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Original Article

Smart Aquaculture: IoT-Enabled Monitoring and Management of Water Quality for Mahseer Fish Farming

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Abstract - *Aquaculture is essential for meeting the growing global demand for seafood by cultivating aquatic species in controlled environments such as ponds and tanks. This study presents an innovative IoT-based water quality monitoring system designed specifically for Mahseer fish farming. The system utilizes an ESP32 Development Board equipped with sensors to monitor water quality parameters and employs the Blynk 2.0 platform for real-time data visualization. A C/C++ algorithm managed through the Arduino IDE facilitates effective communication between the sensors and the microcontroller. The results demonstrate the system's effectiveness in maintaining optimal water conditions, enabling early detection and timely intervention for potential issues. This approach enhances the sustainability and efficiency of Mahseer fish farming. Future research will focus on refining accuracy, improving scalability, and integrating advanced data analytics to boost predictive capabilities and promote more efficient and profitable aquaculture practices.*

Keywords - *Aquaculture, Mahseer, IoT, Blynk, Esp32.*

1. Introduction

Aquaculture, also referred to as aqua farming, is the carefully regulated rearing of aquatic animals, such as fish, mollusks, crustaceans, and plants, in ponds, tanks, and ocean enclosures [1]. With global demand for seafood on the rise, aquaculture has become a crucial contributor to the food supply chain, enhancing the availability of fish for human consumption and meeting nutritional needs worldwide [2]. However, while aquaculture helps address food security, sustainable production faces several challenges, particularly concerning environmental impact and resource efficiency.

A significant gap exists in ensuring sustainable aquaculture that can meet both rising demand and environmental standards. This is especially relevant for producing native species, such as Mahseer, where balancing growth with ecosystem health is essential [3]. Water quality plays a pivotal role in fish health, growth, and reproductive success, making monitoring and managing water conditions vital to sustainable aquaculture practices [4].

To address these challenges, integrating Internet of Things (IoT) technology into aquaculture systems is emerging as a transformative solution. IoT provides real-time monitoring capabilities that enable fish farmers to manage water conditions effectively, thus improving overall efficiency and reducing risks [5]. For developing nations, such as India, where aquaculture contributes significantly to GDP, IoT-based monitoring systems can play a critical role in safeguarding economic interests and supporting local food production [6].

The application of IoT in aquaculture is still evolving, yet it holds vast potential to support sustainable, resilient fish farming practices. Although the concept of IoT was introduced in 1999 by Kevin Ashton, its recent integration into aquaculture represents a novel approach within information technology [7]. In regions with challenging climates, such as Malaysia’s hot and humid conditions, IoT can optimize fish health management, ensuring that temperature, pH, and oxygen levels are maintained for optimal spawning conditions [8, 9].

Moreover, as disease outbreaks pose substantial risks to fish populations, controlling them without heavy reliance on antibiotics many of which are restricted in aquaculture by law becomes imperative [11]. Furthermore, economic challenges, such as high feed costs, push the industry to explore cost-effective, sustainable alternatives, such as using recycled materials in feed [12, 13]. As global demand for protein grows, addressing these economic and environmental constraints through innovative solutions like IoT can lead to more efficient, sustainable aquaculture systems [14].

The novelty of this research lies in its application of IoT technology specifically tailored to the needs and challenges of aquaculture in developing regions, where economic, environmental, and technological constraints often hinder sustainable fish farming. While IoT has shown transformative potential in many industries, its application in aquaculture is relatively recent. It is primarily limited to developed regions with more readily available resources and technological infrastructure.

Existing research on IoT in aquaculture predominantly focuses on high-resource settings where the infrastructure allows for sophisticated, high-cost sensors and management systems. These studies demonstrate the benefits of IoT, including improved water quality control, disease prevention, and cost efficiency. However, they often lack emphasis on scalability and accessibility for resource-limited settings, where aquaculture practices and challenges differ significantly. For example, research in developed countries has implemented IoT-based closed-system fish farming with highly automated environments. However, the high costs and complex maintenance requirements are barriers for small-scale farmers in developing nations.

In contrast, this research proposes a more accessible, low-cost IoT framework tailored for small-scale aquaculture, focusing on robust sensor technology and simplified management systems that address essential parameters such as pH, temperature, and oxygen levels. By streamlining these core functions, this study aims to improve fish health and yield in environments with limited infrastructure, making IoT more adaptable and sustainable for farmers in emerging economies.

2. Literature Review

Hajar Rastegari and colleagues (2023) studied internet Things in aquaculture. Aquaculture involves farming aquatic species under controlled conditions. Challenges in incorporating IoT systems in aquaculture include power grid access, internet connection, and environmental factors.

Aquaculture has seen a technological revolution with the development of IoT, allowing for real-time monitoring of water quality and prediction systems to improve sustainability and profitability in the industry [15].

Aquaculture faces challenges due to rising seafood demand, but IoT-based water quality monitoring systems can boost productivity [16]. Marcelo Moro (2023) discusses the cost-saving and efficiency-improving benefits of IoT in "Implementation of an IoT-Based Water Quality Monitoring System for Aquaculture" [17]. The system, using temperature and quality monitoring sensors, offers remote tracking and instant notifications, addressing industry challenges.

Mohammad Daud and the research team from Institut Teknologi Brunei developed an IoT-based prototype for smart aquaculture shrimp farming, automating manual monitoring and control to improve productivity and shrimp health [18]. Studies on the Malaysian mahseer, a valuable fish in Asian aquaculture, focus on morphology, genetics, reproduction, nutrition, and conservation to support conservation and fish farming initiatives [19].

An IoT-based system has been proposed to simplify pearl farming by monitoring water quality and maintaining an ideal underwater environment. As a result of global warming, annual rainfall has decreased, significantly reducing crop production for developing nations like India. Farmers find aquaculture-based farming challenging due to a lack of skills and monitoring issues [20].

3. Materials and Methods

To address the unique requirements of Mahseer fish farming, this study proposes a detailed IoT-based system for real-time water quality monitoring. The primary objectives focus on designing a system using sensors and microcontrollers, improving accuracy and performance, and making data accessible via the Blynk IoT platform. The study aims to boost operational efficiency, promote environmental sustainability, and support the livelihoods of Mahseer fish farmers.

Central to the approach is integrating the ESP32 Development Board, which features built-in Bluetooth and Wi-Fi, providing connectivity and facilitating seamless data transmission. By using specialized sensors, including those measuring ammonia and water temperature, the system can capture a wide array of critical environmental data. The implementation process prioritizes data logging and calibration methods to ensure the system’s accuracy and reliability in monitoring parameters vital to Mahseer's health.

The system’s decision-making flow, as shown in Figure 1, includes specific thresholds for each parameter to automate environmental adjustments. For example, dissolved oxygen levels are set to maintain a range of 6-8 mg/L. Should these levels fall below 6 mg/L, calcium carbonate is released; if levels drop further to below 3 mg/L, an aerator is activated to oxygenate the water.

Similarly, pH levels are kept within the 6.5-8.5 range, with automated adjustments via alkaline or acidic solutions. Ammonia and temperature thresholds ensure that levels remain optimal for Mahseer by triggering filtration and heating or cooling mechanisms as necessary.

3.1. NodeMCU ESP 32

The NodeMCU ESP32 serves as the system's central processing unit, with its dual-core processor operating at frequencies up to 240 MHz. This microcontroller handles real-time data transmission and logging from multiple sensors. It supports Bluetooth 4.2 and 802.11 b/g/n Wi-Fi, enabling connectivity with the Blynk 2.0 IoT platform for remote monitoring and control [21].

3.1.1. System Architecture

- ESP32 NodeMCU Microcontroller: Interfaces with each sensor to collect, process, and transmit data to the cloud.
- Sensors: Dissolved Oxygen (DO), Ammonia (NH_3), water temperature, and pH sensors connected to the ESP32 via analog or digital GPIO pins.
- Blynk 2.0 Platform: A cloud-based platform used for real-time monitoring, data logging, and system alerts.
- Power Supply: 5V power for the ESP32 and sensors, stabilized with a voltage regulator to prevent fluctuations.
- Actuators: Includes an aerator, heater, and pH correction system, all activated automatically based on sensor data.

The ESP32 is programmed to send data at preset intervals to the Blynk app, allowing fish farmers to receive real-time smartphone alerts when any parameter deviates from optimal levels.

3.1.2. Sensor Selection and Calibration

- DO Sensor: Calibrated with an air-saturated solution for maximum DO levels and a deoxygenated solution for minimum levels.
- Ammonia Sensor: Calibrated using reference ammonia solutions with known concentrations.
- pH Sensor: Calibrated using standard buffer solutions, typically at pH 4, 7, and 10, to ensure accuracy across the full pH range.
- Temperature Sensor: Checked against a reliable thermometer or standard to verify accuracy at different temperature points.

Calibration is performed weekly to maintain accuracy, and each sensor has automated calibration routines programmed into the ESP32.

3.2. Dissolved Oxygen (Do) Sensor

The DO sensor is configured to provide measurements in mg/L or ppm and is calibrated regularly. The system logs readings at 10-minute intervals, which balances capturing real-time fluctuations and managing power consumption. If oxygen levels drop below the threshold, the ESP32 triggers the aerator, ensuring optimal conditions for Mahseer fish [22].

3.3. Ammonia Sensor (NH_3)

The NH_3 sensor monitors ammonia levels, which is critical for preventing toxicity in Mahseer aquaculture. Data from the NH_3 sensor is recorded at 15-minute intervals and compared against preset safe levels (e.g., 0.02 mg/L). Should levels exceed this threshold, the ESP32 activates a filtration system to reduce ammonia concentrations [23].

3.4. Water Temperature Sensor

This sensor monitors water temperature to maintain it within the ideal range of 24-27°C for Mahseer. Data is logged every 5 minutes due to the sensitivity of fish to temperature changes. If temperatures rise or fall beyond the optimal range, the ESP32 will activate a heater or aerator to adjust the temperature. The sensor is calibrated regularly using a standard thermometer for accuracy [24].

3.5. pH Sensor

pH readings are essential for preventing stress and promoting healthy growth in Mahseer. The pH sensor is set to log data every 10 minutes and has a range of 6.5–8.5 as the acceptable threshold. Should the pH drop below 6.5 or rise above 8.5, the ESP32 activates an acid or alkaline solution dispenser to correct the pH [25].

3.6. Software and Programming

The study's algorithm, written in C/C++, controls the signals coming from the system's sensors. Sensor readings are continuously monitored using the Blynk 2.0 IoT platform, with notifications provided through the Blynk application [26]. The Arduino IDE is used to implement the project.

3.7. Blynk 2.0 IoT Platform

The Blynk 2.0 platform, which offers a feature-rich web dashboard with a drag-and-drop user interface editor for managing users, devices, and data, is depicted in Figure 2. It also offers a user-friendly add-on widget for the Blynk IOT smartphone application. Figure 3 shows the structure of the Blynk 2.0 activities.

3.8. System Integration

The Mahseer fish farming monitoring technology seamlessly incorporates a system of sensors, such as temperature, pH, dissolved oxygen, and ammonia. Every sensor has a distinct function in the water quality monitoring system. Coherent operation is ensured by connecting and coordinating various sensors into a single monitoring system through integration.

For instance, the pH sensor determines acidity, the ammonia sensor detects ammonia concentrations, the dissolved oxygen sensor determines oxygen levels, and the temperature sensor determines the water's temperature.

With the help of this integrated system, fish farmers can effectively monitor and control the Mahseer habitat, taking into account elements like stress management, successful reproduction, nutrition availability, and biological processes that run smoothly [27].

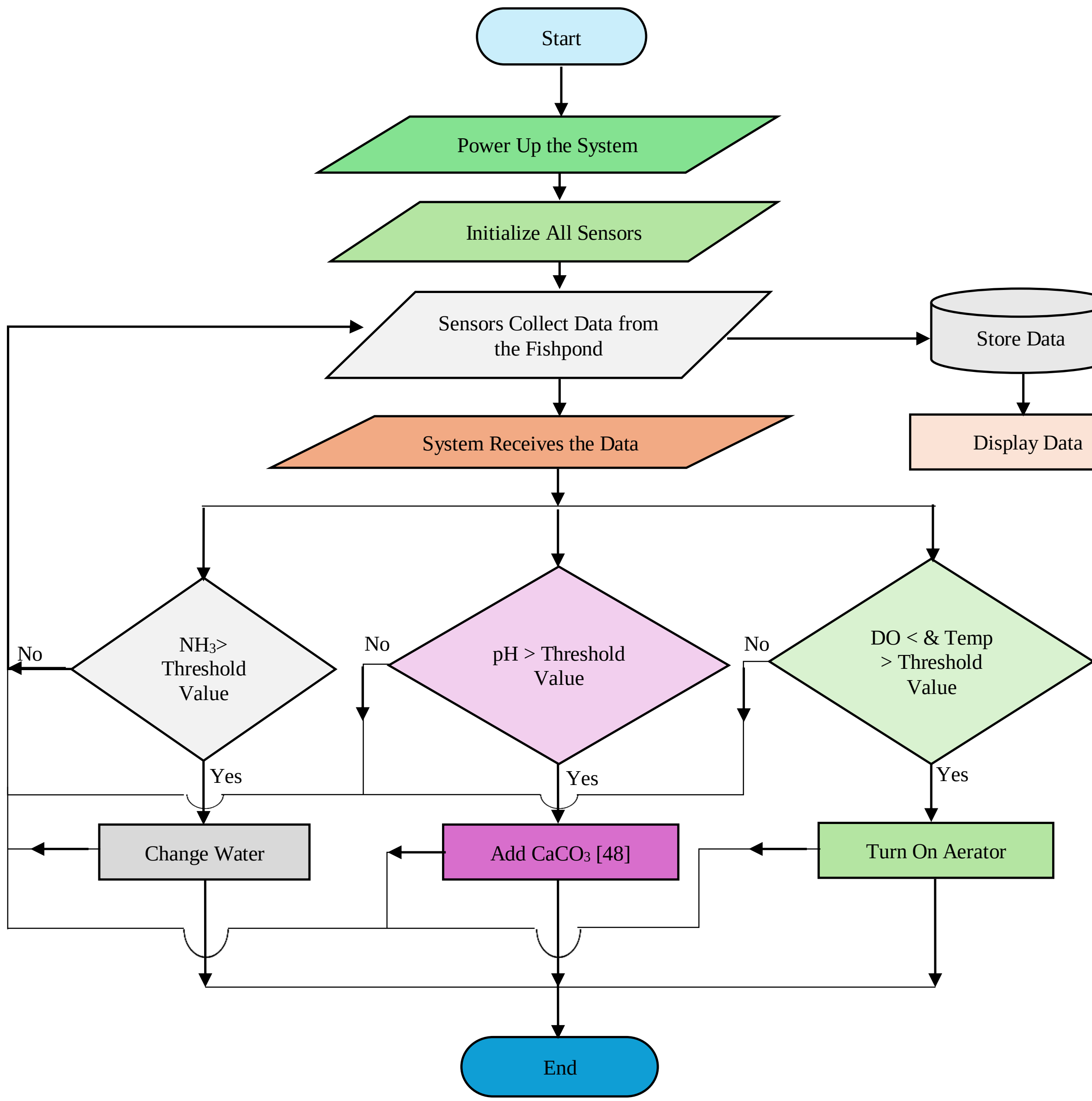

Fig. 1 System flowchart

System integration also includes data processing and communication, and it includes a Wi-Fi module for data access and remote monitoring. The effectiveness of keleh fish farming operations is improved by this comprehensive integration, which promotes general well-being, sustainability, and prosperity.

3.9. Hardware Setup

Dissolved oxygen, ammonia, temperature, and pH sensors were attached to the proper pins on the ESP32 WiFi module to configure the hardware for the Mahseer fish farming monitoring system.

To ensure accurate and dependable data gathering, it is essential to verify compatibility with the microcontroller and ensure adequate cabling. As the central hub, the ESP32 enables wireless connectivity, enabling data access and remote monitoring. This well-organized hardware setup lays the groundwork for a smooth functioning system and possible future growth.

3.10. Software Development

During the software development stage, we programmed the ESP32 WiFi module using the Arduino IDE programming environment. We set up the microcontroller to read data from the temperature, pH, ammonia, and dissolved oxygen sensors using the proper libraries and APIs. The developed code ensures that the sensors and the ESP32 module communicate with each other effectively by encapsulating the logic required for data detection and collecting.

3.11. Blynk Integration

We used the Blynk 2.0 IoT platform, allowing real-time monitoring and data visualization. The authentication token was one of the necessary credentials we acquired after registering and establishing a project specifically for our system. We set up pertinent widgets inside the Blynk project by establishing a connection between the ESP32 WiFi module and the Blynk platform with these credentials.

These widgets are designed to show and track the information obtained from the temperature, pH, ammonia, and dissolved oxygen sensors. They offer a convenient user interface for thorough system management.

3.12. Testing and Deployment

In order to ensure reliable readings, we tested and confirmed the sensor's operation. After securing hardware and guaranteeing steady connections, the system was put into use in the Mahseer fish farming setting. In order to provide a dependable and functional monitoring solution with real-time insights and notifications, system parameters were adjusted through continuous monitoring throughout the deployment.

3.13. Security Measures and Data Privacy

Mahseer fish farming must employ encryption for safe data transfer, access controls to manage permissions, and privacy policy compliance to provide strong security and data privacy. These safeguards, safe means of communication, and frequent security audits establish a reliable and robust monitoring system.

3.14. System Structure

A system structure and schematic design that integrates many sensors with an ESP32 microcontroller that is programmed using the Arduino IDE and linked to the Blynk 2.0 IoT platform are shown in Figures 4 and 5, respectively. The sensors collect data and transmit it to the ESP32 microprocessor. Examples of these sensors include temperature, gas, and pH sensors. As the primary component, this microcontroller processes the incoming data.

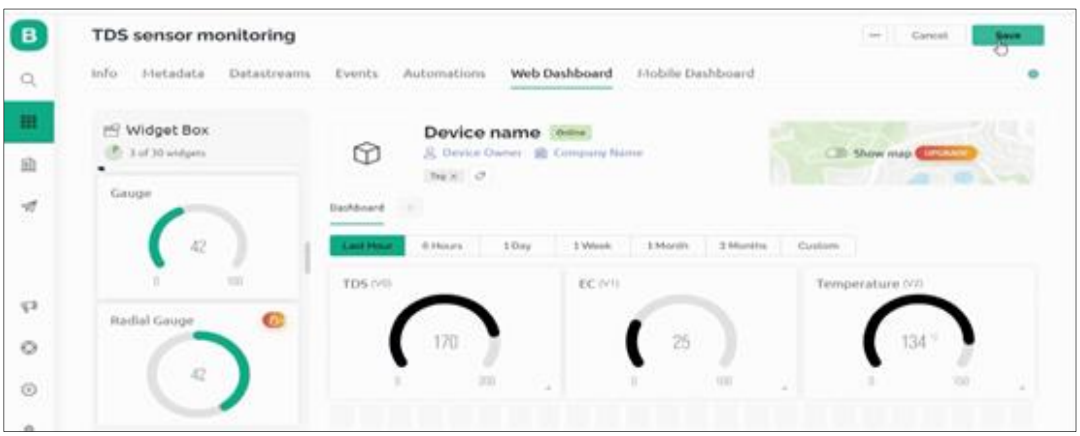

Fig. 2 Blynk dashboard

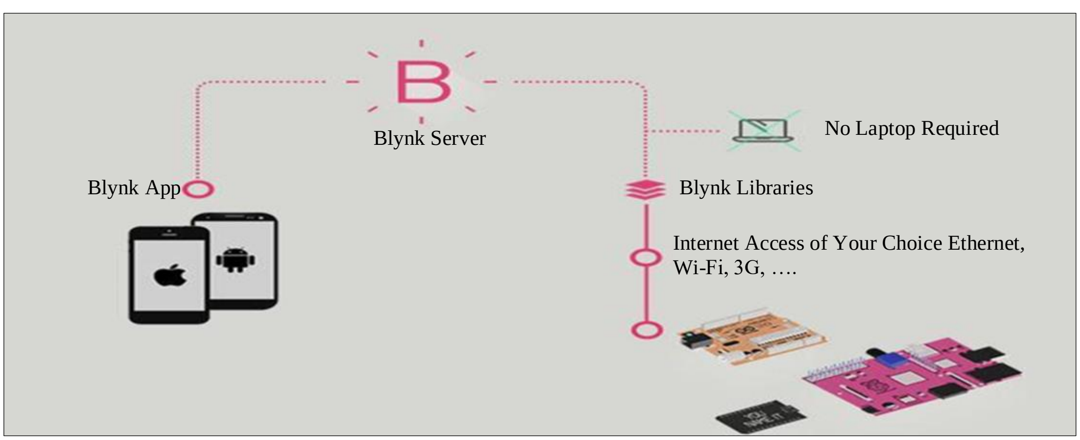

Fig. 3 Blynk configuration topology

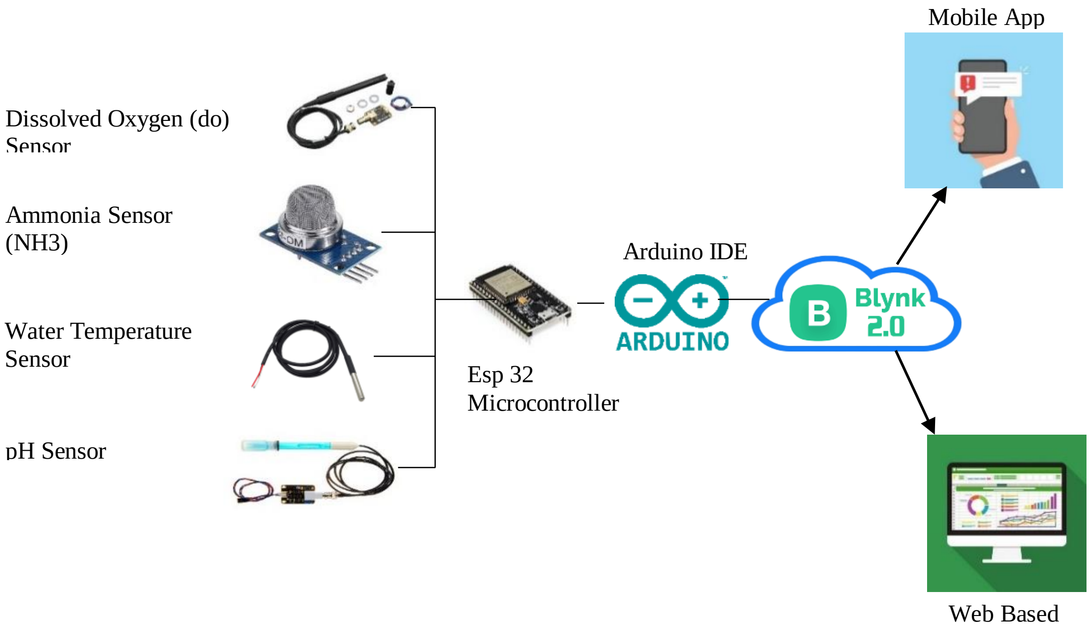

Fig. 4 System architecture

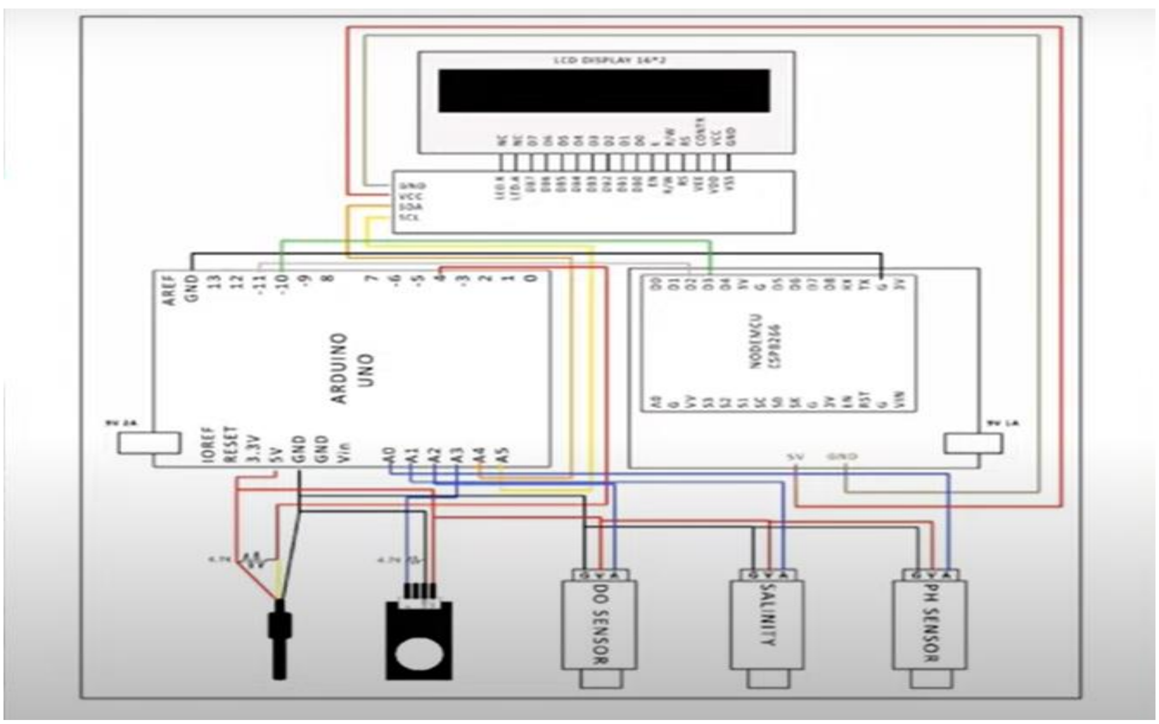

Fig. 5 Schematic diagram

The Arduino IDE is used to write, compile, and upload code to the ESP32 to perform its intended purpose inside the system. The Blynk 2.0 platform enables real-time data visualization and continuous monitoring by linking the system to the cloud. As a result, users may effectively monitor and control the system from a distance by using web-based interfaces and mobile applications to obtain sensor data and get notifications.

4. Results and Discussion

As seen in Figure 6, Information Shown: (a) pH Level; (b) NH_3 Level. The collected data indicates that the pH of the observed water samples is 11.12. There is a fair amount of alkalinity indicated by this alkaline pH result. Mahseer fish prefer neutral to slightly alkaline environments, although careful observation and possible alterations are necessary to guarantee ideal circumstances for their health. Maintaining an appropriate aquatic environment will require more research on the causes of high pH, such as the presence of specific minerals or chemicals.

The detected amount of Ammonia (NH_3) in the water samples is 0.03 parts per million. In aquaculture, ammonia in all forms is an essential metric to keep an eye on since high concentrations can be detrimental to fish. A well-managed ammonia environment is indicated by the detected low concentration, which is encouraging. To avoid any possible increases and guarantee long-term viability, continuous observation of the Mahseer fish population is required. Proactive management plans can be developed by thoroughly examining the system's sources and dynamics of ammonia.

Data presented, as shown in Figure 7: DO level (a); temperature level (b). The water's Dissolved Oxygen (DO) content is measured at 0.20 mg/L. Fish require a sufficient amount of dissolved oxygen to support their respiratory systems. The amount found falls within the range that Mahseer fish can tolerate, indicating that the habitat is favorable and oxygenated. It will be essential to keep an eye out for any potential deviations and maintain the fish's ideal oxygen levels.

The temperature of the water is 29.25°C. The recorded temperature is within the range that Mahseer fish enjoy, and they normally flourish in tropical settings. However, for the general well-being and expansion of the fish population, stability and the avoidance of abrupt temperature swings are crucial.

The data is represented graphically in a graph that makes it easier to monitor in real-time, giving interested parties the ability to track changes and patterns over a customizable time frame of one hour to three months. This dynamic depiction guarantees prompt interventions when needed by enabling quick reactions to abrupt changes in water quality. The visual aid will prove to be an invaluable instrument in trend analysis as data is gathered, helping to spot patterns that might impact the long-term water quality and, in turn, the well-being of Mahseer fish. This flexibility in monitoring duration improves our capacity to make deft judgments and use flexible management strategies inside the fish farming system.

Table 1. Recommended water quality parameters for mahseer fish farming

Parameters	Value Ranges	References
Water Temperature	24ºC – 30ºC	[28, 29]
pH	6.5-8	[24]
DO	6-9 ppm	[30, 31]
NH_3	0.02-0.05ppm	[23]

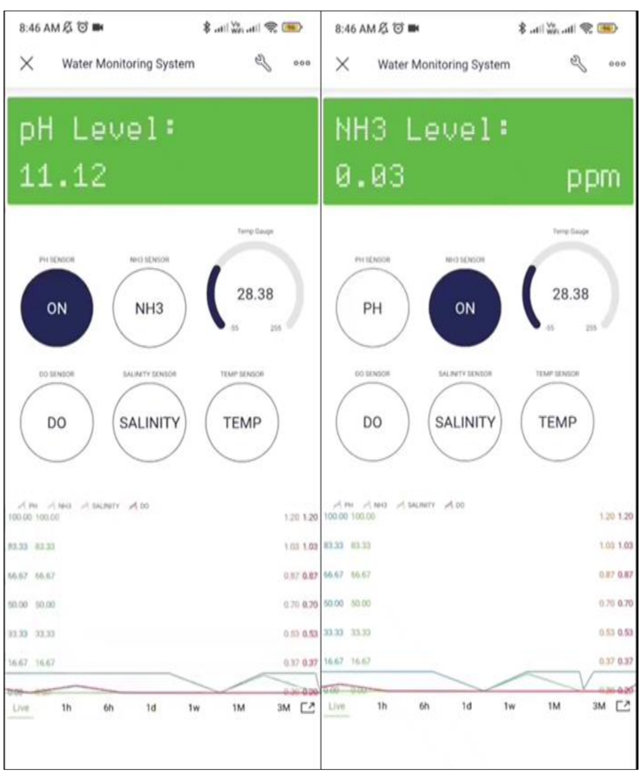

Fig. 6 Data presented (a) pH level, and (b) NH_3 level.

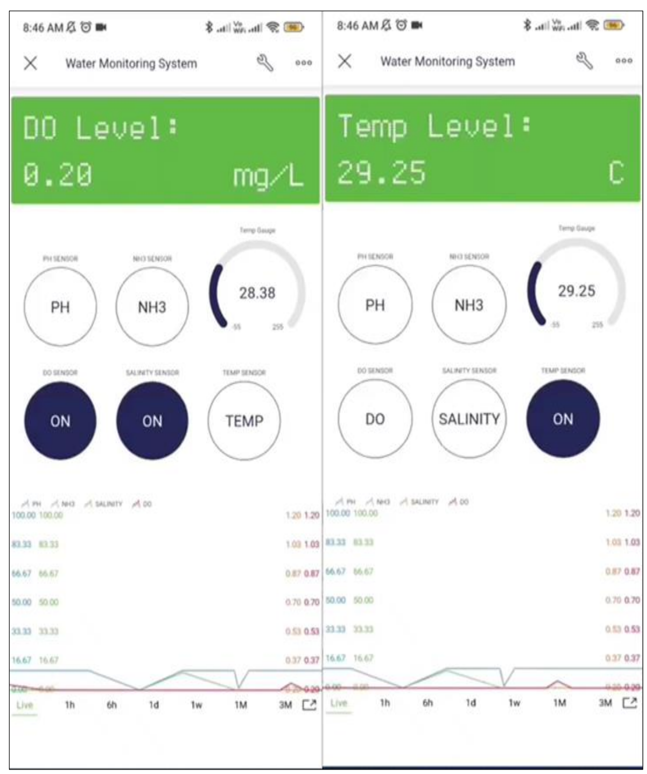

Fig. 7 Data presented (a) DO level, and (b) Temp level.

5. Conclusion

This study addresses the significant challenges faced in Mahseer fish farming by introducing an advanced IoT-based water quality monitoring system. By leveraging precise sensors and integrating them with the ESP32 Development Board, the system provides real-time monitoring of critical water quality parameters, including temperature, pH, dissolved oxygen, and ammonia. The deployment of this technology, supported by the Blynk 2.0 IoT platform, facilitates immediate corrective actions, ensuring optimal conditions for the health and growth of Mahseer fish.

The results demonstrate that the IoT-based system can effectively monitor and maintain suitable water quality conditions. The recorded data on pH, ammonia, dissolved oxygen, and temperature fall within acceptable ranges, ensuring a conducive environment for the fish. Continuous monitoring and the ability to visualize data trends over time are crucial for the early detection of potential issues and timely interventions. This innovative approach not only enhances the sustainability and efficiency of Mahseer fish farming but also contributes to environmental conservation by enabling better management of water resources. Integrating IoT technology in aquaculture practices exemplifies a transformative step towards achieving the Sustainable Development Goals (SDGs), promoting responsible production and consumption and conserving aquatic life.

Future work should focus on expanding the IoT-based water quality monitoring system by incorporating additional parameters and enhancing predictive capabilities through advanced data models. To provide a more comprehensive view of the aquatic environment, additional sensors could be integrated to measure factors such as turbidity, salinity, and nutrient levels alongside pH, dissolved oxygen, and ammonia. This would enable more precise management of fish farming conditions. Furthermore, developing and training machine learning models to analyze the data and predict potential water quality issues, such as oxygen depletion or ammonia buildup, would allow for proactive management. These predictive models could automate corrective actions and improve decision-making by leveraging historical and real-time data. Enhancing the accuracy of these models through larger, more diverse datasets will also be key in improving their reliability across various environmental conditions. These advancements will significantly improve the system's ability to manage water quality and contribute to more efficient, sustainable fish farming practices.

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References

[1] Haochen Hou et al., “An Environmental Impact Assessment of Largemouth Bass (Micropterus Salmoides) Aquaculture in Hangzhou, China,” *Sustainability*, vol. 15, no. 16, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[2] Lahsen Ababouch et al., “Value Chains and Market Access for Aquaculture Products,” *Journal of the World Aquaculture Society*, vol. 54, no. 2. pp. 527-553, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[3] I. Mulyani et al., “The Ecological Analysis of the Habitat of Semah Fish (Tor Tambroides, Bleeker 1854) in the Kampar Kanan Hulu River Koto Kampar Hulu District, Kampar Regency, Riau Province,” *IOP Conference Series: Earth and Environmental Science*, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[4] Peda Gopi Arepalli, and Jairam Naik Khetavath, “An IoT Framework for Quality Analysis of Aquatic Water Data Using Time-Series Convolutional Neural Network,” *Environmental Science and Pollution Research*, vol. 30, pp. 125275-125294, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[5] Harsh Dadhaneeya, Prabhat K. Nema, and Vinkel Kumar Arora, “Internet of Things in Food Processing and its Potential in Industry 4.0 Era: A Review,” *Trends in Food Science and Technology*, vol. 139, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[6] Abu Taher Tamim et al., “Development of Iot Based Fish Monitoring System for Aquaculture,” *Intelligent Automation & Soft Computing*, vol. 32, no. 1, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[7] Andrew B. Gallemit, “Water Monitoring and Analysis System: Validating an IoT-Enabled Prototype Towards Sustainable Aquaculture,” *International Journal of Advanced Multidisciplinary Studies*, vol. 3, no. 6, pp. 496-517, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[8] Danial Mohammad Ghazali et al., “Smart IoT Based Monitoring System for Fish Breeding,” *Journal of Advanced Research in Applied Mechanics*, vol. 104, no. 1, pp. 1–11, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[9] Sanjeev Kimothi et al., “Comprehensive Database Creation for Potential Fish Zones Using IoT and ML with Assimilation of Geospatial Techniques,” *Sustainability*, vol. 15, no. 2, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[10] Isabella D’Ambra, and Louise Merquiol, “Jellyfish from Fisheries By-Catches as a Sustainable Source of High-Value Compounds with Biotechnological Applications,” *Marine Drugs*, vol. 20, no. 4. 2022. [CrossRef] [Google Scholar] [Publisher Link]

[11] Mohammod Kamruzzaman Hossain et al., “Isolation and Identification of Potential Host Probiotic Bacteria from Malaysian Mahseer, Tor Tambroides for Aquaculture Practices,” *Biodiversitas*, vol. 23, no. 10, pp. 5423–5430, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[12] Muhammad Aliyu Sulaiman et al., "Fruit Wastes Improved the Growth and Health of Hybrid Red Tilapia Oreochromis sp. and Malaysian Mahseer, Tor Tambroides (Bleeker, 1854)," *Aquaculture Reports*, vol. 24, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[13] Angel Avadi et al., "How to Enhance the Sustainability and Inclusiveness of Smallholder Aquaculture Production Systems in Zambia," *Aquaculture*, vol. 547, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[14] Umar Farouk Mustapha et al., "Sustainable Aquaculture Development: A Review on the Roles of Cloud Computing, Internet of Things and Artificial Intelligence (CIA)," *Reviews in Aquaculture*, vol. 13, no. 4. pp. 2076-2091, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[15] Maxime Lafont et al., "Back to the Future: IoT to Improve Aquaculture: Real-Time Monitoring and Algorithmic Prediction of Water Parameters for Aquaculture Needs," *2019 Global IoT Summit (GIoTS)*, Aarhus, Denmark, 2019, pp. 1-6. [CrossRef] [Google Scholar] [Publisher Link]

[16] Marcelo Gleiser, and Sergio Moro, "Implementation of an IoT-Based Water Quality Monitoring System for Aquaculture," *International Journal of Research Publication and Reviews*, vol. 4, no. 5, pp. 1449-1452, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[17] Jomsuda Duangwongsa et al., "Real-Time Water Quality Monitoring and Notification System for Aquaculture," *2021 Joint 6th International Conference on Digital Arts, Media and Technology with 4th ECTI Northern Section Conference on Electrical, Electronics, Computer and Telecommunication Engineering*, Thailand, pp. 9-13, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[18] Mohammad Safwan Nasrun Haji Daud, Ravi Kumar Patchmuthu, and Au Thien Wan, "Automated IoT Based Smart Aquaculture Shrimp Farming in Brunei," *Proceedings of the 2022 11th International Conference on Software and Computer Applications*, pp. 116–122, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[19] Melinda Mei Lin Lau et al., "A Review on the Emerging Asian Aquaculture Fish, the Malaysian Mahseer (Tor Tambroides): Current Status and the Way Forward," *Proceedings of the Zoological Society*, vol. 74, pp. 227–237, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[20] Munesh Singh, Kshira Sagar Sahoo, and Anand Nayyar, "Sustainable IoT Solution for Freshwater Aquaculture Management," *IEEE Sensors Journal*, vol. 22, no. 16, pp. 16563-16572, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[21] Kraków-Wieliczka, Hotel Turówka, and Andrzej Kot-Agata Nawrocka, *2019 20th International Carpathian Control Conference (ICCC)*, 2019. [Google Scholar] [Publisher Link]

[22] Mariane Yvonne Schneider et al., "Benchmarking Soft Sensors for Remote Monitoring of On-Site Wastewater Treatment Plants," *Environmental Science & Technology*, vol. 54, no. 17, pp. 10840-10849, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[23] M. Manoj et al., "State of the Art Techniques for Water Quality Monitoring Systems for Fish Ponds Using IoT and Underwater Sensors: A Review," *Sensors*, vol. 22, no. 6, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[24] Nur Syuhada Iskandar et al., "Elevated Carbon Dioxide and Its Impact on Growth, Blood Properties, and Vertebral Column of Freshwater Fish Mahseer, Tor Tambroides Juveniles," *Fishes*, vol. 8, no. 6, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[25] Havala O.T. Pye et al., "The Acidity of Atmospheric Particles and Clouds," *Atmospheric Chemistry and Physics*, vol. 20, no. 8, pp. 4809-4888, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[26] Hala Jassim Mohammed, "IoT-Based Low-Cost Smart Health Monitoring System Using Raspberry Pi Pico W and Blynk Application," *Journal of Engineering*, vol. 30, no. 7, pp. 90–108, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[27] R. Arora et al., "Conserving Freshwater Ecosystems in India: A Call to Action," *Aquatic Conservation: Marine and Freshwater Ecosystems*, vol. 34, no. 5, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[28] Melinda Mei Lin Lau et al., "A Review on the Emerging Asian Aquaculture Fish, the Malaysian Mahseer (Tor Tambroides): Current Status and the Way Forward," *Proceedings of the Zoological Society*, vol. 74, pp. 227-237, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[29] Ahmed Jalal Khan Chowdhury et al., "Phototrophic Purple Bacteria as Feed Supplement on the Growth, Feed Utilization and Body Compositions of Malaysian Mahseer, Tor Tambroides Juveniles," *Sains Malaysiana*, vol. 45, no. 1, pp. 135-140, 2016. [CrossRef] [Google Scholar] [Publisher Link]

[30] Mohammod Kamruzzaman Hossain et al., "Growth Performance, Fatty Acid Profile, Gut, and Muscle Histo-Morphology of Malaysian Mahseer, Tor Tambroides Post Larvae Fed Short-Term Host Associated Probiotics," *Aquaculture and Fisheries*, vol. 9, no. 1, pp. 35-45, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[31] Adil Ikhwan Redhwan et al., "Mahseer in Malaysia: A Review of Feed for Cultured Tor Tambroides and Tor Tambra," *Bioscience Research*, Vol. 19, no. SI-1, pp. 349-359, 2022. [Google Scholar] [Publisher Link]