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Shrimp Pond Monitoring System using Multi-Hop Cooperative Wireless Network based on the Internet of Things

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A B S T R A C T

Water quality is a crucial factor in maintaining the survival and growth of shrimp. Manual water quality monitoring in shrimp ponds is no longer effective due to the need for periodic monitoring to maintain stable water quality. Therefore, online monitoring using various sensors installed in each pond is necessary. However, there are several challenges to overcome, such as the large expanse of the shrimp ponds, which may lead to data loss due to signal disruptions, and limited energy to power the sensors. To address these issues, this paper proposes the cooperative Wireless Sensor Network (WSN) technique with a multi-hop method for communication in the monitoring process. The system consists of five sensor nodes: temperature sensor, pH sensor, water level sensor, intake water flow sensor, and drain water flow sensor. The cooperative WSN multi-hop technique helps reduce energy consumption in the sensor nodes during measurement and data transmission, while also preventing data packet loss. This is achieved through the use of relay nodes that strengthen signals and forward data to the sink node. As a result, the battery life is extended, and energy usage in the monitoring process can be optimized. The system enables real-time online monitoring and can be accessed through a smartphone application. The results of this study show that the total energy consumption for data transmission in the sensor nodes is 9.64 J, while the total energy consumption for data forwarding in the relay nodes is 9.15 J. The total energy consumption in the transmit and receive processes is 18.79 J or 5.2 mWh. Therefore, it can be concluded that the energy savings of the proposed system is 4.3 mWh or approximately 45%, and is more efficient than the previous system.

INTRODUCTION

Shrimp is one of the most widely consumed seafood products worldwide. Moreover, shrimp is the largest fishery commodity exported to foreign countries. Global shrimp consumption has significantly increased over the past few decades. Based on international trade data, the countries that consume the most shrimp are China, the United States, and Europe. Notably, shrimp consumption has also been on the rise in developing countries with rapid economic growth [1], [2]. With this potential, shrimp farmers have an opportunity to enhance shrimp production to meet the growing global demand for shrimp. Efforts to increase shrimp production can be achieved through more effective and efficient aquaculture practices. Aquaculture involves specialized breeding and maintenance activities in coastal ponds [3]. The shrimp cultivation process requires efforts to control water quality parameters, including temperature, salinity, water level, dissolved oxygen (DO), and Potential of Hydrogen (pH) [3]–[5]. Poor water quality can lead to suboptimal production results and even crop failure [6]. Therefore, a wireless water quality monitoring system is required. However, on the other hand, the use of wireless monitoring methods can result in delayed or lost information delivery. Furthermore, inefficient communication methods can lead to energy wastage, causing a shortened battery lifespan as an energy source. This has the potential to reduce shrimp cultivation productivity and increase financial risks for shrimp farmers. Hence, to address these issues, the cooperative wireless sensor network multi-hop communication method based on the Internet of Things (IoT) is implemented.

The concept of the IoT has been widely applied in various fields, enabling data transfer over the internet without requiring human interaction [7], [8]. One of the advantages of IoT is its ability to independently interact with other connected devices [9], [10]. The connection between these devices forms a collection of nodes organized in a wireless network system called a wireless sensor network (WSN) [11]. WSN technology can organize various sensor nodes, allowing each node to obtain specific information according to desired characteristics. In the paper [12], WSN and IoT technologies were utilized to monitor water quality in shrimp ponds online. The measured parameters included temperature, pH, salinity, and DO. Furthermore, in paper [13], the process of

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monitoring water quality in shrimp ponds used IoT with the Blynk platform. The water quality parameters measured were temperature, pH, and DO. Based on these studies, several challenges need to be addressed with WSN technology, including limited transmission range, data loss due to disturbances, and short battery life of the nodes. Therefore, there is a need for further development of WSN technology to overcome these challenges. In this work, the development of WSN technology is proposed to work cooperatively in forwarding data through multiple sensor nodes until it reaches the final destination, which is the sink node. Sensor nodes will collaborate to form communication paths, thereby extending the data transmission range and preventing data loss due to disruptions [14]–[16]. By implementing a cooperative communication system, energy usage in the sensor nodes can be conserved, resulting in an extended battery life [17]–[21].

In this paper, a shrimp pond water quality monitoring system is proposed using the Cooperative WSN Multi-hop technique. The purpose of this system is to obtain real-time monitoring information on water parameters. By monitoring these water parameters, shrimp farmers can optimize the pond's water conditions and create a more suitable environment for shrimp growth and health, thereby reducing the risk of diseases and mortality. Additionally, the use of the Cooperative WSN Multi-hop communication technique enables the sensors to communicate with each other wirelessly, leading to energy-saving benefits by optimizing battery usage. The monitoring system is designed by leveraging WSN technology, where wireless sensors are placed in a network that is interconnected in a multi-hop manner.

The multi-hop technique allows the data collected by these sensors to be forwarded through several relay nodes before reaching the destination point. In this system, monitoring is conducted through a mobile application on smartphones. The sensor nodes used include a temperature sensor, pH sensor, water level sensor, intake water flow sensor, and drain water flow sensor. Additionally, there are actuators in the form of an intake pump to supply clean water and a drain pump to remove wastewater. The monitoring results will be displayed in real-time on the smartphone application. The implementation of this system will enhance the efficiency of shrimp cultivation, thereby increasing harvest productivity.

The main contribution of this paper is the design of a prototype water quality monitoring system via a smartphone, enabling shrimp farmers to monitor the conditions of their shrimp ponds easily. The proposed prototype uses the cooperative WSN communication methods employing a multi-hop technique for its communication system. So, it can save energy consumption at each sensor node, thus extending the battery life as an energy source.

METHODS

In this paper, a water quality monitoring system for shrimp ponds using a cooperative wireless sensor network multi-hop is proposed. The communication system model and the implementation of the system are presented in this section. There are several stages carried out as part of the research process. The first stage involves hardware design, including the sensor design and configuration. In this stage, the system is assembled by selecting the components used for the prototype, such as pH sensors, ultrasonic sensors, temperature sensors, water flow sensors, relays, 12 V pumps, batteries, Wemos D1 mini, and styrofoam as the enclosure. Furthermore, in the second stage, the sensors on Wemos D1 mini are programmed using the Arduino IDE software.

The research also involves setting up a database using Firebase and designing a mobile application using the Ionic framework version 6.19.1. The Ionic framework is an open-source framework. Moving on to the third stage, the system is implemented based on the established design, to test the system's functionality in monitoring and control using the Cooperative WSN technique. In the final stage, the proposed system is tested to evaluate the compatibility of sensor data with the smartphone application to determine the sensor accuracy level. Data collection is performed online using the Firebase Real-time Database platform. Subsequently, a measurement process is carried out by comparing the original measurement data with the sensor readings. Then, an energy calculation is performed to determine the amount of energy used by each sensor. Finally, an energy efficiency calculation is conducted to assess the effectiveness of the proposed communication method.

Communication Technique

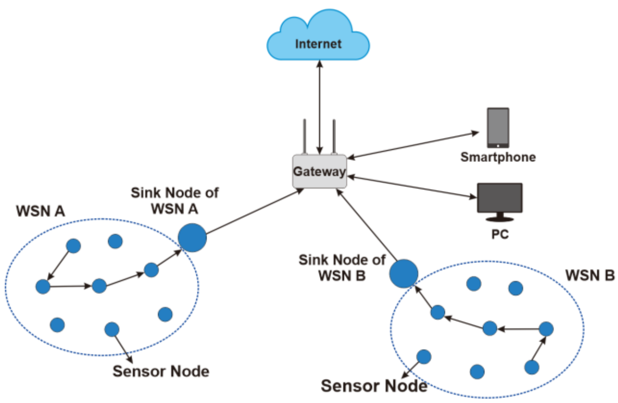

Figure 1. Cooperative WSN Multi-hop Scheme

WSN is a network of embedded devices comprising a group of interconnected sensor nodes that communicate wirelessly. Each sensor node can collect data and communicate with other nodes. Due to its wireless communication method, WSN has limitations in terms of distance. To overcome this issue, the cooperative WSN multi-hop communication method is utilized. This method utilizes relay nodes as intermediaries to facilitate communication between sensor nodes and the target node located at a distance that is difficult to reach directly. The scheme of the cooperative WSN multi-hop is illustrated in Figure 1. In this scheme, each sensor node functions as a relay to forward data until it reaches the sink node.

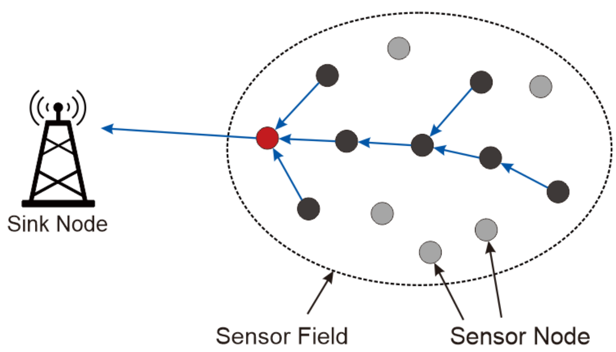

Figure 2. Multi-hop Routing Method

In the multi-hop WSN routing method, each sensor node gradually sends measurement data to other nearby sensor nodes. This process continues until the data reaches the sink node. The multi-hop routing method is illustrated in Figure 2. This method can result in high latency due to the use of multiple relay nodes. The more relay nodes are used, the higher the latency. This is caused by the decoding and packetization processes that occur in the relay nodes. To reduce the number of relay nodes, a clustering process is implemented.

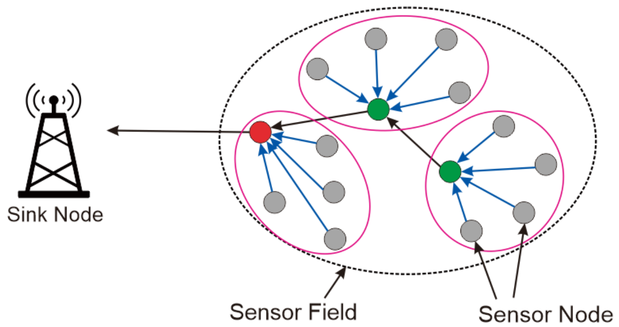

Figure 3. Multi-hop Cluster Routing Method

The clustering method is a development of the multi-hop routing method, where each sensor node is divided into several clusters. Each cluster contains a cluster head node responsible for collecting data from every node within that cluster. Subsequently, the data on the cluster head node is sent to the sink node. This routing method is illustrated in Figure 3.

Model System

The proposed monitoring system utilizes five sensor nodes, consisting of a water flow sensor node on the intake pump, a pH sensor node, a temperature sensor node, a water level sensor node, and a water flow sensor node on the drain pump. The model of the monitoring system can be seen in Figure 4, where sensor nodes 2, 3, and 4 send data to the relay node, which is subsequently forwarded to the cloud server. However, sensor nodes 1 and 5 directly transmit data to the cloud server without passing through a relay node. The access point acts as a modem utilized to access the internet. The information stored in the cloud server can be accessed through a smartphone. Meanwhile, the model for the controlling system can be seen in Figure 5, where the cloud server sends commands to the pump node, responsible for controlling both pumps. In the image, Pump 1 represents the intake pump, while Pump 2 represents the drain pump.

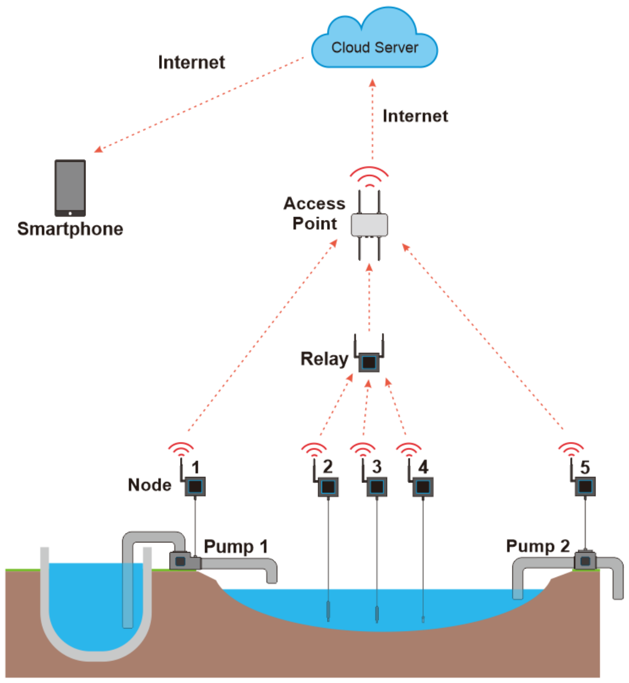

Figure 4. Monitoring System Model

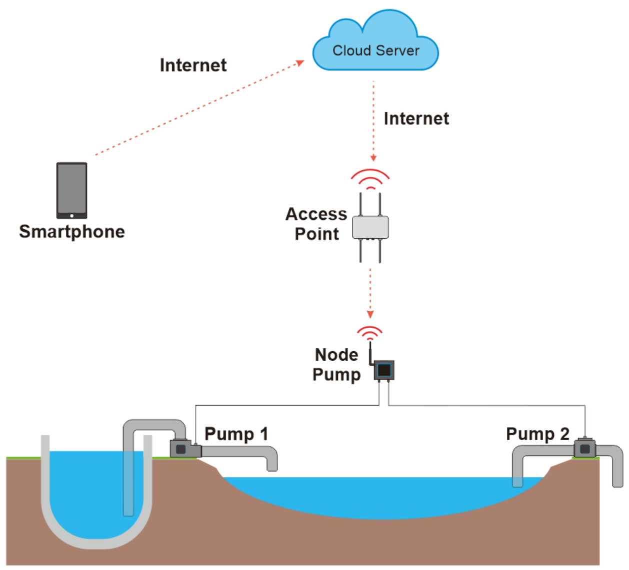

Figure 5. Controlling System Model

Hardware Design

The proposed design of the monitoring system utilizes the DS18B20 temperature sensor, 4502C pH sensor, and HC-SR04 water level sensor. Each sensor node is equipped with a Wemos D1 mini microcontroller based on ESP8266. The energy source for each node is a 9V battery with a capacity of 550 mAh. This capacity can store 4.95 Wh or 17,820 J of energy. The cloud server used for data processing is Firebase, a data-based cloud server platform developed by Google. This service provides developer API (Application Programming Interface) that enables applications to synchronize with various clients. In this study, the monitoring data is stored using the Firebase Real-time Database service. The design of the shrimp pond monitoring system is illustrated in Figure 6.

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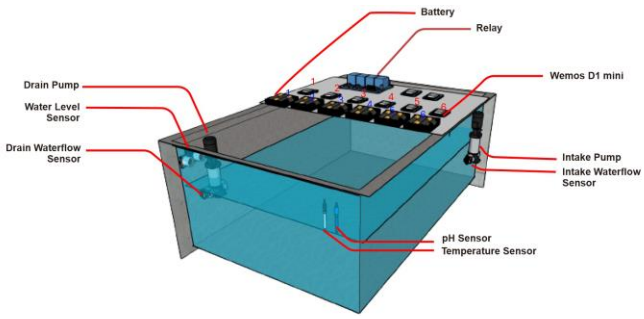


Figure 6. Shrimp Pond System Monitoring Design

The prototype system is built to facilitate shrimp cultivation management by leveraging IoT technology for real-time monitoring and pump control. The system's monitoring process involves collecting data from each sensor node, which is then sent by the cloud server to a smartphone application for users to access measurement results. The water pump is used to control the water level in the reservoir pond by adding or reducing water. Additionally, the water addition and reduction process can also be manually performed through the smartphone.

Software Design

Figure 7 shows the flowchart of the monitoring system. The monitoring application is developed using the Ionic Framework, which is an open-source framework designed to build hybrid mobile applications that can run on various operating systems. The framework utilizes HTML5, CSS, and AngularJS tags, simplifying the application development process.

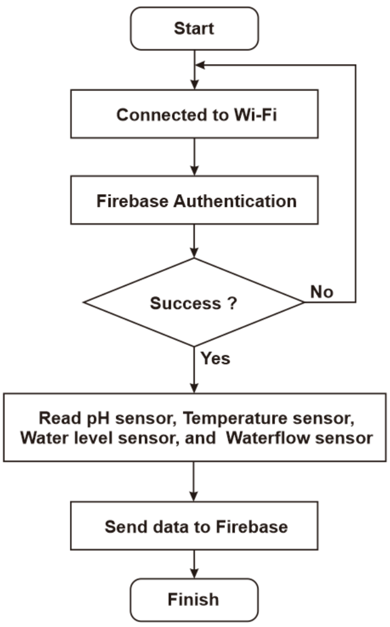


Figure 7. Flowchart for Monitoring System

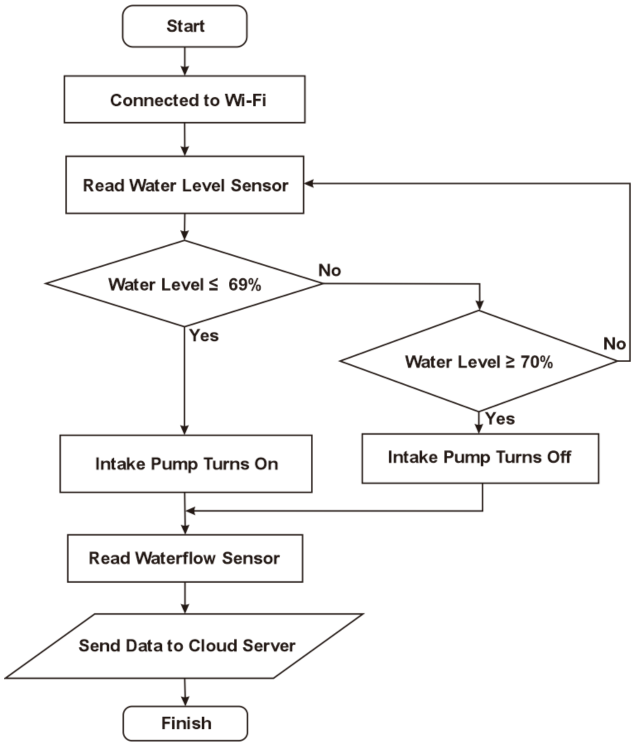


Figure 8. Flowchart for Controlling Intake Pump System

In Figure 8, there is a flowchart of the intake pump system. The pump will activate when the water level reaches below 69%. Meanwhile, in Figure 9, there is a flowchart of the drain pump system. The pump will activate when the water level reaches above 80%. Both pumps function to maintain a stable water level condition. The water flow sensor will send information to the cloud server to indicate the status of the activated pumps.

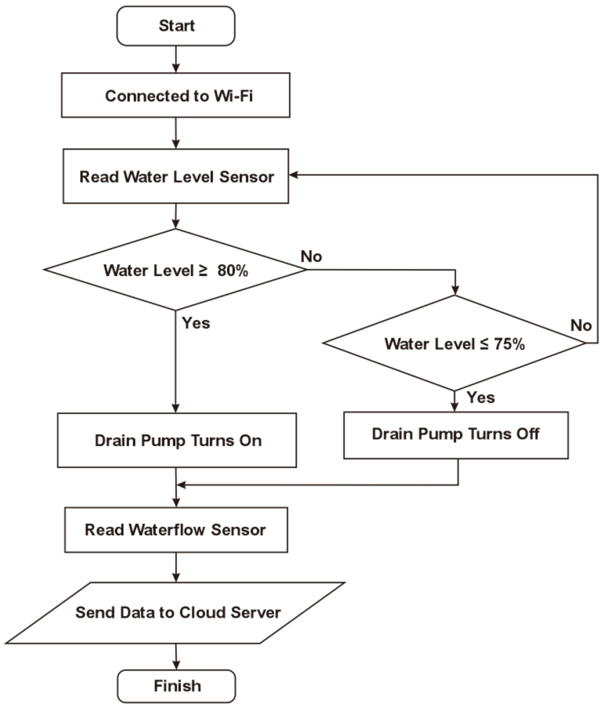


Figure 9. Flowchart for Controlling Drain Pump System

Energy Consumption

The energy consumption in WSN can be calculated by determining the energy used in each component, including the energy required for data transmission, data reception, and the energy needed to perform sensing operations, including data processing. To transmit data, transmit energy is required. The amount of this energy depends on the transmission power, the distance between nodes, and the number of bits transmitted. Transmit energy can be calculated using Equation (1), where E_{Tx} is the transmit energy, E_{elec} is the energy required to send one bit of data, E_{amp} is the energy required for power amplification, k is the number of bits transmitted, and d is the distance between nodes. It can be calculated as

$$E_{Tx}(k,d) = E_{elec}.k + E_{amp}.k.d^2 \quad (1)$$

Meanwhile, to receive data, receive energy is required. The amount of this energy depends on the number of received data bits. Receive energy can be calculated using Equation (2), where E_{Rx} represents the receive energy as follows.

$$E_{Rx}(k) = E_{elec}.k \quad (2)$$

The overall energy consumption is calculated using Equation (3), where E_{sensor} represents the energy required for sensing operations, and $E_{process}$ represents the energy required for data processing. E_{sensor} is typically used for measurements and signal conversions, and its magnitude depends on the type of sensor used. Meanwhile, $E_{process}$ is generally used for data compression, aggregation, and calculations. This energy depends on the complexity of the algorithms and the amount of data processed. The total energy is

$$E_{total} = E_{Tx} + E_{Rx} + E_{sensor} + E_{process} \quad (3)$$

Based on the energy consumed by the sender node and the energy consumed by the relay node, the energy efficiency can be calculated using Equation (4), where E_{eff} represents the energy efficiency value as

$$E_{eff} = \frac{E_{Tx} - E_{Rx}}{E_{Rx}} \; x \; 100\% \quad (4)$$

RESULTS AND DISCUSSION

The results of the prototype monitoring system design for shrimp cultivation can be seen in Figure 10. This monitoring system is constructed using a styrofoam box with dimensions of 50 cm in length, 36 cm in width, and 33 cm in height. This monitoring system utilizes a communication technique called Cooperative WSN Multi-hop. In this technique, each sensor node not only functions as a data sender or receiver but also acts as a relay to forward data from one node to another. The system comprises 5 sensor nodes and 1 pump node. The sensor nodes consist of temperature sensors, pH sensors, water level sensors, intake waterflow sensors, and drain waterflow sensors. Meanwhile, the pump node is responsible for controlling the intake pump and drain pump. Each sensor node includes a Wemos D1 mini as the microcontroller, a 9V battery as the power source, and various sensor devices. On the other hand, the pump node consists of a Wemos D1 mini as the microcontroller, relay switches for activating the pumps, a 12V 5A adapter as the power supply, an intake pump, and a drain pump.

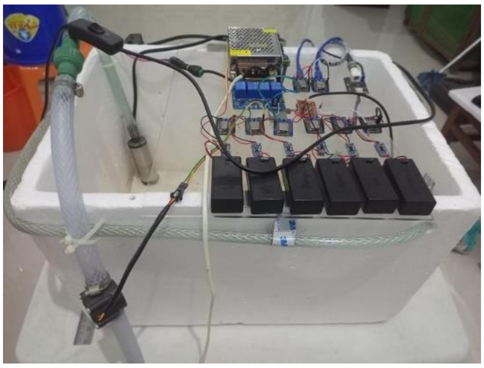
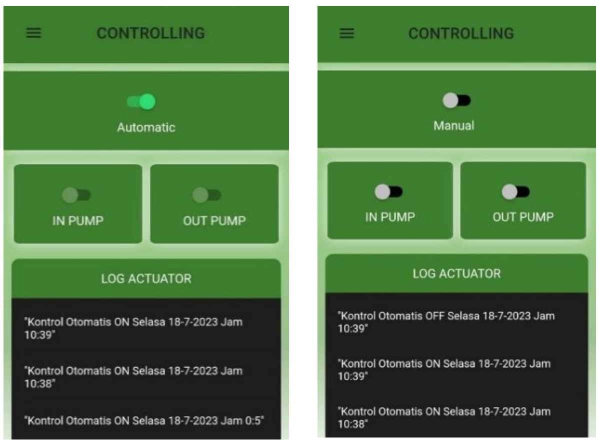


Figure 10. Prototype of Shrimp Pond Monitoring System

The application used for monitoring the shrimp pond utilizes the Ionic framework. This application is connected to a cloud server to display real-time monitoring information. The interface of this application includes five parameters: water level, temperature, pH, intake water flow, and drain water flow. The interface of the smart shrimp cultivation monitoring application can be seen in Figure 11, while the control page interface can be seen in Figure 12.

(a) (b)

Figure 11. Interface of the Monitoring Application on Smartphone, (a) Front Page, (b) Dashboard



(a) (b)

Figure 12. Interface of the Controlling Page, (a) Automatic, (b) Manual

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Sensor Testing Analysis

The sensor testing analysis was conducted to determine the error value between the sensor measurements and the measuring instrument. The sensor testing included temperature sensor, pH sensor, and water level sensor. In the temperature sensor testing, the measurement data was compared with a thermometer. The comparison results of the temperature can be seen in Table 1. Based on the measurement results, a maximum error rate of 2.39% was found at a temperature of 38.5°C.

Table 1. Temperature Sensor Test

Experiment	Temperature (°C)	Sensor Measurement (°C)	% Error
1	26.8	27.2	1.34
2	28.8	29.3	1.57
3	30	30.6	1.96
4	33.3	33.9	1.79
5	38.5	39.4	2.39
6	40.5	41.3	1.87

Next, in the pH sensor testing, the measurement data was compared with a pH meter. The comparison results of the pH can be seen in Table 2. Based on the measurement results, a maximum error rate of 2.62% was found at a water pH of 5.72.

Table 2. pH Sensor Test

Experiment	pH	Sensor Measurement	% Error
1	5.72	5.87	2.62
2	6.53	6.67	2.14
3	7.56	7.75	2.47
4	7.78	7.9	1.5
5	7.82	7.97	1.88
6	8.24	8.09	1.86

Then, in the water level sensor testing, the measurement data was compared with a meter. The comparison results of the water level can be seen in Table 3. Based on the measurement results, a maximum error rate of 2.54% was found at a water height of 10.5cm.

Table 3. Water Level Sensor Test

Experiment	Water Level (cm)	Sensor Measurement (cm)	% Error
1	10.5	10.8	2.54
2	13.5	13.3	1.23
3	16	16.3	1.88
4	18.5	18.5	0.18
5	22	22.3	1.36
6	37	37.5	1.35

Energy Consumption Analysis

The cooperative communication technique in WSN can help reduce energy consumption in sensor nodes. The use of relay nodes as intermediaries for data can assist sensor nodes in reducing energy consumption during data transmission. As a result, the battery life of sensor nodes becomes longer. The energy consumption in WSN can be calculated by knowing the energy used in each component. The energy consumption required for measurement and data processing in each sensor node is shown in Table 4. Based on this data, the total energy consumption used in sensor nodes per hour is 657 J.

Table 4. Energy Consumption at Each Node for An Hour

Node	Voltage (V)	Current (A)	Power (W)	Energy Consumption (J)
Water Level Sensor	5	0.015	0.075	270
pH Sensor	5	0.005	0.025	90
Temperature Sensor	5	0.0015	0.0075	27
Waterflow Sensor	5	0.015	0.075	270

Meanwhile, the energy consumption required for data transmission and reception in each sensor node is shown in Table 5. Based on this data, the total energy consumption in sensor nodes for transmitting data per hour is 9.64 J, and the total energy consumption in relay nodes per hour is 9.15 J. Therefore, the total energy consumption during the monitoring process with cooperative WSN multi-hop technique is 675.7 J per hour.

Table 5. Total Energy used in the Process of Sending and Receiving Data in Cooperative Communication for An Hour

Node	k (bit)	E_{elec} (J)	E_{amp} (J)	E_{Tx} (J)	E_{Rx} (J)	E_{total} (J)
Water Level Sensor	80	0.075	2	6.4	6	282.4
pH Sensor	72	0.025	0.1	1.818	1.8	93.618
Temperature Sensor	80	0.0075	0.1	0.62	0.6	28.22
Waterflow Sensor	10	0.075	2	0.8	0.75	271.55

Furthermore, the energy efficiency obtained in the cooperative WSN technique is shown in Table 6. The cooperative WSN technique with the addition of relay nodes has reduced energy consumption during data transmission. The total efficiency achieved over an hour is 5.36%. Therefore, by implementing this cooperative WSN technique, the battery life, which is a crucial component in wireless communication systems, will be extended.

Table 6. Energy Efficiency with Cooperative WSN Techniques for An Hour

Node	E_{Tx} (J)	E_{Rx} (J)	E_{ff} (%)
Water Level Sensor	6.4	6	6.25
pH Sensor	1.818	1.8	0.99
Temperature Sensor	0.62	0.6	3.23
Waterflow Sensor	0.8	0.75	6.25
Total	**9.64**	**9.15**	**5.36**

Based on the above analysis, the total energy used in the transmit and receive processes is 18.79 J or 5.2 mWh. In contrast, in a study [22] that also examined IoT-based WSNs, the total energy consumption was 9.5 mWh. Therefore, the proposed communication method in this paper achieves energy savings of

4.3 mWh, which is approximately 45% more efficient compared to the previous system. For a more detailed comparison with related research, refer to Table 7. By implementing the cooperative multi-hop WSN method, this submitted paper has achieved a more efficient energy consumption in transmission and reception than in other papers. This is due to the data transfer process being conducted through multi-hop, thereby reducing energy usage for data transfer over long transmission distances.

Table 7. The comparison of the Proposed Paper with Other Related Studies

Paper	E_{Tx} (J)	E_{Rx} (J)	E_{total} (J)
Proposed Paper	9.64	9.15	5.36
Gazi M. E et al. [22]	-	-	34.2
Agustin B. et al. [23]	39.26	45.15	84.41
Karan N. et al. [24]	54	54	108
Maria C. et al. [25]	82.33	45.35	127.68

CONCLUSIONS

Based on the test results, the shrimp cultivation monitoring system can measure several water quality parameters such as temperature, pH, and water level. Real-time monitoring of temperature, pH, and water level is performed using a smartphone. The test results for the temperature sensor obtained a maximum error rate of 2.39%, for the pH sensor is 2.39%, and for the water level sensor is 2.54%. The water level in the pond can be controlled using pumps for water filling and drainage. The cooperative WSN multi-hop technique used can reduce energy consumption in the sender node. The sender node can use lower power to transmit data because of the presence of relay nodes that help in forwarding data. The total energy consumption used in the sender node for data transmission per hour is 9.64 J. Meanwhile, the total energy consumption in the relay node per hour is 9.15 J. Thus, the total energy used for the shrimp cultivation monitoring process using the cooperative WSN multi-hop technique per hour is 675.5 J. Based on this data, the process that consumes the most energy is the water level sensor node, with a total of 282.4 J or 41.8% of the total energy. Meanwhile, the process that consumes the least energy is the temperature sensor node, with a total of 28.22 J or 4.2% of the total energy. The total energy efficiency obtained by implementing this cooperative WSN technique is 5.36%. In comparison with the previous study, the proposed cooperative WSN multi-hop communication method in this paper results in energy savings of 4.3 mWh, which is approximately 45% more efficient. So, this paper demonstrates the importance of implementing cooperative WSN communication with multi-hop techniques in monitoring systems. It has a significant impact on battery life as an energy source. By applying this communication method, the monitoring system becomes more environmentally friendly and energy-efficient. Further research can be conducted by adding solar panels to each sensor node as a self-energy generator.

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