Implementation of an IoT-Integrated Feedback Control System for Water Quality and Feeding Automation in Aquaculture

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ABSTRACT

This study introduces an IoT-based automated system for freshwater aquaculture, enabling real-time monitoring of water quality and control of fish feeding. The system utilises an ESP32 microcontroller integrated with pH, ultrasonic, infrared, temperature, and RTC sensors to monitor pond conditions. A servo motor is used for feed dispensing, while a fluid and clean water pump automatically adjusts pH levels when they fall outside the optimal range of 6.5–8.5. Sensor data is sent to the cloud via the Blynk platform, allowing remote monitoring and notification through a mobile app. Laboratory and field tests over three days demonstrated a fast response time of 1.78 seconds, accurate feed monitoring, and stable pH control. The system provides an efficient and low-cost solution for small to medium-scale aquaculture.

KEYWORDS: *Sensors, Fish feeding system, Blynk, RTC.*

1.0 INTRODUCTION

The rapid development of digital technology and automation has brought significant changes in various sectors, including the fisheries sector [1]. One of the most affected subsectors is fish farming (aquaculture), where the use of technology can increase operational efficiency and productivity [2]. The demand for fish as a source of animal protein continues to increase along with population growth, while its availability from natural waters is decreasing due to excessive exploitation, the use of fishing gear that damages habitats, and pollution of the aquatic environment [3].

This condition is also observed in Riau Province, particularly in the Pekanbaru area, where the population of river fish, such as *Baung, Wild Patin, and Semah*, has decreased drastically and is becoming increasingly rare [4]. This highlights the need for concerted efforts in developing freshwater fish farming as a means to sustain the sustainability of local protein sources while mitigating pressure on river ecosystems.

Aquaculture is a primary sustainable strategy to address the challenges of declining natural fish stocks [5–7]. However, cultivation practices still face several obstacles, particularly in terms of improving feeding efficiency and managing water quality [8–10]. Environmental parameters such as temperature, pH, and dissolved oxygen levels are important factors that significantly affect fish growth and health [11],[12]. Unstable water quality, mainly due to pH fluctuations and accumulation of organic waste, can cause stress, decreased appetite, and even death in farmed fish [13].

Several studies have stated that the ideal water pH for freshwater fish farming, such as catfish and tilapia, is in the range of 6.5 to 8.5 [14],[15]. In this context, automatic and real-time monitoring of water quality parameters is critical to maintain optimal environmental conditions [9],[16]. In addition, automation technology can also be applied to increase efficiency in feeding, which has been one of the most significant cost components in fish farming [17].

In line with technological advancements, Internet of Things (IoT)-based approaches are increasingly being adopted in modern aquaculture [18]. These systems enable real-time, remote monitoring and control of pond environments [10]. Numerous studies have proposed water quality monitoring systems incorporating pH, temperature, and Total Dissolved Solids (TDS) sensors [19–21]. Several implementations utilise NodeMCU microcontrollers with data visualisation via the Blynk application [21–26]. Other innovations have introduced automatic feeding mechanisms based on timers and Real Time Clock (RTC) modules [24]; however, these systems typically do not feature integrated water quality control.

Some developments have attempted to combine pH control and automated feeding using microcontroller-based platforms, but these remain limited to local monitoring without remote access capabilities. Additional studies have explored the integration of sensors and actuators within IoT frameworks, although these often focus solely on parameters such as temperature and water level [27]. They suggest that the integration of pH monitoring and automated feeding into a single, compact, and remotely accessible IoT system remains relatively underexplored.

Based on the research gap, this study aims to develop an IoT-based automatic water quality monitoring and feeding system using an ESP32 microcontroller. This system will integrate pH sensors and feeding actuators to support precision aquaculture practices, especially for small and medium-scale farmers. With cloud-based real-time monitoring and remote control capabilities, this system is expected to improve production efficiency and reduce the risk of failure due to manual errors in pond management.

2.0 METHOD

This study applies an Internet of Things (IoT)-based system engineering approach to design a prototype of water quality monitoring and automatic feeding in freshwater fish farming [18],[22],[28]. This system is designed for small to medium-scale farmers who require an efficient, affordable, and user-friendly solution [18]. The ESP32 microcontroller is used as the control centre because it has high data processing capabilities, power efficiency, and integrated Wi-Fi connectivity, allowing real-time data transmission to a cloud-based platform [19],[26]. The system's input components include a pH sensor to monitor the Water's acidity or alkalinity in real time, as pH is a vital parameter in fish growth [9],[18],[26],[29]. Additionally, a water temperature sensor is installed to detect temperature changes that impact fish metabolism and immunity. An ultrasonic sensor is used to measure the water level or the amount of feed remaining in the container [30],[31]. An infrared (IR) sensor detects the presence of objects or falling feed, and an RTC module ensures that every process, such as feeding and pH adjustment, is carried out on time [16]. Figure 1 illustrates the schematic design of the automatic fish feeding system, detailing the integration between the ESP32 microcontroller, sensors, and actuator components. This diagram provides a clear representation of the system's operational flow and its functional interconnections.

The actuation system comprises a servo motor and a fluid pump, which serve two primary functions. First, the servo motor controls the valve opening mechanism of the automatic feeder based on a schedule or detected conditions. Second, the pump system is used to inject a pH stabiliser solution into the pond, either a pH-up or pH-down solution, when the pH value is outside the optimal threshold, which is between 6.5 and 8.5 [14],[15]. The solution used can be a pH reducer (such as diluted vinegar) or a pH increaser (such as $NaHCO_3$), depending on the sensor detection results. Suppose the pH value remains unstable after chemical correction is carried out. In that case, the system can also activate an additional pump to automatically inject clean Water, thereby maintaining stable water quality and reducing the concentration of hazardous substances that accumulate due to unwanted feed residues or dissolved metabolic waste.

Data obtained from all sensors used are sent in real time to a cloud-based IoT platform, such as Blynk, and visualised through a mobile application or web-based dashboard [19],[20],[25],[26]. Through this system, users can monitor pond water quality parameters, control actuators, and receive notifications if there is a deviation in parameter values from the set threshold limits [32]. This system is also programmed to automatically send alerts if values outside the normal range are detected, enabling immediate corrective actions to be taken.

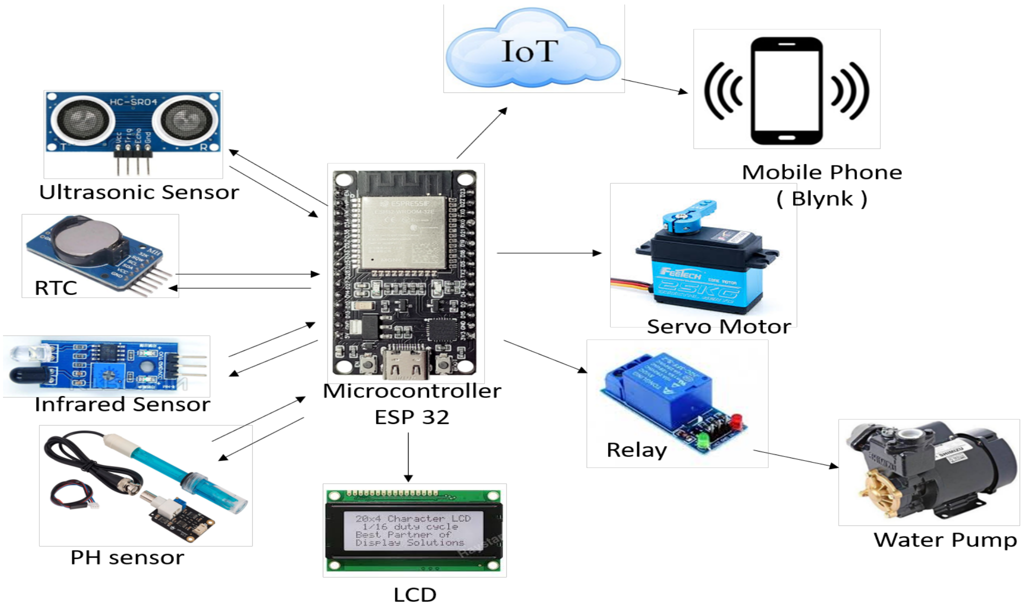

Figure 1: Automatic feeding device scheme

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With cloud-based remote monitoring and control capabilities, this system increases efficiency and responsiveness in sustainable fish farming management, even though users are not physically present at the farming location.

The stages of this research include the hardware and software design process, integration of sensors and actuators with the ESP32 microcontroller, and implementation of a cloud-based user interface. After the system integration is complete, laboratory testing is conducted to ensure that the sensor and actuator functions are operating correctly. Additionally, field trials are conducted on a small-scale pond to evaluate system performance directly. Evaluation parameters include sensor reading accuracy, actuator control reliability, connection stability, and ease of use of the system by operators.

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The overall system workflow is shown in Figure 2, which illustrates the process stages from initialisation to the implementation of automatic control of feeding and water quality monitoring.

3.0 RESULTS AND DISCUSSION

In this study, the results of designing and testing an automatic fish feeding system based on the Internet of Things (IoT) and integrated with the Blynk application on an Android smartphone were obtained. The results presented cover three main aspects: (1) hardware and software design results, (2) test results for each system component, and (3) analysis of overall system performance based on field trials.

3.1 Results of System Planning

The design of the mechanical system focuses on developing the main structure in the form of a panel box, which serves as a protector against external environmental disturbances affecting electronic components. Additionally, a feed tube is designed to be integrated with a servo motor, which regulates the valve opening and closing mechanism for the automatic feed distribution process. An ultrasonic sensor is installed at the top of the tube to measure the height of the remaining feed, while an infrared sensor is placed at the bottom to detect the release of feed in real time.

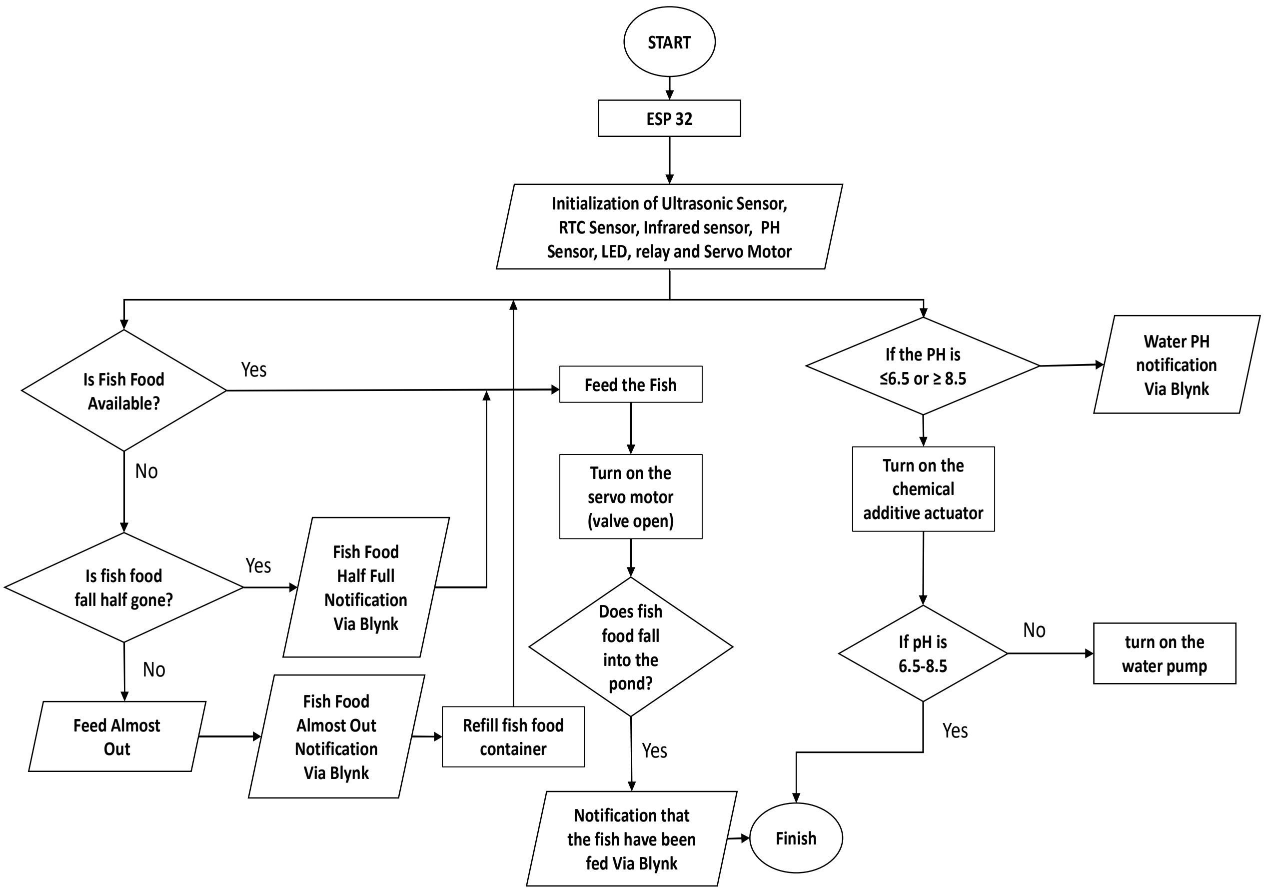

Figure 2: System flowchart

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In the electronic schematic design aspect, a 9×7 cm printed circuit board (PCB) serves as a medium for placing and connecting system components, comprising an ESP32 microcontroller, various sensors, and actuators. All components are connected using pin header connectors and jumper cables to facilitate assembly and maintenance. The system obtains its power supply from a 5V DC adapter that converts the 220V AC PLN voltage to 5V DC, as needed by the microcontroller and sensors.

In terms of user interface development, the Blynk platform is utilised as an Internet of Things (IoT)-based application, enabling online monitoring and control of the system. The interface offers features such as manual control buttons for feeding, a history graph of feeding activity, and a notification system. This system automatically schedules feedings three times a day, and all activities are recorded and can be monitored in real-time via the Blynk dashboard

3.2 Component Test Results

The results of the voltage testing on the components and sensors used in the designed equipment are presented in Table 1.

Table 1: Results of voltage testing on the components used

No	Component	Voltage Source	Voltage Data Sheet (V)	Voltage Measurement Results (V)	Difference (V)
1	Adaptor power supply	220 PLN	5	5.04	0.04
2	ESP32	Adaptor power supply	5	4.89	0.11
3	Sesor PH	ESP32	5	4.98	0.02
4	Utrasonic	ESP32	5	4.98	0.02
5	Infrared	ESP32	5	4.92	0.08
6	Motor Sevo	ESP32	3.3	3.26	0.04
7	RTC	ESP32	3.3	3.22	0.08

Based on the results of the voltage test, the power supply adapter connected to the 220 V PLN source produces an output of 5.04 V, exceeding the reference value of 5 V by 0.04 V. The voltage received by the ESP32 microcontroller is 4.89 V, which is 0.11 V lowers than the specified value, but still within the operational tolerance limit. Other components that receive power from the ESP32, such as the pH sensor and ultrasonic sensor, each receive a voltage of 4.98 V with a slight deviation of 0.02 V.

The infrared sensor records a voltage of 4.92 V, deviating 0.08 V from the nominal value of 4.84 V. Meanwhile, the servo motor and RTC module, which operate at a voltage of 3.3 V, show measurement results of 3.26 V and 3.22 V, respectively, with a difference of 0.04 V and 0.08 V. All components are still operating within acceptable voltage limits, indicating stable power distribution and system reliability in providing voltage supply according to the operational needs of each module.

Ultrasonic Sensor Testing

Ultrasonic sensor testing includes resistance, output voltage, calibration, and measurement accuracy. The resistance measurement results between the input cable and ground, at 630 Ω, indicate a reasonable impedance value without electric current. The output voltage test was carried out with variations in object distance (10–100 cm) and an input voltage of 5 V. The results show that the further the object distance, the sensor output voltage decreases, from 3.27 mV at 10 cm to 2.55 mV at 100 cm. This decreasing voltage trend is due to the characteristics of the ultrasonic sensor, where the distance is inversely proportional to the resulting voltage signal.

Calibration was performed by placing the object 30 cm away for 15 minutes. Through calculations based on echo pulses, a calibration value of 29.99 cm was obtained, very close to the actual distance. Accuracy testing was performed by comparing the sensor measurements with a ruler, showing a minimum difference of 0.01–0.15 cm. The accuracy level of the ultrasonic sensor reached 99.5% with an average error of only 0.3 cm, indicating that this sensor has a high level of accuracy and is suitable for use in automatic distance monitoring systems.

Infrared Sensor Resistance and Voltage Testing

The results of the infrared sensor resistance test showed that the resistance value between the input and output voltage lines was 10.19 kΩ. Furthermore, in the output voltage test, the sensor was given an input voltage of 5 V and tested with fish feed samples at two different distances. As a result, at a distance of 5 cm, the output voltage was obtained at 3.26 mV, while at a distance of 10 cm, the voltage decreased to 2.52 mV. These data indicate that the closer the object is to the sensor, the greater the voltage produced, indicating that the sensor has significant sensitivity to changes in object distance.

Servo Motor Testing

Based on the test results in Table 2, the servo motor is given an input voltage of 3.3 V. The results show that the angle setting value influences the magnitude of the output voltage. The greater the angle given, the greater the output voltage also increases. At an angle of 0°, the output voltage is recorded at 0.21 mV, while at an angle of 90°, the output voltage value increases to 0.55 mV.

Table 2: Servo motor voltage test results

Input Voltage	Sensor (degree)	Output (mV)
3.3	0	0.21
	30	0.29
	60	0.42
	90	0.55

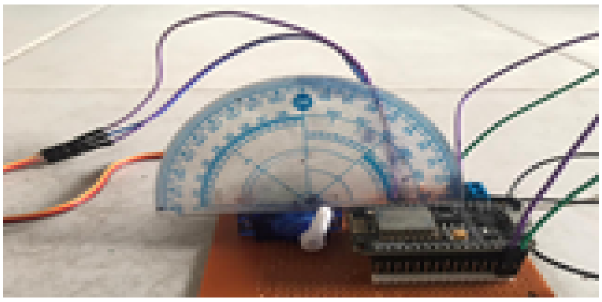

Figure 3: Servo motor angle testing

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Servo motor angle accuracy testing is done by comparing the motor response to pulse signal variations in different time ranges, namely 0.2 ms, 0.5 ms, and 0.8 ms. The test results are shown in Figure 3, which shows the relationship between pulse duration and servo motor movement angle.

Blynk Application Connection Testing

Connectivity testing indicates that the system can establish a stable connection with the Blynk application. After the initialisation process, the "Running Success" display appears on the serial monitor, indicating that the system is active and ready to operate.

Daily Test Results and Analysis

Overall, the designed system functions well and is integrated through smartphone control. The work process begins when the power source is activated, followed by filling the tube with 50 grams of feed. The system then performs the initialisation process and displays the message "Connecting Pakan System" on the serial monitor. After successful initialisation, the system displays the message "Running Success", which indicates that the device has operated normally.

1. First Day

The system was evaluated through three scheduled automated feeding sessions at 08:00, 13:00, and 18:00, with sensor data and system responses assessed one minute after each event. At 08:00, three feed portions were dispensed, with two detected as remaining at 08:01, indicating partial feed uptake. The system successfully identified the event and transmitted a notification at 08:01.2, resulting in a response latency of 2 seconds. The corresponding water pH reading was 6.63. At 13:00, two portions were dispensed, and one remained, followed by a notification at 13:01.2 (a 2-second delay) and a pH measurement of 6.54. During the 18:00 session, a single portion was dispensed and fully consumed, with a success notification received at 18:01.3 (a 3-second delay) and a pH of 6.78 recorded.

The system achieved an average notification delay of 2.33 seconds, indicating reliable real-time response and effective integration between the ESP32 microcontroller, sensors, and the cloud-based notification platform. Moreover, water pH remained within the optimal threshold for freshwater aquaculture, confirming the stability of environmental monitoring. These results demonstrate the system's capability for accurate event detection, low-latency communication, and efficient control, making it suitable for IoT-based aquaculture automation. A detailed summary of the test results is presented in Table 3.

Table 3: Test data on the first day

Feeding Time	Food Remains Volume	Reading of feeding success	Notification Receive Time	Time Difference	Water pH
8.00	3				
8.01	2	√	8.01.2	2 s	6.63
13.00	2				
13.01	1	√	13.01.2	2 s	6.54
18.00	1				
18.01	0	√	18.01.3	3 s	6.78

2. Second Day

The second day of system performance involved three automated feeding sessions conducted at 08:00, 13:00, and 18:00. In the first session at 08:00, food was dispensed, and two portions remained at 08:01, indicating 2/3 of the fish's feed was left. The system successfully detected the event and sent a notification at 08:01.2, with a response delay of 2 seconds. The measured water pH was 7.26. At 13:00, food was dispensed, with one portion remaining at 13:01. A success notification was received at 13:01.1 with a delay of 1 second, and the pH reading was 7.12. In the final session at 18:00, one portion was dispensed and completely consumed at 18:01. The system responded with a notification at 18:01.2, indicating a delay of 2 seconds, while the recorded pH level was 7.52. These observations confirmed that the system consistently detected feeding results with an average notification delay of approximately 1.67 seconds, demonstrating low-latency communication and effective integration between the sensors, microcontroller, and IoT platform. Furthermore, the water pH remained within the optimal range for freshwater aquaculture, indicating stable environmental monitoring. A detailed summary of these results is presented in Table 4.

Table 4: Test data on the second day

Feeding Time	Food Remains Volume	Reading of feeding success	Notification Receive Time	Time Difference	Water pH
8.00	3				
8.01	2	√	8.01.2	2 s	7.26
13.00	2				
13.01	1	√	13.01.1	1 s	7.12
18.00	1				
18.01	0	√	18.01.2	2 s	7.52

3. Day Three

The system was tested over three scheduled feeding sessions at 08:00, 13:00, and 18:00, with performance metrics evaluated one minute after each event. At 08:00, three portions of feed were dispensed, with two remaining at 08:01, indicating partial consumption. The system accurately detected this outcome and transmitted a success notification at 08:01.1, corresponding to a 1-second response time. The water pH at this point was measured at 7.47. Similarly, during the 13:00 session, two portions were dispensed, and one remained at 13:01. The system responded with a success notification at 13:01.2 (2-second delay), accompanied by a pH reading of 7.42. In the final session at 18:00, a single portion was dispensed and fully consumed by 18:01, as reflected by the notification received at 18:01.1 with a 1-second delay. The corresponding pH level was 6.97.

These results demonstrate the system's reliability in real-time event detection and notification, achieving an average response time of 1.33 seconds. The consistent performance across all sessions highlights the effective synchronisation between the feeding mechanism, sensor readings, and cloud-based communication. Additionally, the pH values remained within acceptable limits for freshwater aquaculture, indicating the system's capability to support both operational control and environmental monitoring. The detailed results are presented in Table 5.

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Table 5: Test data on the third day

Feeding Time	Food Remains Volume	Reading of feeding success	Notification Receive Time	Time Difference	Water pH
8.00	3				
8.01	2	√	8.01.1	1 s	7.47
13.00	2				
13.01	1	√	13.01.2	2 s	7.42
18.00	1				
18.01	0	√	18.01.1	1 s	6.97

The analysis of the test results confirms that the integrated system is capable of executing feeding commands with high accuracy and minimal latency. The average notification delay of 1.33 seconds indicates a responsive communication flow between the microcontroller, sensors, and cloud-based platform, which is essential for real-time monitoring in IoT-based aquaculture systems. Moreover, the consistent detection of feed consumption across all sessions demonstrates the effectiveness of the system's feedback mechanism. The water pH values, ranging from 6.97 to 7.47, remained within the optimal range for freshwater aquaculture, suggesting that the system not only supports automation but also ensures stable environmental conditions. These findings validate the system's reliability and suitability for use in real-world aquaculture environments requiring autonomous control and monitoring

4.0 CONCLUSION

This research presents an IoT-based feeding and water quality monitoring system utilising an ESP32 microcontroller, which operates automatically and in real-time through the Blynk application. The system successfully provides feed 3 times per day with an average notification interval of 1.3 minutes. The pH sensor recorded values ranging from 6.54 to 7.52 during testing, within the optimal range for freshwater fish farming. The results of the voltage test showed that all components worked within a maximum deviation range of ±0.11 V from the reference value. The accuracy level of the ultrasonic sensor reached 99.5% with an average error of only 0.3 cm. The system demonstrated stable and responsive performance, making it feasible to implement on a small to medium-scale cultivation to improve operational efficiency and sustainability.

5.0 REFERENCES

[1] Rowan, N.J. (2023). The role of digital technologies in supporting and improving fishery and aquaculture across the supply chain–Quo Vadis? *Aquaculture and Fisheries, 8*(4), 365–374.

[2] Føre, M., Frank, K., Norton, T., Svendsen, E., Alfredsen, J. A., Dempster, T., ... & Berckmans, D. (2018). Precision fish farming: A new framework to improve production in aquaculture. *Biosystems Engineering, 173*, 176–193.

[3] Vianna, G.M.S., Zeller, D. & Pauly, D. (2020). Fisheries and policy implications for human nutrition. *Current Environmental Health Reports, 7*, 161–169.

[4] Prianto, E., Marini, M., Triharyuni, S. & Purwoko, R. M. (2020). The effect of anthropogenic changes on the sustainability of eastern Sumatran floodplain fisheries resources. In *IOP Conference Series: Earth and Environmental Science* (p. 012022). IOP Publishing.

[5] Pahlow, M., Van Oel, P.R., Mekonnen, M.M. & Hoekstra, A.Y. (2015). Increasing pressure on freshwater resources due to terrestrial feed ingredients for aquaculture production. *Science of the Total Environment, 536*, 847–857.

[6] Blanchard, J.L., Watson, R.A., Fulton, E.A., Cottrell, R.S., Nash, K.L., et al. (2017). Linked sustainability challenges and trade-offs among fisheries, aquaculture and agriculture. *Nature Ecology & Evolution, 1*(9), 1240–1249.

[7] Boyd, C.E., McNevin, A.A., Davis, R.P., Godumala, R., Mohan, A.B.C. & Nunes, A.J.P. (2020). Achieving sustainable aquaculture: Historical and current perspectives and future needs and challenges. *Journal of the World Aquaculture Society, 51*(3), 578–633.

[8] Echiegu, E.A., Ezeugwu, L.I. & Ugwu, S.N. (2018). Effects of water hyacinth (*Eichhornia crassipes*) on the physicochemical properties of fishpond water and growth of African catfish. *African Journal of Agricultural Research, 13*(2), 54–66.

[9] Lindholm-Lehto, P. (2023). Water quality monitoring in recirculating aquaculture systems. *Aquaculture and Fisheries and Fish, 3*(2), 113–131.

[10] Nagothu, S.K., Sri, P.B., Anitha, G., Vincent, S. & Kumar, O. P. (2025). Advancing aquaculture: Fuzzy logic-based water quality monitoring and maintenance system for precision aquaculture. *Aquaculture International, 33*(1), 32.

[11] Mariu, A., Chatha, A.M.M., Naz, S., Khan, M.F., Safdar, W., & Ashraf, I. (2023). Effect of temperature, pH, salinity and dissolved oxygen on fishes. *Journal of Zoological Systematics, 1*(2), 1–12.

[12] Chowdhury, S. & Saikia, S. K. (2020). Oxidative stress in fish: A review. *Journal of Scientific Research, 12*(1), 145–160.

[13] Pepe-Victoriano, R., Espinoza, J., Herrera, M., et al. (2025). Evaluation of water quality in the production of rainbow trout (*Oncorhynchus mykiss*) in a recirculating aquaculture system (RAS) in the Precordilleran region of Northern Chile. *Water, 17*(11), 1685.

[14] Kelany, N.F., Abdel-Mohsein, H. S., Kotb, S. & Ismail, A.E.M.A. (2024). Significant impact of physicochemical water parameters in tilapia aquaculture. *Journal of Advanced Veterinary Research*, *14*(6), 1060-1064.

[15] SAUOO, U. (2012). Effects of agricultural lime ($CaCO_3$) on water quality and fish growth under outdoor hard water fish culture conditions. *West Bengal University of Animal and Fishery Sciences*.

[16] Adu-Manu, K.S., Tapparello, C., Heinzelman, W., Katsriku, F.A. & Abdulai, J.-D. (2017). Water quality monitoring using wireless sensor networks: Current trends and future research directions. *ACM Transactions on Sensor Networks, 13*(1), 1–41.

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[17] Zhou, C., Xu, D., Lin, K., Sun, C. & Yang, X. (2018). Intelligent feeding control methods in aquaculture with an emphasis on fish: A review. *Reviews in Aquaculture, 10*(4), 975–993.
[18] Jais, N.A.M., Abdullah, A.F., Kassim, M.S.M., Abd Karim, M.M. & Muhadi, N. (2024). Improved accuracy in IoT-based water quality monitoring for aquaculture tanks using low-cost sensors: Asian seabass fish farming. *Heliyon, 10*(8).
[19] Sugiharto, W.H., Susanto, H. & Prasetijo, A. B. (2023). Real-time water quality assessment via IoT: Monitoring pH, TDS, temperature, and turbidity. *Ingénierie des Systèmes d'Information, 28*(4), 823–831.
[20] Susanti, N.D., Sagita, D., Apriyanto, I.F., Anggara, C.E.W., Darmajana, D.A. & Rahayuningtyas, A. (2022). Design and implementation of water quality monitoring system (temperature, pH, TDS) in aquaculture using IoT at low cost. In *6th International Conference of Food, Agriculture, and Natural Resource (IC-FANRES 2021)* (pp. 7–11). Atlantis Press.
[21] Abu Bakar, A.A., Bakar, Z.A., Yusoff, Z.M., Mohamed Ibrahim, M.J., Mokhtar, N.A. & Zaiton, S.N. (2025). IoT-based real-time water quality monitoring and sensor calibration for enhanced accuracy and reliability. *International Journal of Interactive Mobile Technologies, 19*(1).
[22] Zulkifli, C.Z., Rahman, N.A.A., Zulkifli, S.Z., et al. (2022). IoT-based water monitoring systems: A systematic review. *Water, 14*(22), 3621.
[23] Farouk, M.I.H.Z., Latip, M.F.A. & Jamil, Z. (2022). Integrated water quality monitoring system and IoT technology for surface water monitoring. In *AIP Conference Proceedings*. AIP Publishing.
[24] Maharmi, B., Kardova, T., & Ermawati. (2019). Development of cost-saving energy for home lighting based on microcontroller and RTC. *International Journal of Electrical Energy and Power System Engineering, 2*(2), 20–24. https://doi.org/10.31258/ijeepse.2.2.20-24.
[25] Maharmi, B., Bijaksono, C., Machdalena, M. & Yolnasdi, Y. (2024). Desain kontrol smart home berbasis IoT dan Bluetooth. *SAINSTEK, 12*(1), 154–159.
[26] Maharmi, B., Samsudin, S., Ramdha, T. & Hanifulkhair, H. (2024). Integrated IoT-based fire prevention and evacuation system for high-rise buildings. *Journal of Ocean Mechanical and Aerospace-Science Engineering, 68*(3), 161–168.
[27] Selvam, A.P. & Al-Humairi, S.N.S. (2023). The impact of IoT and sensor integration on real-time weather monitoring systems: A systematic review.
[28] Prapti, D.R., Mohamed Shariff, A.R., Che Man, H., Ramli, N.M., Perumal, T. & Shariff, M. (2022). Internet of Things (IoT)-based aquaculture: An overview of IoT application on water quality monitoring. *Reviews in Aquaculture, 14*(2), 979–992.
[29] Amalia, F. & Nasution, S. (2024). Implementation system monitoring and control temperature and pH in urban silver catfish hatchery to enhance efficiency and responsiveness based on IoT. *Jurnal Sistem dan Manajemen Industri, 8*(1), 22–34.
[30] Maharmi, B., Widyastomo, B., & Palaha, F. (2022). Water flow measurement-based data acquisition using Arduino microcontroller and PLX-DAQ software. *Jurnal Ilmiah Teknik Elektro Komputer dan Informatika, 8*(1), 107. https://doi.org/10.26555/jiteki.v8i1.23637.
[31] Mohammed, S.L., Al-Naji, A., Farjo, M.M., & Chahl, J. (2019). Highly accurate water level measurement system using a microcontroller and an ultrasonic sensor. In *IOP Conference Series: Materials Science and Engineering* (p. 042025). IOP Publishing.
[32] Elmessery, W.M., Ibrahim, M.J.M., Bakar, Z.A., Mokhtar, N.A., et al. (2025). A deep deterministic policy gradient approach for optimizing feeding rates and water quality management in recirculating aquaculture systems. *Aquaculture International, 33*(4), 253.