in batteries, which are generally lithium-ion or lead-acid batteries.
- Solar Charge Control: Ensure that the battery is not subjected to overcharging or deep discharging, which can shorten the life of the battery.

3. Energy Conversion from DC to AC

- Inverter: DC electricity from the battery is converted into alternating current (AC) electricity by an inverter.

4. Energy Regulation by Auto Transfer Switch (ATS)

- Auto Transfer Switch: If a disruption or power outage is detected, the ATS automatically switches to using electricity from the solar farm without manual intervention.

5. Street Lighting and Sensor Control

- PZEM Sensor: Measuring electrical parameters such as voltage, and current used by lighting lamps.
- Real Time Clock (RTC): Set the system to turn lighting on and off at set times, for example, lights will turn on at night and off in the morning.
- PIR Sensor: When the PIR sensor detects movement, the lighting system can adjust the light intensity or turn on the lights in certain areas for energy efficiency.
- Dimmer AC: Dimmers control whether lights should be dim or bright, which also contributes to energy savings.

6. Data Communication by LoRa

- LoRa on Node 1: Used for long-range wireless communication with low frequency (433 MHz). Data from sensor nodes, such as light condition and energy consumption, is sent to the master node via the LoRa (Long Range) communication protocol.
- LoRa on Master Node: Receives data from sensor nodes and acts as a control and monitoring center. This data is then stored and processed for further decision-making.

7. Data Storage and Integrity with Website

- Firebase: Data collected by the master node, such as lamp status, energy consumption, and sensor conditions, are stored in Firebase. The Bedengan Tourism Park manager can access this data through the website to monitor and control the lighting system in real-time.

C. Flowchart System

The system flowchart describes the operational sequence of the street lighting system from initialization to normal operation. This flowchart is used to represent the logical steps executed by the system in controlling and monitoring the lighting process. It begins with system initialization, followed by sensor data acquisition, decision-making based on predefined conditions, and execution of control actions. The flowchart helps visualize how the system responds to environmental conditions, time settings, and user commands, ensuring that the system operates efficiently and reliably in real-time conditions.

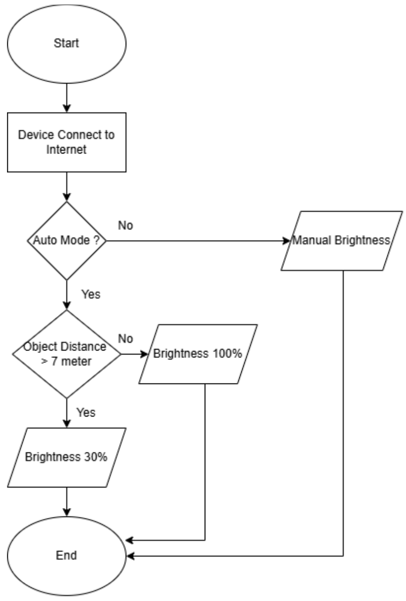

Figure 3. Flowchart system

In Figure 3 is a flowchart of the WSN-based street lighting system website with the following explanation:

1. First the device is connected to the internet.
2. Selection of auto mode and manual mode.
3. In auto mode, there are 2 controlling and monitoring options that can be activated. The light intensity of the lamp will switch automatically according to the distance of the object detected by the PIR.
4. Distance less than 7 meters, Light on light 100%.
5. Distance more than 7 meters, Light on 30% light.
6. In manual mode, there are also 2 controlling and monitoring options that can be activated. Users can select 3 control systems, namely on/off lights, and manually setting the intensity of the light on the lamp.
7. Finish

D. Flowchart Website

The website flowchart explains the workflow of the web-based monitoring and control platform used by the system manager. This flowchart outlines how users interact with the website, starting from accessing the platform, viewing sensor data, selecting control modes, and sending commands to the lighting system. The flowchart is important to illustrate how data received from the WSN nodes is processed and displayed on the website interface, as well as how user inputs are transmitted back to the system for execution.

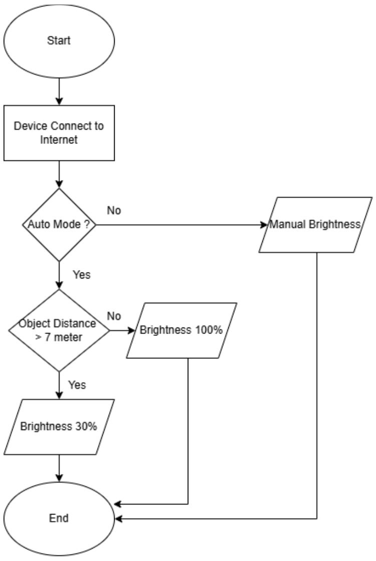

Figure 4. Use case diagram

Figure 4 is a flowchart of the WSN-based street lighting system website with the following explanation:

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III. RESULTS AND DISCUSSION

A. System Design and Results

This subchapter describes the tools that have been designed, developed, and successfully implemented in the street lighting system using WSN-based solar panels at Bedengan Tourism Park Malang. The system integrates renewable energy sources, wireless communication, and web-based monitoring to provide an efficient and reliable lighting solution for public areas. The implementation results demonstrate that the system is capable of monitoring electrical parameters, controlling lighting operations, and transmitting data wirelessly over a certain distance.


Figure 5. Solar panel pole placement

The specifications of the solar panel mast results in Figure 5 are described as follows:

- The poles are made of galvanized iron and are equipped with brackets to securely support the solar panels, ensuring durability and resistance to outdoor environmental conditions.
- The panel box is constructed using fiber material, which provides protection for electronic components while maintaining a lightweight structure.
- The solar panel used in this system is a monocrystalline type with a maximum power output of 200 Wp, chosen for its high efficiency and suitability for outdoor solar energy harvesting.

These specifications were selected to ensure that the solar panel system operates reliably in outdoor environments while providing sufficient energy to support the street lighting system. In addition, the use of durable materials helps minimize maintenance requirements and extends the operational lifespan of the system.

Figure 6. Lamp pole placement

Figure 6 illustrates the physical structure and placement of the system components:

- The pole has a height of 1.5 meters, which is considered adequate for illuminating the surrounding area.
- The sensor node is placed at the top of the pole and positioned facing downward to optimize environmental data collection and system monitoring.
- The lamp is installed below the node to ensure effective light distribution while maintaining safe and efficient operation.

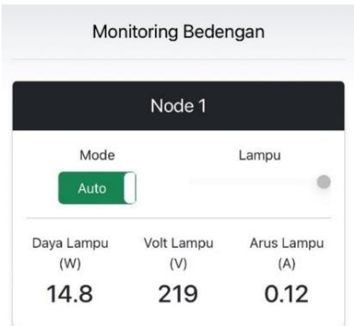

Figure 7. Auto mode website display

Figure 7 shows the website interface that allows the manager to control and monitor the lighting system. The manager can select an automatic mode, where the platform controls the device based on predefined parameters such as time and sensor values. For example, when the system time reaches 5:00 PM, the lights will automatically turn on without manual intervention. In addition, a manual control button is provided, allowing managers to directly control the lighting system if the automatic mode does not function as expected or if immediate adjustments are required. This dual-mode control enhances system flexibility and reliability in real operational conditions.

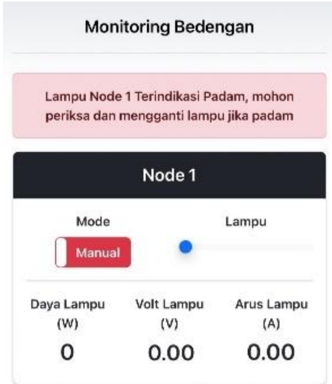

Figure 8. Manual mode website display

This manual button feature allows managers to control the lights when the automatic mode is not working.

TABLE I
TESTING THE PZEM SENSOR AT 100% LIGHT

No	P= Power A= Ampere	V Value of PZEM On The Website	Avometer V Value	Error (%)
1	P= 35.5 W A= 0.17 A	207 V	207 V	0%
2	P= 35.1 W A= 0.17 A	206 V	206 V	0%
3	P= 35.3 W A= 0.17 A	206 V	207 V	0.485%
4	P= 35.2 W A= 0.17 A	206 V	206 V	0%
5	P= 35.7 W A= 0.17 A	208 V	208 V	0%
		Average		0.097%

As shown in Table 1, the PZEM sensor was tested under 100% light intensity conditions to evaluate its voltage measurement accuracy. The comparison between the voltage values displayed on the PZEM website and those measured using an avometer indicates very small differences, with most measurements showing 0% error and a maximum error of only 0.485%. The average error obtained from all measurements is 0.097%, demonstrating that the PZEM sensor provides highly accurate voltage readings under full lighting conditions.

As shown in Table 2, the PZEM sensor performance was also evaluated under reduced lighting conditions of 30%. The results show that the voltage readings from the PZEM sensor are consistent with the avometer measurements, with all test points producing 0% error. This indicates that changes in lighting conditions do not significantly affect the accuracy of the PZEM sensor, confirming its reliability in both high and low illumination environments.

TABLE II
TESTING THE PZEM SENSOR IN 30% LIGHT

No	Power and Current	Voltage (V)		Error (%)
		PZEM Value	Avometer Value	
1	P = 11.9 W C = 0.12 A	210 V	210 V	0%
2	P = 11.8 W C = 0.05 A	209 V	209 V	0%
3	P = 11.9 W C = 0.05 A	210 V	210 V	0%
4	P = 11.7 W C = 0.05 A	208 V	208 V	0%
5	P = 11.8 W C = 0.05 A	209 V	209 V	0%
Average				0%

TABLE III
LORA DISTANCE TESTING

No	Base Station		Data Input Point		Distance	Status
	Latitude	Longitude	Latitude	Longitude		
1	-7.939 7439	112.529 3179	-7.939 7220	112.529 4439	20	Message Received
2	-7.939 7439	112.529 3179	-7.939 7220	112.529 7219	40	Message Received
3	-7.939 7439	112.529 3179	-7.939 7220	112.529 9998	60	Message Received
4	-7.939 7439	112.529 3179	-7.939 5912	112.530 1551	80	Message Received
5	-7.939 7439	112.529 3179	-7.939 4441	112.530 2781	100	Message Received
6	-7.939 7439	112.529 3179	-7.939 4520	112.530 4250	120	Message Received
7	-7.939 7439	112.529 3179	-7.939 4441	112.530 5561	140	Message Received
8	-7.939 7439	112.529 3179	-7.939 2950	112.530 7170	160	Message Received
9	-7.939 7439	112.529 3179	-7.939 1671	112.530 8330	180	Message Received

As shown in Table 3, the LoRa communication distance test was conducted to determine the maximum range at which data transmission remains reliable. The results indicate that messages were successfully received at distances ranging from 20 meters up to 180 meters between the base station and the data input point. These findings demonstrate that the LoRa module is capable of maintaining stable communication over relatively long distances, even when environmental factors and obstacles are present.

TABLE IV
QOS TESTING DAY 1

Experiment	Time	Total Package	Throughput (Kb/s)	Packet Loss (%)	Delay Average (s)
1	17.00	1250	213	2,8	0,103011
2	18.00	1312	425	3,963	0,087919
3	19.00	1342	136	2,60	0,187448
4	19.30	1178	470	2,122	0,365756
5	20.00	1084	247	0,992	0,546081
6	20.30	1032	204	1,162	0,634192
7	21.00	1084	666	2,398	0,34672
8	22.00	1115	236	0,179	0,769897
9	04.30	1260	275	1,269	0,123015
10	05.00	1116	229	0,627	0,56211

As shown in Tables 4 and 5, the Quality of Service (QoS) testing on Day 1 and Day 2 presents variations in throughput, packet loss, and delay across different time intervals. The throughput values fluctuate depending on network conditions, while packet loss remains relatively low in most experiments. The recorded delay values indicate acceptable communication performance, suggesting that the system is capable of supporting reliable data transmission during the first day of testing.

TABLE V
QOS TESTING DAY 2

Experiment	Time	Total Package	Throughput (Kb/s)	Packet Loss (%)	Delay Average (s)
1	17.00	1248	825	0,996	0,5851543
2	18.00	1126	387	1,687	0,396975
3	19.00	1131	253	5,658	0,139853
4	19.30	1128	394	1,329	0,394368
5	20.00	1208	877	0,579	0,2658919
6	20.30	1809	944	1,105	0,186796
7	21.00	1055	357	1,611	0,49985
8	22.00	1128	394	1,329	0,256378
9	04.30	1108	877	0,579	0,323036
10	05.00	1128	394	1,329	0,539821

IV. CONCLUSION

Based on the testing and data collection that have been conducted, it can be concluded that the PZEM 004-T sensor demonstrates a high level of accuracy in detecting lamp voltage, achieving a reading accuracy of up to 99.995%. The LoRa data transmission distance testing shows that the maximum reliable communication range reaches 160 meters, with tests carried out at Bedengan Tourism Park, Malang, where obstacles such as tall trees are present. Furthermore, a 200 Wp solar panel is capable of charging a 100 Ah battery to full capacity within 6 hours under sunny weather conditions, while during the discharge process with a power load of 0.2588 A per hour, the battery can operate for approximately 386 hours or 16 days without recharging. In addition, the lighting system can be controlled via a website using both automatic and manual modes, and it is also able to detect the lamp usage period, providing notifications when the lamp has reached the end of its operational lifespan so that timely replacement can be carried out.

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