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Mamdani fuzzy-based water quality monitoring and control system in vannamei shrimp farming using the internet of things

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ABSTRACT

Indonesia's vast ocean expanse, spanning two-thirds of its land, is a treasure trove of marine resources, with shrimp being a vital commodity in the country's fisheries exports. To ensure successful shrimp production, maintaining optimal water conditions is paramount, necessitating extensive, large-scale monitoring. Enter our innovative prototype an internet of things (IoT) system designed for comprehensive pond water quality oversight. This smart system monitors crucial parameters like pH, turbidity, temperature, and dissolved solids in vannamei shrimp cultivation. The Mamdani fuzzy approach dynamically adjusts operations in response to changing weather conditions, fine-tuning both pump and windmill speeds. This adaptive methodology significantly improves water quality control, enhancing overall efficiency. Our IoT infrastructure ensures real-time monitoring and control, creating an ideal environment for shrimp cultivation. The Mamdani fuzzy technique’s effectiveness shines in adapting to dynamic environmental shifts. Noteworthy findings underscore the system's ability to automate and elevate pond water quality, promising increased shrimp production. This technology has the potential to revolutionize traditional shrimp farming, particularly in regions like Rembang, by promoting sustainable aquaculture practices.

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1. INTRODUCTION

Indonesia, being mostly a marine nation, possesses an extensive expanse of sea that exceeds its land area. Indonesia's distinctive geographical location makes it abundant in marine resources, with shrimp becoming a crucial product in the country's fisheries exports. Indonesia's ability to develop large shrimp ponds along its coastal areas puts it in a favorable position to emerge as a dominant force in global shrimp production and export. Nevertheless, conventional shrimp farming techniques, especially in locations like Rembang, encounter obstacles such as manual water quality monitoring, leading to elevated labor expenses and ineffective procedures [1], [2]. The responsibility of conditioning water quality characteristics encompasses maintaining appropriate levels of dissolved oxygen (DO), maintaining a normal temperature, ensuring normal water turbidity, and maintaining a balanced level of acidity (pH) [3]. The primary factors in water quality control are temperature and water turbidity.

The practice of shrimp farming in Rembang, namely in vast or traditional ponds, has challenges in attaining maximum productivity due to the use of manual monitoring methods. Shrimp growers depend on evaluating water quality indicators directly at the location, which includes measuring DO, temperature, turbidity, and acidity (pH). The arduous and time-consuming characteristics of these procedures impede the possibility of enhanced manufacturing efficiency. In addition, the utilization of conventional ponds without sophisticated infrastructure further exacerbates the production of below-average yields [4], [5]. Prior to the harvest, it is necessary to install a water wheel for the shrimp in order to maintain proper levels of DO, temperature, and water turbidity. However, due to the classification of shrimp farmer's pond as an extended or traditional pond, the productivity is below average. Extensive or traditional ponds refer to ponds that employ management strategies involving low stocking densities, utilization of natural feed and commercial feed pellets for shrimp growth, and the absence of water pumps, mills, or other equipment. Mr. Fauizin's pH level in the city of Rembang is currently measured manually. Operators use a pH meter to measure the acidity level, but this method is prone to inaccuracies and can result in misleading information that may not align with the pond owner's expectations. Hence, it fails to consider the potential scenario where shrimp farmers have discontinued the use of manual pH readings due to their inferior quality.

This project endeavors to create a cutting-edge prototype that utilizes internet of things (IoT) technology to monitor and regulate water quality in shrimp farming in Rembang. The objective is to tackle the issues encountered by shrimp producers in the region [6]–[10]. During the fourth industrial revolution, it was essential to implement efficient and effective real-time systems. The proposed approach entails the use of sophisticated sensors that are capable of continuously evaluating the water conditions in the pond. The sensors will send live data to an internet-based platform, enabling shrimp producers to oversee and control water quality factors remotely. This project aimed to optimize shrimp farming operations by incorporating IoT technology, particularly in vannamei shrimp agriculture. It aims to empower farmers to boost harvests without requiring their personal presence at the farm. The use of modern, automated monitoring is anticipated to bring about a significant transformation in conventional shrimp farming practices and support the sustainable expansion of the sector in Rembang [11]–[13]. Pond water quality will be monitored and managed using intelligent sensors that can analyze pond water conditions in real-time and transmit data to the internet [14], [15]. The objective of this project was to enhance the productivity of vannamei shrimp cultivation for shrimp farmers in Rembang city without necessitating their personal presence at the site [2], [16].

2. RESEARCH METHOD

The research method used was Mamdani fuzzy. The defuzzification process yielded input values for output control. This section describes the sequential steps that comprise the Mamdani fuzzy approach.

2.1. Internet of things

The scientific advancement of the IoT holds great potential in the era of Industry 4.0 for enhancing lives through intelligent control, coordination, and automation systems that connect physical devices over the internet. Utilizing the IoT facilitates the implementation of human dictatorship in daily life. For instance, we may effortlessly monitor room temperature by means of a computer or similar device. The ability to share information between computers and electronic devices has led to a decrease in human interaction. The availability of numerous internet facilities and services driven by user needs has further amplified this trend. The architecture of the IoT model is shown in Figure 1.

Figure 1 depicts a system sequence diagram that showcases the links between components that will be used in future applications. The system design includes an Arduino Mega 2560 for data processing and uses the NodeMCU as an intermediate to transport data from the Arduino Mega 2560 to the Adafruit.io web service provider. The primary data sources consist of the DFRobot analogue turbidity sensor, the pH sensor, the Dallas DS18b20 temperature sensor, and the analogue DO sensor. Adafruit IO uses the message queuing telemetry transport (MQTT) protocol for the purpose of control and monitoring [17]–[19]. Users may use Adafruit IO's dashboard features to engage with the system. Users may use these capabilities to pick certain feeds and choose related blocks to display data [20]–[22]. Adafruit IO provides a wide range of blocks, such as text boxes, momentary buttons, gauges, toggle buttons, color pickers, number sliders, line graphs, icons, pictures, indicators, number pads, and remotes. Within this particular framework, the designations "MQTT client" and "MQTT broker" may be used interchangeably to denote the MQTT server. When the MQTT client wishes to send data to the MQTT broker, a connection is created with the broker. The customer initiates the connection, prompting the broker to establish the connection after both sides are successfully connected.

2.2. Fuzzy set formation

In this research case study, there were two inputs, namely temperature and turbidity conditions. The fuzzification process on the temperature variable has 3 fuzzy sets: cold, normal, and hot. For the domain in the cold temperature variable, it is in the range of 20-30, normal 20-40, and for hot 30-40 [23]–[25]. The (1)-(3) explanation pertains to the computation of the temperature setting.

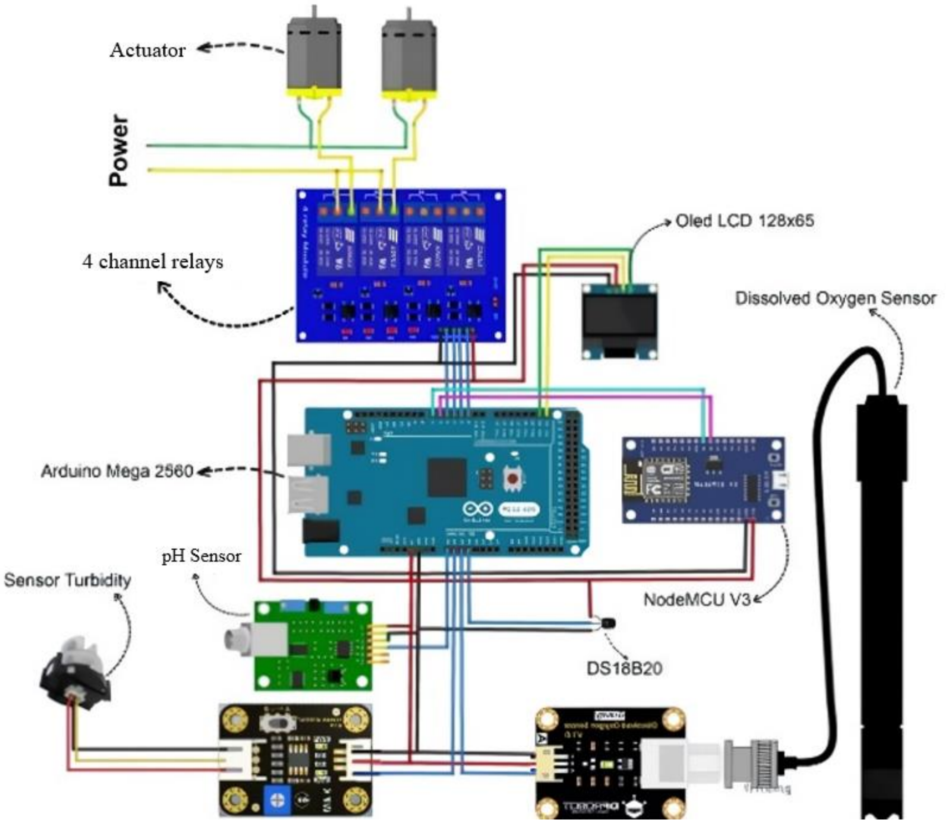

Figure 1. Architecture IoT

$$\mu Cold[z] = \begin{cases} 1; & z \leq 20 \\ (30 - z)/(30 - 20); & 20 \leq z \leq 30 \\ 0; & z \geq 30 \end{cases} \quad (1)$$

$$\mu Normal[z] = \begin{cases} 0; & z \leq 20 \; atau \; z \geq 30 \\ (z - 20)/(30 - 20); & 20 \leq z \leq 30 \\ (40 - z)/(40 - 30); & 30 \leq z \leq 40 \end{cases} \quad (2)$$

$$\mu Hot[z] = \begin{cases} 0; & z \leq 30 \\ (z - 30)/(40 - 30); & 30 \leq z \leq 40 \\ 1; & z \geq 40 \end{cases} \quad (3)$$

The fuzzification process on the turbidity variable has three fuzzy assemblies that are normal, slightly cloudy and very cloudy. For the domain on the normal variable, it is in the range 0-50, a little rough 0-100, and for the rough 50-100. The computation of the total turbulence aggregate can be seen in (4)-(6):

$$\mu \text{Normal}[\text{z}] = \begin{cases} 1; & \text{z} \leq 0 \\ (50 - \text{z})/(50 - 0); & 0 \leq \text{z} \leq 50 \\ 0; & \text{z} \geq 50 \end{cases} \quad (4)$$

$$\mu \text{Slightly cloudy}[\text{z}] = \begin{cases} 0; & \text{z} \leq 0 \text{ atau z} \geq 100 \\ (\text{z} - 0)/(50 - 0); & 0 \leq \text{z} \leq 50 \\ (100 - \text{z})/(100 - 50); & 50 \leq \text{z} \leq 100 \end{cases} \quad (5)$$

$$\mu \text{Very cloudy}[\text{z}] = \begin{cases} 0; & z \leq 50 \\ (\text{z} - 50)/(100 - 50); & 50 \leq z \leq 100 \\ 1; & z \geq 100 \end{cases} \quad (6)$$

The system has two outputs: the output to activate the water pump and the second output to activate the fan. The output range of the water pump starts from 200-1000, and for the fan, it ranges from 20-100. For the domain of the waterwheel, it is between 20-60 for the very slow set, 20-100 for the slow set, and 60-100 for the fast set. The condition of the waterwheel is determined using (7)-(9).

$$\mu\text{Very slow } [z] \begin{cases} 1, & z \le 20 \\ \frac{60-z}{40}, & 20 \le z \le 60 \\ 0, & z \ge 60 \end{cases} \quad (7)$$

$$\mu\text{Slow } [z] \begin{cases} 1, & z \le 20 \text{ atau } x \ge 100 \\ \frac{z-20}{40}, & 20 \le z \le 60 \\ \frac{100-z}{40} & 60 \le z \le 100 \\ 0, & \end{cases} \quad (8)$$

$$\mu\text{Fast } [z] \begin{cases} 1, & z \le 60 \\ \frac{z-60}{40}, & 60 \le z \le 100 \\ 0, & z \ge 100 \end{cases} \quad (9)$$

For the domain, the pump is between 400 and 700 for the severely decreased set, 400 and 1000 for the normal set, and 700 and 1000 for the increased set. The (10)-(12) determine the output status of the water pump.

$$\mu\text{Decrease } [z] \begin{cases} 1, & z \le 400 \\ \frac{700-z}{300}, & 400 \le z \le 700 \\ 0, & z \ge 700 \end{cases} \quad (10)$$

$$\mu Normal[z] \begin{cases} 1, & z \le 400 \; atau \; x \ge 1000 \\ \frac{z-400}{300}, & 400 \le z \le 700 \\ \frac{1000-z}{300} & 700 \le z \le 1000 \\ 0, & \end{cases} \quad (11)$$

$$\mu Increase \; [z] \begin{cases} 1, & z \le 700 \\ \frac{z-700}{300}, & 700 \le z \le 1000 \\ 0, & z \ge 1000 \end{cases} \quad (12)$$

2.3. Application of the implication function

The implication function is crucial in water quality management for shrimp farming since it enables the flexible adjustment of pump and waterwheel velocities. This function is essential for the implementation of the Mamdani fuzzy approach as it enables the system to dynamically modify and conform to various environmental conditions. Tables 1 and 2 provide a thorough examination of the existing efficiency of the waterwheel and pump, respectively. Table 1 displays the recorded measurements for temperature, turbidity, and waterwheel state, offering significant insights into the system's response to changes in pond conditions. Table 2 analyzes the variables of temperature, turbidity, and pump status, showcasing the system's ability to control and adjust pump speeds effectively.

Table 1. Waterwheel output status

No	Temperature	Turbidity	Waterwheel status
1	Cold	Normal	The speed of the waterwheel is very slow
2	Cold	Slightly cloudy	The speed of the waterwheel is slow
3	Cold	Very cloudy	The speed of the waterwheel is fast
4	Normal	Normal	The speed of the water wheel is very slow
5	Normal	Slightly cloudy	The speed of the water wheel is fast
6	Normal	Very cloudy	The speed of the water wheel is fast
7	Hot	Normal	The speed of the water wheel is very slow
8	Hot	Slightly cloudy	The speed of the water wheel is slow
9	Hot	Very cloudy	The speed of the water wheel is fast

Table 2. Pump output status

No	Temperature	Turbidity	Waterwheel status
1	Cold	Normal	The pump speed decreases
2	Normal	Normal	The pump speed is normal
3	Hot	Normal	The pump speed increases
4	Cold	Slightly cloudy	The pump speed decreases
5	Normal	Slightly cloudy	The pump speed is normal
6	Hot	Slightly cloudy	The pump speed increases
7	Cold	Very cloudy	The pump speed decreases
8	Normal	Very cloudy	The pump speed is normal
9	Hot	Very cloudy	The pump speed increases

2.4. Rule composition

The suggested technique comprises deriving the solution of the fuzzy set by extracting the largest value from the rule set. The highest value is used to modify the fuzzy area and then applied to the output using the OR (union) operator [16], [26]. This technique guarantees that the most important rule is taken into account while forming the fuzzy solution, highlighting the significance of the highest value in impacting the ultimate result. By selecting the highest value from the rule set, the fuzzy set solution is modified to represent the strong impact of certain rules accurately. Adapting is essential for accurately capturing the many linkages within the system and improving the precision of the fuzzy solution. The OR (union) operator is then applied to combine these updated fuzzy areas, resulting in a cohesive output that represents the intricate interactions inside the fuzzy logic framework [16], [26]. This methodological approach enables a precise and context-sensitive calculation of fuzzy solutions, enhancing the resilience and efficiency of the entire system.

2.5. Defuzzy

The technique employed at this particular stage is the centroid method. The centroid of a cluster of objects can be conceptualized as the representative object of the cluster, regardless of its physical existence or being a purely mathematical abstraction. The formula for the centroid method is (13).

$$z^* = \frac{\int_Z z\mu(z)dz}{\int_Z \mu(z)dz} \tag{13}$$

3. RESULTS AND DISCUSSION

Figure 2 depicts the detailed assembling procedure of the equipment. The components were meticulously organized to guarantee the flawless incorporation of temperature sensors (DS18B20), turbidity sensors, pH sensors, and total dissolved solids (TDS) sensors in pond water. This step was crucial for the effective functioning of the monitoring system. The operational equipment, seen in Figure 3, comprises a container housing sensors for detecting temperature (DS18B20), turbidity, pH, and TDS in pond water [3], [5]. Various experiments were conducted using varying levels of pond water quality, as seen in the glass container.

The design of the Adafruit web monitor interface, as seen in Figure 4, consists of four gauges (temperature, turbidity, mill speed, and pump speed), a multiline text element, and a line chart that displays data from the TDS and pH meters. The objective of this interface is to provide a comprehensive overview of crucial elements for efficiently monitoring the quality of water in ponds. The system employs two defuzzification methods: pump defuzzification and waterwheel defuzzification. The line chart depicts the temporal fluctuations of dissolved solids and acidity levels using data obtained from TDS and pH meters.

The statistical analyses highlight the significance of the data, demonstrating the efficacy of the suggested monitoring system. The presentation effectively conveys the results by removing redundancy, resulting in clarity, and simplicity. The proposed methodology is notable for its distinct attributes, as shown by comparisons with prior research discoveries. The dashboard effectively communicates the present state of the pump and waterwheel, offering a solid foundation for the study's findings and facilitating a comprehensive discussion. The use of visual representations, such as diagrams, graphs, and instruments, enhances the reader's understanding and strengthens the overall impact of the study [14], [15]. The discussion comprises comprehensive sub-sections that meticulously analyze the complexities of the findings, emphasizing their practical implications and addressing any limitations. The objective of this comprehensive investigation is to authenticate the significance of the document, showcasing its contribution to the area and providing practical insights for prawn growers in Rembang.

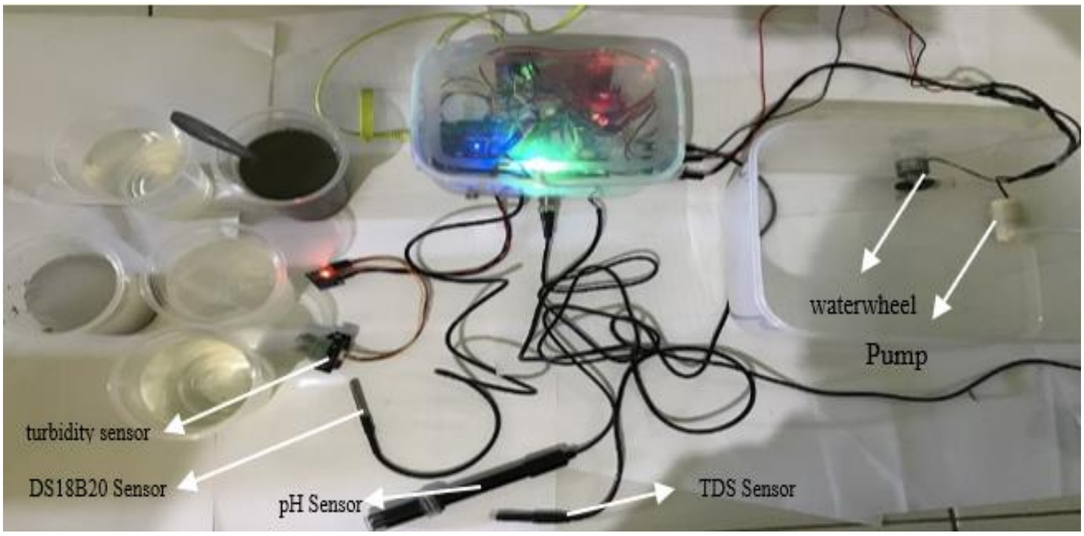

Figure 2. Tool range and box 1

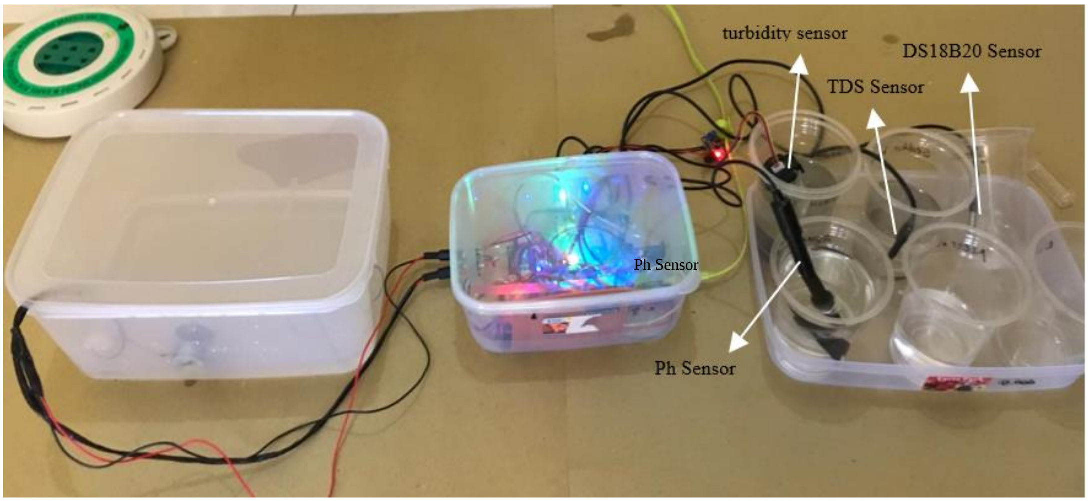

Figure 3. Tool range and box 2

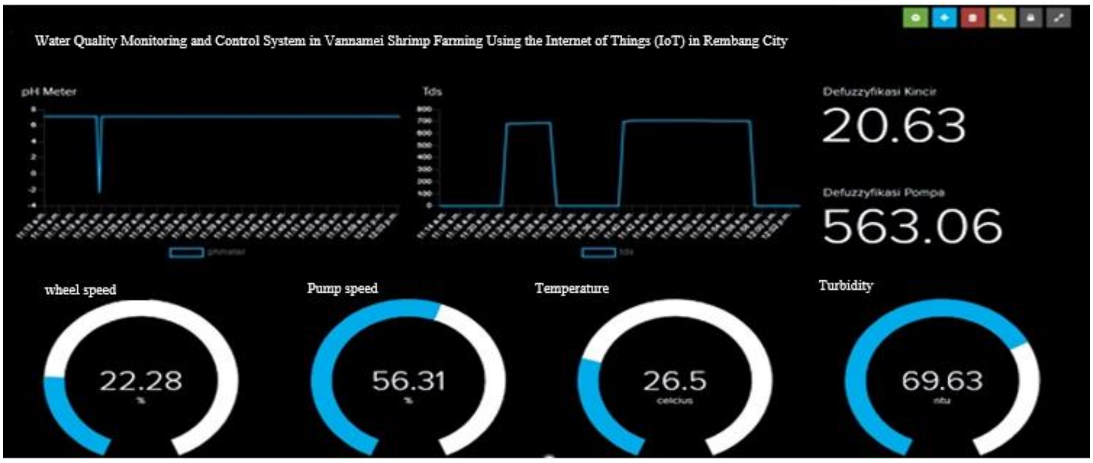

Figure 4. Dashboard monitor data

4. CONCLUSION

The research findings indicate that the implementation of Mamdani fuzzy for monitoring and controlling water quality in vannamei shrimp ponds, using the IoT in Rembang city, has successfully automated the process to meet the shrimp's requirements for temperature, turbidity, acidity level, and dissolved solids/particles. The research yielded data indicating that the wheel can be activated automatically at a speed of 69.33 Rpm when the pond water temperature reaches 32 °C, and the turbidity level is 52 nephelometric turbidity unit (NTU). Similarly, the pump can be activated at a speed of 853.33 Rpm when the maximum speed value is 1000 Rpm. The velocity of the wheels and pumps will perpetually vary in response to the conditions identified by the temperature and turbidity sensors until they reach a state of equilibrium.

The temperature sensor generates the windmill's output, while the turbidity sensor triggers the pump to activate automatically when there are fluctuations in both temperature and turbidity conditions. TDS sensors and pH sensors solely monitor the presence of dissolved solids and the level of acidity in pond water. These measurements are then displayed on the Adafruit IO server through the website. These sensors do not have any actuators and do not generate any output. Therefore, the solution to address unstable pH and TDS conditions is to gradually remove and replace the pond water.

The optimal circumstances for vannamei shrimp growth include a temperature range of 25-31 °C, water turbidity ranging from 0-25 NTU, dissolved solids/particle conditions TDS ranging from 150-250 ppm, and a pH level between 7.5–8.5. The server utilized is the complimentary edition of Adafruit IO, which has a maximum data rate of 30 per minute. Additionally, there is a delay of more than 2 seconds each time data is transmitted to the cloud. It is imperative to ensure compatibility between the expected outcomes mentioned in the "INTRODUCTION" section and the subsequent "RESULTS AND DISCUSSION" section. Furthermore, it is worth considering the potential for advancing study findings and the future application possibilities of further investigations in subsequent studies (based on the results and discussions).

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