Toilet Water Management in Bedengan Tourism Park Malang Using LoRa-Based Wireless Sensor Network

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***Abstract*— The availability of adequate public facilities at Bedengan Tourism Park, Malang, is essential, particularly toilet facilities that require a reliable water supply. Currently, toilet water distribution is channeled through a single main pipe divided into several outlets, resulting in limited water flow due to small pipe dimensions and the absence of a water storage reservoir. These conditions cause insufficient water availability, especially during peak usage. To address this issue, this study designs and implements a toilet water distribution system using a wireless sensor network integrated with solar energy. The proposed system utilizes an ESP32 microcontroller, HC-SR04 ultrasonic sensor, YF-S201 water flow sensor, and a LoRa E220-900T22D module for long-range communication. Experimental results show that the HC-SR04 sensor achieves an accuracy of 99.951%, while the YF-S201 water flow sensor reaches an accuracy of 97.943%. The maximum LoRa transmission distance achieved is 560 meters. Solar charging for 6 hours fully charges a 100 Ah battery, while the discharge rate is 0.236 Ah, allowing the system to operate for up to 423 hours. Quality of Service evaluation indicates a throughput of 82.5%, packet loss of 0.996%, and an average delay of 0.585 seconds. The system enables both automatic and manual pump control via a website and provides real-time monitoring of water volume and reservoir level.**

Keywords*— *ESP32, LoRa, Solar energy, Toilet water distribution, Water flow sensor, Wireless sensor network

I. INTRODUCTION

The availability of adequate public facilities is a crucial factor in supporting tourism activities, particularly sanitation facilities such as toilets. At Bedengan Tourism Park in Malang, toilet water distribution currently relies on a single main pipeline that branches into several toilet cubicles. This configuration results in insufficient water flow due to limited pipe capacity and the absence of a water storage reservoir, especially during peak usage periods [1], [2]. As a consequence, toilet water availability becomes unreliable and affects visitor comfort.

Water resource management in public facilities requires an efficient distribution system supported by real-time monitoring and control mechanisms. Several studies have shown that integrating sensor-based monitoring systems can significantly improve water usage efficiency and operational reliability in public infrastructures [3], [4]. In recent years, Wireless Sensor Networks (WSN) have gained increasing attention due to their ability to provide scalable, low-power, and autonomous monitoring solutions for environmental and utility management applications [5], [6].

One of the most widely adopted communication technologies in WSN is LoRa (Long Range), which offers long-distance data transmission with low power consumption, making it suitable for outdoor and remote-area deployments [7], [8]. LoRa-based systems have been successfully implemented in various applications, including water level monitoring, smart irrigation, and water distribution management [9]–[11]. Compared to conventional wireless technologies, LoRa provides better coverage and energy efficiency, particularly in areas with limited network infrastructure [12].

In addition to communication reliability, sustainable energy sources are essential to support continuous system operation. Solar energy has been extensively used to power WSN-based monitoring systems due to its renewable nature and suitability for outdoor environments [13], [14]. The integration of solar panels with energy storage systems enables uninterrupted operation even in locations without access to the main power grid [15].

Based on these considerations, this research aims to design and implement a toilet water management system at Bedengan Tourism Park Malang using a LoRa-based wireless sensor network powered by solar energy. The system consists of sensor nodes and a master node equipped with an ESP32 microcontroller, HC-SR04 ultrasonic sensor for reservoir water level detection, YF-S201 water flow sensor for monitoring water usage, and a LoRa E220-900T22D module for data communication. The proposed system enables real-time monitoring, automatic and manual pump control, and data logging through a web-based interface, with the objective of ensuring sufficient water availability and improving management efficiency [16]–[20].

II. METHOD

A. Research Methodology

This research adopts a Research and Development (R&D) approach to design, implement, and evaluate a toilet water management system at Bedengan Tourism Park, Malang. The R&D method is suitable for developing engineering systems that involve hardware–software integration and performance validation through experimental testing [5], [6]. The research stages include system requirement analysis, hardware and software design, system implementation, testing, and performance evaluation.

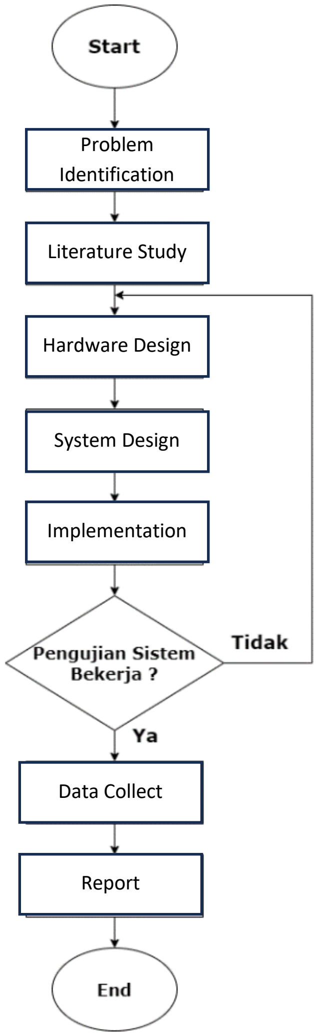

Figure 1. Research stages flowchart of the LoRa-based toilet water management system, illustrating the sequence from system analysis, design, implementation, testing, to performance evaluation.

B. System Architecture

The overall architecture of the proposed system is based on a LoRa-based Wireless Sensor Network (WSN) powered by solar energy. The system consists of two main components, namely the sensor node and the master node. The sensor node is installed near the water reservoir and toilet facilities, while the master node is located at the monitoring and control center. Each node uses an ESP32 microcontroller due to its low power consumption and suitability for IoT-based applications.

The sensor node integrates an HC-SR04 ultrasonic sensor to measure the water level in the reservoir and a YF-S201 water flow sensor to monitor water usage. Sensor data are transmitted wirelessly to the master node using a LoRa E220-900T22D module. The complete interaction between sensors, microcontroller, LoRa communication, power supply, and web monitoring is shown in the system block diagram.

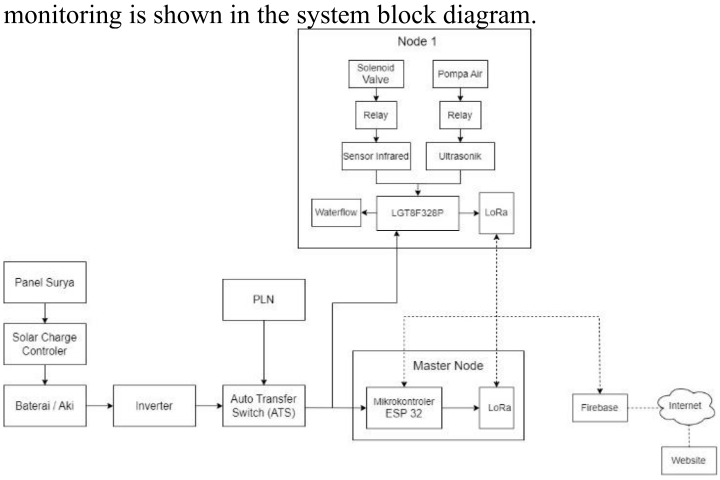

Figure 2. Block diagram of the toilet water management system at Bedengan Tourism Park Malang based on a LoRa wireless sensor network and solar power supply.

C. Solar Power System Design

To support autonomous operation, the system is powered by renewable solar energy. A solar panel is installed to convert sunlight into electrical energy, which is then regulated by a solar charge controller and stored in a 100 Ah battery. The stored DC power is converted into AC power using an inverter to supply the water pump and other system components. An Automatic Transfer Switch (ATS) is used to automatically switch the power source between the public electricity grid and the solar power system when required.

The physical installation of the solar panel used as the main power source is shown below.

Figure 3. Installation of the solar panel pole used as the main power source for the toilet water management system at Bedengan Tourism Park Malang.

The placement of the water reservoir and water pump is designed to ensure sufficient water availability and efficient distribution to toilet cubicles.

Figure 4. Placement of the water reservoir and water pump used in the toilet water distribution system at Bedengan Tourism Park Malang.

D. Water Pump Control Mechanism

The water pump operation is controlled automatically and manually through a web-based interface. In automatic mode, the ultrasonic sensor continuously monitors the water level in the reservoir. When the water level reaches a predefined threshold of 50 cm from the sensor, the system activates the relay to turn on the water pump. The pump is turned off automatically when the water level reaches 15 cm, indicating that the reservoir is sufficiently filled. This threshold-based control strategy ensures stable water availability while preventing overflow [10], [16].

Figure 5. Website Display Control Mechanism

In manual mode, system operators can directly control the pump through the website interface based on operational needs. This dual-mode control mechanism provides flexibility and improves system usability.

E. Data Communication and Web Monitoring

All sensor data and control commands are transmitted between nodes using LoRa communication and forwarded to a cloud-based database for data logging and visualization. The website interface allows users to monitor reservoir water level, water usage, pump status, and system performance in real time. Quality of Service (QoS) parameters such as throughput, packet loss, and delay are evaluated to assess communication reliability [18], [20].

Figure 6. Web Monitoring.

F. Performance Evaluation

System performance is evaluated through experimental testing, including sensor accuracy testing, LoRa communication range testing, solar charging and battery discharge testing, and QoS analysis. Sensor readings are compared with conventional measuring instruments to calculate error percentages. LoRa range testing is conducted in a residential environment with obstacles to reflect real deployment conditions. These evaluation methods are commonly used in WSN and IoT-based monitoring system assessments [4], [9], [19].

G. System Deployment and Implementation Details

The deployment of the proposed toilet water management system was carried out at Bedengan Tourism Park, Malang, which is characterized by outdoor environmental conditions, uneven terrain, and the presence of trees that may affect wireless communication performance. The sensor node was installed near the water reservoir at an appropriate height to ensure accurate ultrasonic distance measurement, while the master node was placed at the monitoring location with clear accessibility for system operators. The distance between the sensor node and the master node was adjusted gradually during testing to evaluate real field communication performance.

The placement of the ultrasonic sensor was carefully configured to minimize measurement errors caused by water surface turbulence. The sensor was mounted perpendicular to the water surface and protected from direct exposure to sunlight and rain. The water flow sensor was installed inline with the distribution pipe to accurately measure water usage during toilet operation. All wiring connections were enclosed to prevent damage from moisture and outdoor conditions.

Threshold values used for automatic pump control were determined based on practical operational considerations. The upper threshold of 15 cm was selected to prevent reservoir overflow, while the lower threshold of 50 cm was chosen to ensure sufficient water availability for toilet usage. These threshold values were validated through repeated testing to balance pump operation frequency and water supply stability.

LoRa communication parameters were configured to optimize reliability rather than maximum data rate. The system used a fixed transmission interval to periodically send sensor data to the master node, reducing network congestion and power consumption. Field testing was conducted at different times of the day to observe variations in signal quality due to environmental conditions and human activity within the tourism area.

The solar power system was deployed in an open area to maximize solar exposure. Charging and discharging tests were conducted under sunny weather conditions to evaluate energy sustainability. The system demonstrated stable operation without interruption, confirming its suitability for long-term deployment in outdoor public facilities without continuous reliance on grid electricity.

H. System Testing Scenario and Measurement Procedure

System testing was conducted to evaluate the performance and reliability of each subsystem under real operational conditions. The testing scenario was designed to represent actual usage patterns of toilet facilities at Bedengan Tourism Park, including variations in water consumption, pump operation frequency, and environmental conditions. Testing was performed over multiple days to ensure that the system behavior was consistent and not influenced by temporary conditions.

Sensor accuracy testing was carried out by comparing the HC-SR04 ultrasonic sensor readings with manual measurements using a ruler, while the YF-S201 water flow sensor readings were compared with a conventional flowmeter. Each measurement was repeated several times to reduce random error and obtain representative average values. The difference between sensor readings and reference instruments was used to calculate accuracy percentages and error rates.

LoRa communication testing was conducted by gradually increasing the distance between the sensor node and the master node. Measurements of received data were recorded to evaluate communication stability, packet loss, and delay. Testing was performed under both Line of Sight (LoS) and Non-Line of Sight (NLoS) conditions to reflect real deployment environments within the tourism area.

For the solar power system, charging and discharging tests were performed to observe energy sustainability. Battery voltage and current were monitored during daytime charging and nighttime operation to estimate total operating duration without solar input. These tests were intended to verify that the solar energy system could support continuous operation of the monitoring and control system.

The water pump control mechanism was tested in both automatic and manual modes. In automatic mode, the response of the pump to water level thresholds was observed to ensure proper activation and deactivation. In manual mode, control commands sent via the web interface were evaluated to confirm correct execution and system responsiveness. These comprehensive testing procedures ensure that the proposed system operates reliably and is suitable for long-term deployment in public toilet facilities.

III. RESULTS AND DISCUSSION

A. Sensor Accuracy Evaluation

The accuracy of the HC-SR04 ultrasonic sensor was evaluated by comparing the measured water level with a reference ruler. The results show a very small measurement deviation, indicating high accuracy in detecting reservoir water levels. This level of precision is sufficient to support automatic pump control without causing overflow or insufficient filling.

TABLE I
ACCURACY COMPARISON BETWEEN HC-SR04 ULTRASONIC SENSOR MEASUREMENTS AND RULER REFERENCE.

Testing To-	Ruler Measurement Tool Result (cm)	HC-SR04 Ultrasonic Sensor Measured Result (cm)	Error(%)	Status
1	10 cm	10 cm	0	Pompa off
2	10 cm	10 cm	0	Pompa off
3	16 cm	17 cm	0.62	Pompa off
4	16 cm	16 cm	0	Pompa off
5	16cm	16 cm	0	Pompa off
6	25 cm	25 cm	0	Pompa off
7	25 cm	26 cm	0.04	Pompa off
8	35 cm	35 cm	0	Pompa off
9	35 cm	36 cm	0.02	Pompa off
10	35 cm	36 cm	0.02	Pompa off
11	50 cm	50 cm	0	Pompa on
12	50 cm	50 cm	0	Pompa on
13	50 cm	50 cm	0	Pompa on

Testing To-	Ruler Measurement Tool Result (cm)	HC-SR04 Ultrasonic Sensor Measured Result (cm)	Error(%)	Status
14	50 cm	51 cm	0.02	Pompa on
15	50 cm	51 cm	0.02	Pompa on

Similarly, the YF-S201 water flow sensor was tested by comparing its readings with a standard flowmeter. The results indicate stable and consistent measurements, with only minor deviations observed during testing. These results confirm that the sensor is reliable for monitoring water consumption in toilet facilities.

TABLE II
ACCURACY COMPARISON BETWEEN YF-S201 WATER FLOW SENSOR MEASUREMENTS AND FLOWMETER REFERENCE.

Test	Manual Measurement (ml)	Result (ml)	Error(%)
1	330	350	6,06
2	330	336	1,81
3	330	330	0
4	330	340	3,03
5	330	353	6,96
6	330	345	4,54
7	330	330	0
8	330	342	3,63
9	600	600	0
10	600	600	0
11	600	612	2
12	600	602	0,33
13	600	610	1,67
14	600	602	0,33
15	600	603	0,5

B. LoRa Communication Performance

The performance of LoRa communication was evaluated in terms of transmission range, throughput, packet loss, and delay. Testing was conducted in real deployment conditions within Bedengan Tourism Park, including obstacles such as trees and uneven terrain. The maximum transmission distance achieved was 560 meters, which demonstrates reliable long-range communication despite environmental interference.

TABLE III
LORA COMMUNICATION RANGE TESTING RESULTS UNDER FIELD CONDITIONS.

No	Base station		Titik input data		Jarak (m)	Status
	latitude	longitude	latitude	longitude		
1	-7.9397439	112.5293179	-7.9397220	112.5294439	20	Pesan diterima
2	-7.9397439	112.5293179	-7.9397220	112.5297219	40	Pesan diterima
3	-7.9397439	112.5293179	-7.9397220	112.5299998	60	Pesan diterima
4	-7.9397439	112.5293179	-7.9395912	112.5301551	80	Pesan diterima
5	-7.9397439	112.5293179	-7.9394441	112.5302781	100	Pesan diterima
6	-7.9397439	112.5293179	-7.9394520	112.5304250	120	Pesan diterima
7	-7.9397439	112.5293179	-7.9394441	112.5305561	140	Pesan diterima
8	-7.9397439	112.5293179	-7.9392950	112.5307170	160	Pesan diterima
9	-7.9397439	112.5293179	-7.9391671	112.5308330	180	Pesan tidak terkirim

Although the achieved range is lower than the theoretical value stated in the datasheet, the obtained distance is sufficient for the intended application. Signal attenuation caused by obstacles and terrain conditions is considered the main factor affecting communication range.

C. Quality of Service Analysis

Quality of Service (QoS) parameters were evaluated to assess the reliability of data transmission between sensor nodes and the master node. The system achieved an average throughput of 82.5%, packet loss of 0.996%, and an average delay of 0.585 seconds. These values indicate stable communication performance suitable for real-time monitoring and control.

TABLE IV
QUALITY OF SERVICE (QOS) EVALUATION RESULTS INCLUDING THROUGHPUT, PACKET LOSS, AND DELAY.

No	Day	Time	Total paket	Throughput (Kb/s)	Paket loss (%)	Rata-rata delay (s)
1		Pagi	1250	213	2,8	0,103011
2		Pagi	1312	425	3,963	0,087919
3		Pagi	1342	136	2,60	0,187448
4		Siang	1178	470	2,122	0,365756
5		Siang	1084	247	0,992	0,546081
6	HARI KE 1	Sore	1032	204	1,162	0,634192
7		Sore	1084	666	2,398	0,34672
8		Malam	1115	236	0,179	0,769897
9		Malam	1260	175	1,269	0,123015

10	Malam	1116	229	0.627	0,56211

The low packet loss and acceptable delay ensure that sensor data and control commands are delivered accurately, minimizing the risk of delayed pump activation or incorrect system responses.

D. Solar Power System Performance

The solar power system was tested to evaluate its charging and discharging performance under real operational conditions at Bedengan Tourism Park. During testing under sunny weather conditions, the 100 Ah battery reached full charge after approximately 6 hours of solar panel exposure. This charging duration indicates that the installed solar panel capacity is sufficient to meet the daily energy requirements of the system.

Battery discharge testing shows an average current consumption of 0.236 Ah during system operation. Based on this consumption rate, the system is capable of operating continuously for up to approximately 423 hours without additional charging. This long operational duration demonstrates that the energy consumption of the monitoring and control system is relatively low, mainly due to the use of low-power components such as the ESP32 microcontroller and LoRa communication module.

The results also indicate that the integration of solar energy provides stable and sustainable power for the toilet water management system. Even during periods without solar input, such as nighttime operation or cloudy conditions, the battery capacity remains sufficient to maintain continuous system functionality. This characteristic is particularly important for outdoor public facilities located in tourism areas where access to the main electrical grid may be limited or unreliable.

Furthermore, the use of solar energy reduces dependence on conventional electricity sources and contributes to environmentally friendly system operation. The solar-powered configuration supports long-term autonomous deployment and minimizes operational costs related to electricity consumption. Overall, the performance of the solar power system confirms its suitability for supporting reliable and uninterrupted operation of the proposed toilet water management system in outdoor tourism environments.

E. System Control and Monitoring Performance

The functionality of the web-based monitoring system was tested in both automatic and manual modes. In automatic mode, the system successfully controlled the water pump based on predefined water level thresholds, ensuring continuous water availability without operator intervention. In manual mode, operators were able to directly control the pump through the website interface when required.

Overall, the experimental results confirm that the proposed system operates reliably and effectively in real deployment conditions. The combination of accurate sensors, stable LoRa communication, and renewable energy support provides a practical solution for toilet water management in tourism areas.

TABLE V
QUALITY OF SERVICE (QOS) EVALUATION RESULTS RSSI.

No.	Nilai RSSI	Waktu (Loop Time)
1	-29 dBm	00.00.00 s
2	-24 dBm	00.08.00 s
3	-25 dBm	00.16.00 s
4	-26 dBm	00.24.00 s
5	-26 dBm	00.32.00 s
6	-26 dBm	00.40.00 s
7	-25 dBm	00.48.00 s
8	-24 dBm	00.56.00 s
9	-23 dBm	01.04.00 s
10	-24 dBm	01.12.00 s
11	-24 dBm	01.20.00 s
12	-24 dBm	01.28.00 s
13	-23 dBm	01.36.00 s
14	-25 dBm	01.44.00 s
15	-24 dBm	01.52.00 s
16	-24 dBm	02.00.00 s
17	-24 dBm	02.08.00 s
18	-37 dBm	02.16.00 s
19	-38 dBm	02.24.00 s
20	-41 dBm	02.32.00 s
21	-43 dBm	02.40.00 s
22	-44 dBm	02.48.00 s
23	-42 dBm	02.56.00 s
24	-44 dBm	03.04.00 s
25	-42 dBm	03.12.00 s
26	-45 dBm	03.20.00 s
27	-43 dBm	03.28.00 s
28	-42 dBm	03.36.00 s
29	-42 dBm	03.44.00 s
30	-42 dBm	03.52.00 s
31	-42 dBm	04.00.00 s

No.	Nilai RSSI	Waktu (Loop Time)
32	-39 dBm	04.08.00 s
33	-39 dBm	04.16.00 s
34	-40 dBm	04.24.00 s
35	-40 dBm	04.32.00 s
36	-45 dBm	04.40.00 s
37	-41 dBm	04.48.00 s
38	-39 dBm	04.56.00 s
39	-44 dBm	05.04.00 s
40	-49 dBm	05.12.00 s
41	-43 dBm	05.20.00 s
42	-43 dBm	05.28.00 s
43	-49 dBm	05.36.00 s
44	-50 dBm	05.44.00 s
45	-45 dBm	05.52.00 s
46	-48 dBm	06.00.00 s
47	-46 dBm	06.08.00 s
48	-47 dBm	06.16.00 s
49	-46 dBm	06.24.00 s
50	-48 dBm	06.24.00 s

IV. CONCLUSION

This research has successfully designed and implemented a LoRa-based toilet water management system powered by solar energy at Bedengan Tourism Park, Malang. The proposed system integrates an ESP32 microcontroller, HC-SR04 ultrasonic sensor, YF-S201 water flow sensor, and LoRa E220-900T22D module to enable real-time monitoring and control of toilet water distribution. Experimental results show that the ultrasonic sensor achieves an accuracy of 99.951%, while the water flow sensor reaches 97.943%, indicating reliable performance for water level and usage monitoring. LoRa communication is capable of maintaining stable data transmission up to a distance of 560 meters under real field conditions. Quality of Service evaluation demonstrates satisfactory performance, with a throughput of 82.5%, packet loss of 0.996%, and an average delay of 0.585 seconds. The solar power system is able to fully charge a 100 Ah battery within 6 hours of sunlight and supports long-term system operation. Overall, the proposed system effectively improves water availability, operational efficiency, and management reliability of public toilet facilities in tourism areas.

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