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Towards Sustainable Aquaculture: An IoT-Driven Indoor Fish Farming System

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***Abstract*—This study presents an innovative IoT-driven fish farming system to enhance aquaculture efficiency and sustainability. The system utilizes Arduino microcontrollers integrated with DS18B20 temperature sensors and analog pH meters to enable real-time monitoring and control of environmental conditions. Key functionalities include automated fish feeding, dynamic feed quantity calculations, and pH adjustments using a mobile application interface. The system demonstrated effective temperature and pH regulation, though minor variations were noted in the automated feeding mechanism. Alerts for critical conditions were generally timely but occasionally delayed during simultaneous updates. This IoT-based solution significantly improves fish farming management, contributing to the optimal well-being of aquatic species.**

***Index Terms*—Aquaculture, IoT-driven system, DS18B20 temperature sensors, analog pH meters, automated fish feeding, pH adjustments, MG995 motor, mobile application, sustainable aquaculture, pH control, alert system, technological advancements, aquatic species.**

I. Introduction

Aquaculture stands as a vital component of the global food production system, playing a crucial role in meeting the escalating demand for fish products. This is particularly noteworthy in countries such as Bangladesh, Nepal, and India, where a significant proportion of the population relies heavily on fish as a primary source of protein. As these nations grapple with the challenge of providing sustenance for their burgeoning populations, the importance of aquaculture becomes pronounced. Beyond its role in addressing nutritional needs, aquaculture contributes substantially to the economies of these countries, promoting employment opportunities and bolstering food security.

Fishery products are vital for global food security, contributing significantly to the overall fish production of 179 million tons in 2018, with aquaculture contributing 82 million tons. The annual growth rate in global fish consumption outpaced that of the world population and other animal protein foods at 3.1% from 1961 to 2017, indicating fish's potential as a substitute for livestock and poultry protein. Fish offer superior protein quality and cost-effectiveness, without the epidemic issues prevalent in other animal protein production. However, the fishery industry faces challenges, including the impact of the COVID-19 pandemic on travel restrictions affecting migrant labor, an aging agricultural workforce complicating the supply chain, and issues such as excessive fishing, outdated aquaculture methods, industrial pollution, and declining water quality. These challenges demand comprehensive solutions to ensure the sustainability and resilience of the global fishery industry [1], [2].

Extension education in agriculture is critical, as highlighted by [3], [4] emphasizing its role in disseminating proven agricultural technologies and enhancing outreach and informed decision-making. The application of IoT, robotics, and UAVs in aquaculture is comprehensively reviewed by [5], focusing on transitioning to unmanned systems for deep-sea farming. Technological advancements in aquaculture that improve efficiency and environmental management are discussed by [6]. Additionally, [7] presents an IoT system automating fish farming through water quality sensors and Arduino control. Maintaining aquarium water quality is vital for fish health, and a holistic solution addressing feeding and water monitoring is proposed in [6].

Our innovative IoT-based indoor fish farming system represents a significant departure from traditional aquaculture management methods. By seamlessly integrating IoT technology and microcontrollers, our system automates the real-time monitoring and control of essential parameters, ensuring optimal conditions for fish health and growth. What sets our project apart is its user-friendly mobile application developed using MIT App Inventor [8], enabling intuitive interaction with the system. Unlike conventional approaches, our system incorporates a fish-specific database, allowing for precise and customized feeding strategies tailored to individual fish needs. The adaptability of our system is a key highlight, accommodating diverse aquaculture requirements while maintaining technological sophistication. With an emphasis on resource efficiency and economic empowerment, our project offers a novel and comprehensive solution in indoor fish farming, fully automated with microcontroller-based technology, providing users with complete real-time control over various parameters.

To provide a clearer comparison of our system with recent advancements, we present the following table:

TABLE I: Comparative Analysis of IoT-driven Aquaculture Systems

Feature	This Study	Ref [7]	Ref [5]	Ref [9]
Real-time Monitoring	Yes	Yes	Yes	Yes
Automated Feeding	Yes	No	Yes	No
Automated Adjustment	Yes	No	No	No
Fish-specific Database	Yes	No	No	Yes
User-friendly Interface	Yes	No	No	Yes

II. Methodology

In the development of our IoT-based indoor fish farming system, we adopted a meticulous and systematic design methodology. This approach employed the seamless integration of sensors, actuators, and control mechanisms to ensure the precise management of critical parameters, such as pH and temperature, alongside the automation of pivotal tasks, including feeding and water changes. Fig. 1 illustrates the circuit diagram of our prototype.

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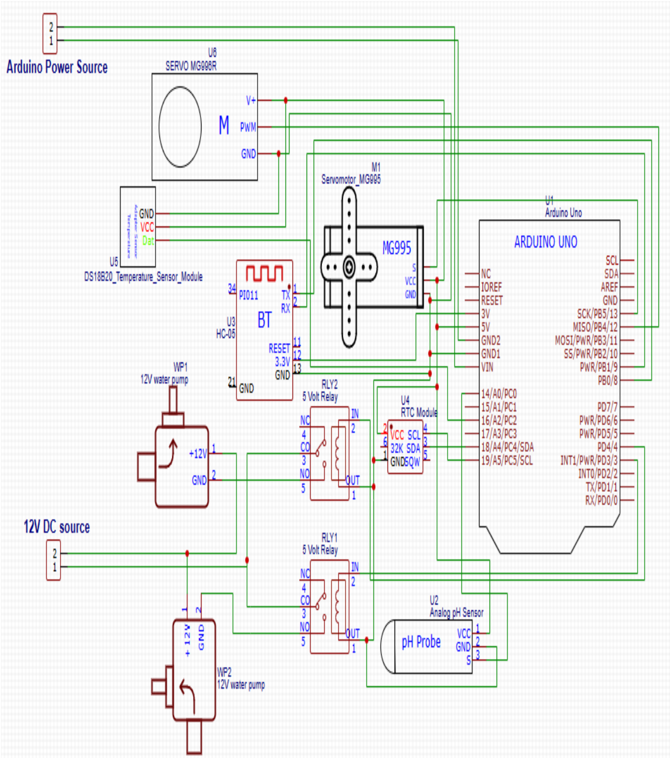

Fig. 1: Circuit diagram

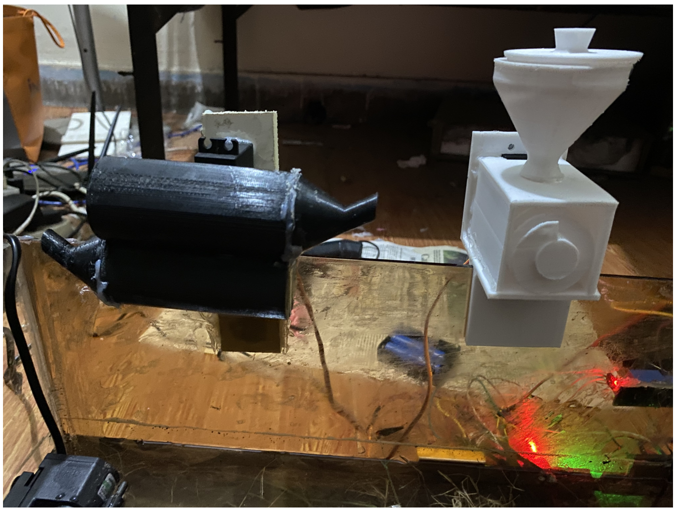

Fig. 2: A dual-container system automatically feeds fish three times a day. One container (black) holds acid and base (citric acid and NaHCO3) for controlled release, while the other (white) stores fish food.

A. pH Control and Adjustment

To regulate the pH of the water within the fish tanks, we incorporated an analog pH sensor [10] into our system. Our designated pH range for optimal fish growth spans from 6 to 9 [11], guaranteeing the well-being of the fish. In instances where the pH level deviates from this optimal range, a stepper motor (MG996) is activated. This motor facilitates the controlled introduction of base (NaHCO3) or acid (citric acid) from reservoirs (Fig. 2) to restore the water pH to the desired range. This process is iterative, employing a give-and-check approach wherein a calculated amount of base or acid is added, followed by a verification of whether the pH falls within the optimal range. This cycle repeats up to 10 times. Should the pH persistently remain outside the desired range, an alert is transmitted to the mobile application, indicating a challenge in pH control.

B. Temperature Regulation and Water Circulation

To control the temperature, a waterproof DS18B20 sensor [12] was used, with a target range of 25 to 33 degrees Celsius [13]. If the temperature deviates from this range, a submersible pump is activated to draw water from a reserve source, adjusting the tank's water temperature. Additionally, two submersible pumps for the inlet and outlet are used to replace the tank water daily, maintaining water quality and oxygen levels.

The equation governing the temperature adjustment process can be represented as:

$$T(t+1) = T(t) + \frac{Q}{V} \cdot (T_{\text{res}} - T(t)) \tag{1}$$

Here, T(t) is the current tank temperature. T(t+1) is the temperature after adjustment. Q is the flow rate of the submersible pump. V is the volume of the tank. T_{res} is the temperature of the reserve water.

C. Automated Feeding

For the automated feeding mechanism, an MG995 [14] motor is employed with a food container (Fig. 2). Our feeding schedule includes three daily sessions. The quantity of daily feed is determined by the following calculation:

$$\text{Daily Feed} = \text{No. of Fish} \times \text{Avg Body Weight} \times \%\text{Feed} \tag{2}$$

Users input the fish species through the mobile application, where a default %feed value corresponding to the species' body weight is presented in Table III. Users maintain the flexibility to adjust these values as needed. Moreover, users can introduce up to two additional fish species to augment the system's adaptability. These user-defined parameters are then transmitted to the Arduino microcontroller for processing. The motor's rotation is precisely controlled to dispense the calculated quantity of food during each feeding session. The prototype's food storage capacity is configured at 30 grams, and each motor rotation releases 2 grams of food. The required number of rotations is determined by the following formula:

$$\text{Rotation Required} = \text{ceil}\left(\frac{\text{Food Required}}{\text{One Rotation Food Supplied}}\right) \tag{3}$$

The functionality overview of the Arduino Fish Tank Control Code is provided in Table II.

D. Mobile Application Interface

The MIT App Inventor [8] facilitates user-friendly interaction, providing continuous updates on vital metrics, including fish population, inventory levels (food, acid, base), and graphical representations of pH and temperature trends. Real-time data collection is ensured through the integration of an RTC module [15] with the Arduino. Users input parameters such

TABLE II: Functionality Overview of the Arduino Fish Tank Control Code

Functionality	Description
Sensor Reading and Control	Reads data from pH and temperature sensors.
Fish Management	Tracks species, weight, and number of fish. Updates data based on commands or manual entries.
Water Management	Control water pumps for simulating changes.
Automatic Feeding	Calculates food amount based on fish count and weight. Dispenses food using a servo motor.
Communication	Uses Serial and Bluetooth for data exchange. Receives commands to update food inventory, add/remove fish, and sends data back to the user.
Error Handling	Implements basic error handling mechanisms. Detects low food, issues with temperature/pH control. Sends error messages.

Fig. 3: The Homepage acts as a central dashboard, displaying real-time fish population, resource levels, and insightful graphs on pH and temperature trends, offering a comprehensive view of the aquatic environment.

as fish quantity, body weight, species, and inventory status through the app, seamlessly transmitted to the Arduino for efficient control.

In instances of critically low food, base, or acid levels, the system generates prompt alerts within the mobile app, guiding user actions for effective management of indoor fish farming. The intuitive design includes three screens: the Homepage (Fig. 3) functions as a real-time dashboard, displaying fish population and resource availability.

The Database interface (Fig. 4) serves as a pivotal tool, allowing users to manage the fish feed database, ensuring accuracy and adaptability for various fish species. The Inventory interface (Fig. 5) provides a user-friendly platform for inputting essential inventory status and fish specifications, crucial for precise system operation and responsiveness to specific fish needs.

E. Experiment and Data Collection

As previously explained, determining the daily food quantity relies on the %feed value that corresponds to the average

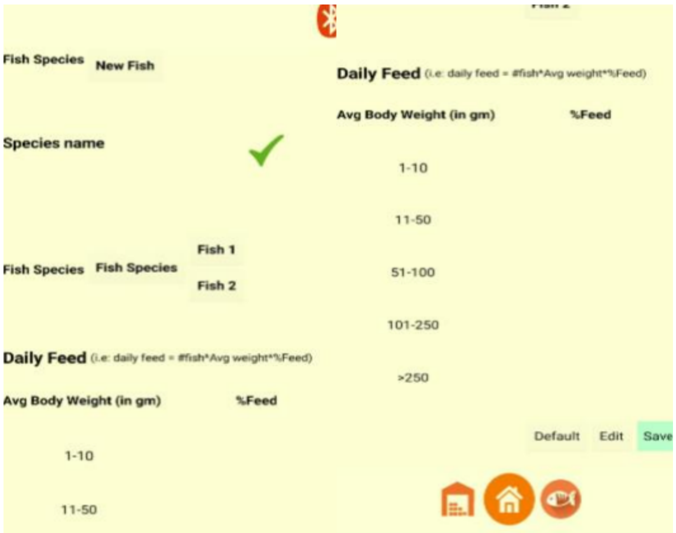

Fig. 4: The Database screen lets users choose a fish species and its feeding data (default or custom) based on average weight. It even allows adding and customizing data for two more fish species.

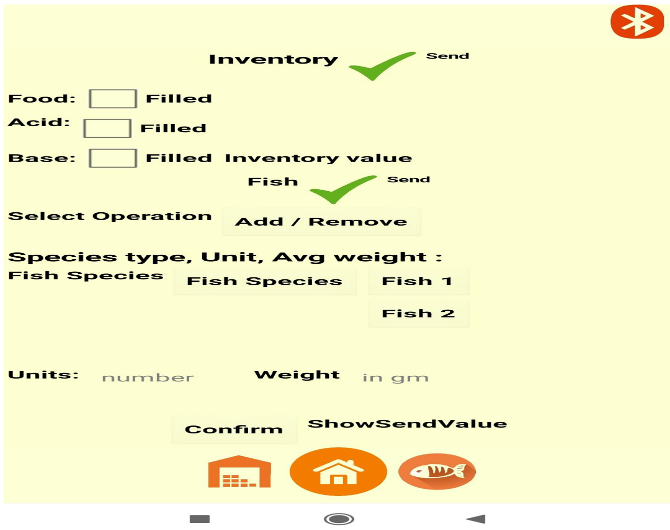

Fig. 5: The figure shows how to input inventory in the fish farm system. By checking a box when refilling food or chemicals, the system automatically updates their levels to 100%, keeping resource monitoring accurate.

body weight of the fish. Refer to Table III for a comprehensive reference chart that illustrates the relationship between average body weight and the appropriate %feed value.

TABLE III: Average Body Weight vs % Feed

Average Body Weight (in gm)	Tilapia	Pangasius	Rohu	Mrigal	Catla
1-10	6	6	6	6	6
11-50	4	5	5	5	5
51-100	3	4	4	4	4
101-250	2	3	3	3	3
250+	2	3	3	3	3

We build our model as a prototype. For a large system, we calculated different parameters [9] as shown below:

Fig. 6: Developed prototype of smart fish farming system

Fish density of *Labeo Rohita* is $1.6 - 4.9\,\mathrm{m}^{-3}$.
Weight = $50\,\mathrm{gm/fish}$.
According to our database, the required food is $(50 \times 1.6 \times 5\% - 50 \times 4.9 \times 5\%)$ or $4 - 12.5\,\mathrm{gm/m}^{-3}$.
The fish density of *Tilapia* is $75\,\mathrm{m}^{-3}$.
Weight = $38.4\,\mathrm{gm/fish}$.
According to our database, the required food is $(75 \times 38.4 \times 4\%)$ or $115.2\,\mathrm{gm/m}^{-3}$.
Therefore, a $1\,\mathrm{m}^3$ volume food container provides an ample supply of food for several days.

III. Results and Discussions

A. Hardware implementation

The system, as depicted in Fig. 6, utilizes Arduino microcontrollers for central data processing and control in a fish tank. DS18B20 temperature sensors strategically placed in the tank maintain optimal conditions, while an analog pH meter assesses water acidity. Automated fish feeding, driven by user inputs through the mobile app, is facilitated by the MG995 motor in three daily sessions. Continuous monitoring of food inventory triggers alerts for critical levels, ensuring optimal nutrition. The pH sensor, vital for maintaining optimal conditions, prompts adjustments with $NaHCO_3$ or citric acid based on predefined thresholds. Persistent pH control failures trigger alerts for potential challenges.

B. pH Level Analysis

The pH control system employs an analog pH sensor to maintain the water pH between 6 and 9, crucial for fish health. When deviations occur, the MG996 stepper motor activates, adding either base $NaHCO_3$ or acid (citric acid) to restore pH. This process, repeating up to 10 cycles, triggers an alert if unsuccessful. Continuous monitoring ensures optimal conditions. Data is collected in real-time or at set intervals, filtered for noise, and compared to pH thresholds (see Fig. 7). Control mechanisms adjust pH levels, with alerts for persistent deviations. The system maintained pH within ±0.2 units of the optimal range, with occasional larger fluctuations due to sensor calibration and water chemistry variations.

The pH control mechanism consistently maintains pH within the optimal range (6 to 9), rectifying deviations with the MG996 stepper motor. Observed pH deviations typically stayed within ±0.2 units, considered acceptable. Occasional fluctuations beyond this range were noted, attributed to sensor calibration and water chemistry variations.

TABLE IV: Approximate cost breakdown of the developed prototype. Costs may vary depending on location and quantity.

Components	Price (in USD)
Arduino Uno (x1)	$ 7.00
DS18B20	$ 1.20
Analog pH meter	$ 16.00
Pump (2x)	$ 1.20
Fish Tank	$ 3.00
RTC Module	$ 3.40
HC05	$ 2.50
Wire, relay, and others	$3.40
3d printing	$15.00
Miscellaneous cost	$5.00
Total	**$ 57.70 (Approx.)**

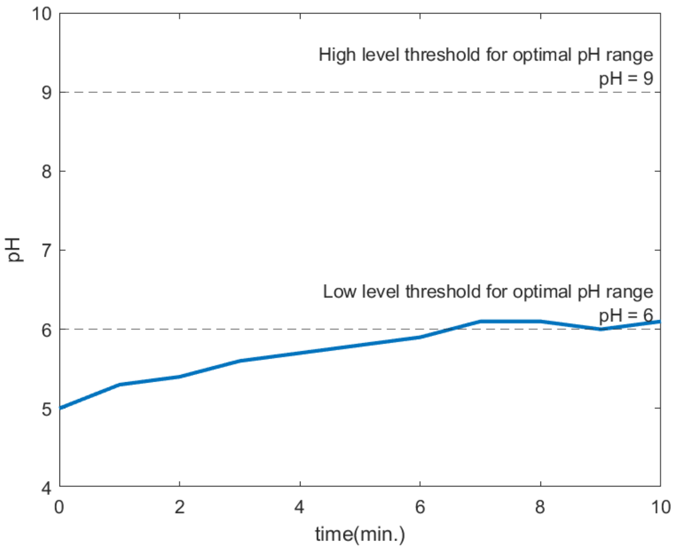

Fig. 7: Figure illustrates a pH versus Time Plot in a Testing Environment. The initial pH set to 5 for testing purposes. The plot illustrates the system's response as the pH is adjusted using the MG996 stepper motor and NaHCO3 from the container. When the pH falls below the optimal range of 6 to 9, the motor is triggered to add NaHCO3, halting when the pH returns to the desired range. This cyclic process ensures precise pH control in the testing scenario.

C. Temperature Analysis

The system effectively regulated water temperature, maintaining it within the target range of 25 to 33 degrees Celsius. Deviations were generally within ±1 degree Celsius, supporting optimal fish conditions. The submersible pump and daily water changes contributed to stable temperature control. Fig. 8 shows temperature versus time, demonstrating the system's

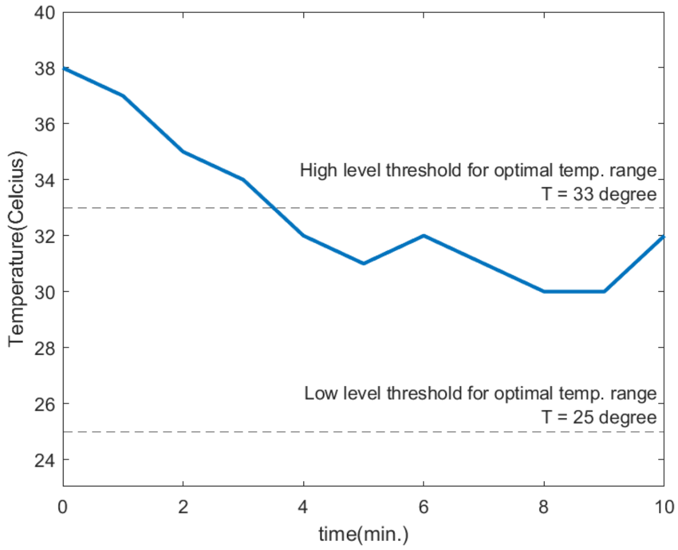

Fig. 8: The figure shows a temperature vs time (minutes) plot for a controlled fish tank. The submersible pump automatically adds cooler water to maintain the temperature between 25-33°C.

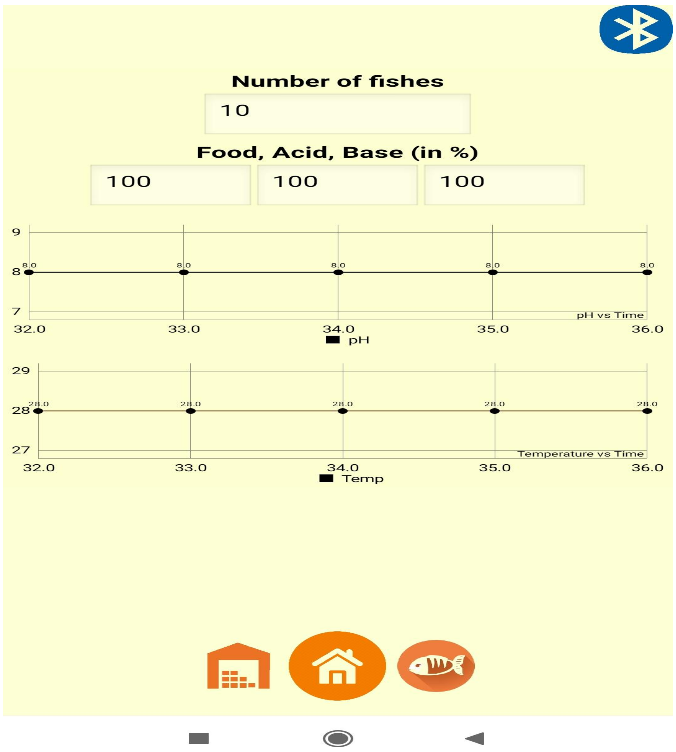

Fig. 9: The figure shows the current fish population, resource levels, and graphs for recent pH and temperature trends (5 data points, 1 minute intervals).

efficiency in maintaining the desired temperature range using the pump and reserve water in a controlled environment.

D. Automatic Food Analysis

Automated fish feeding is integral to our system, driven by user input parameters for fish quantity, average weight, and species. The system calculates daily feed quantities based on user-defined criteria and feed percentage, dispensing three daily feedings through the MG995 motor. It vigilantly monitors food inventory, issuing alerts (Fig. 10 for critically low levels. Simultaneously, the system effectively regulates water temperature within the optimal range of 25 to 33 degrees Celsius, showcasing deviations within ±1 degrees Celsius. The submersible pump and daily water change routine contribute to this stable temperature control, ensuring ideal conditions for fish comfort and growth.

E. Real-Time Monitoring and User Interaction

The mobile app serves as an intuitive interface for real-time monitoring and control in our IoT-based fish farming system. Users input additional data directly, leading to dynamic adjustments in feeding schedules and accurate inventory maintenance. Data analysis remains an ongoing process, ensuring optimal pH, temperature, and feeding schedules, and providing users with real-time insights.

Furthermore, users can access graphical representations, in the form of plots illustrating dynamic trends in pH versus time and temperature versus time (Fig. 9), offering valuable insights into the aquatic environment.

F. Performance Evaluation with Tilapia Species

Our IoT-based indoor fish farming system proved effective during testing, with a focus on tilapia species, known for their popularity among fish farmers and adaptability. We introduced 10 tilapia fish, averaging 22.5 grams each, into the tank. Over 25 days, the system demonstrated notable results, with the fish weight increasing to 56 grams, indicating natural growth. This success underscores the system's capacity to foster an optimal environment for fish development. Although manual interventions for food and water refills were necessary every 2-3 days, larger storage capacities could extend maintenance intervals. The promising outcomes observed with tilapia suggest the system's potential applicability to other fish species. The results of the testing phase are summarized in Table V.

TABLE V: Summary of Testing Results for Tilapia Species

Parameter	Value
Number of Tilapia Fish	10
Average Initial Weight (grams)	22.5
Average Final Weight (grams)	56
Duration of Experiment (days)	25
Manual Interventions (frequency)	Every 2-3 days

IV. Future Directions for Advancements in IoT-Based Indoor Fish Farming

The successful deployment of the IoT-based indoor fish farming system has identified strategic areas for future enhancements. These include improving the Wi-Fi module to enhance connectivity, refining the mobile application for additional features and improved user-friendliness, exploring large-scale implementation for commercial aquaculture, creating comprehensive data sheets with additional average body weight vs %feed values for various fish species, and integrating water recycling and purification systems to enhance sustainability. These directions are expected to contribute significantly to the ongoing development and sustainability of IoT-based indoor fish farming, with a focus on optimizing efficiency, user experience, and environmental stewardship.

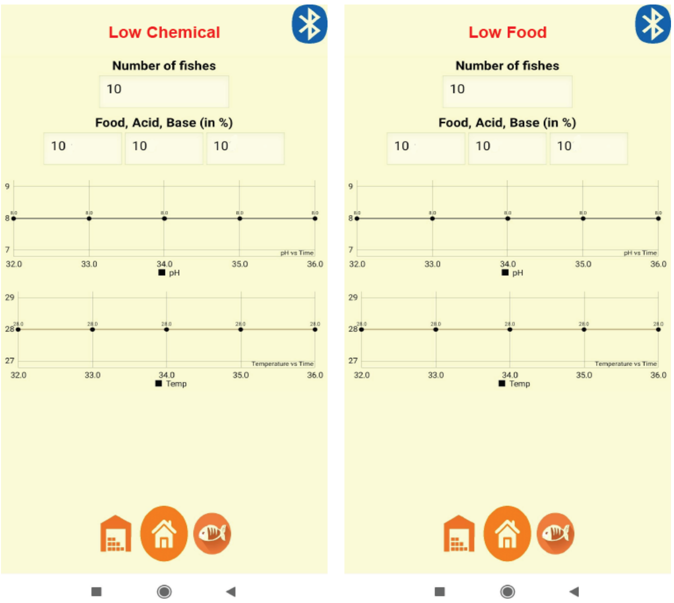

Fig. 10: The image depicts a scenario where the levels of food, base, and acid have reached a low threshold of 10%, triggering alerts for 'Low Food' and 'Low Chemical' within the mobile application.

V. Conclusion

The IoT-based Indoor Fish Farming System introduced in this study represents a significant advancement in aquaculture technology. This innovative system, designed for ease of use and automation, aims to simplify fish farming while making it more sustainable and accessible. By integrating IoT technology, the system continuously monitors and adjusts critical conditions in fish tanks, ensuring optimal growth and health of the fish. The mobile app interface empowers users to manage feeding schedules, pH levels, temperature, and other parameters seamlessly, transitioning from traditional, labor-intensive methods to a more intelligent and sustainable approach.

Key contributions of this study include the development of a precise automated feeding mechanism, effective pH and temperature regulation, and an advanced user notification system. The automated feeding mechanism has demonstrated high efficacy in delivering accurate nutrition based on user inputs and fish parameters, despite minor variations in the rotation-based mechanism. The pH control system effectively maintains water quality within the optimal range, with deviations typically within ±0.2 units, ensuring a healthy environment for the fish. The temperature regulation system consistently maintains the water temperature within the desired range of 25 to 33 degrees Celsius, with deviations generally within ±1 degree Celsius. Additionally, the user notification system efficiently alerts users to critical situations, although occasional delays have been observed.

The study highlights the potential of IoT-based solutions in revolutionizing fish farming practices by enhancing efficiency, reducing labor, and promoting sustainability. However, there are areas for further improvement and research. Future work should focus on refining the response times of the alert system to minimize delays and enhance user experience. Integrating advanced analytics and machine learning algorithms could further optimize feeding schedules and environmental control, improving the system's adaptability and resilience. Exploring the use of blockchain technology could also enhance traceability and transparency in the aquaculture supply chain, ensuring better management and sustainability.

This initiative invites stakeholders, including researchers, practitioners, and policymakers, to participate in the ongoing revolution of fish farming practices. By adopting and further developing such innovative technologies, the aquaculture industry can move towards a more sustainable and efficient future, contributing to global food security and environmental conservation.

Data Availability

To facilitate future research endeavors in this field, interested individuals can obtain access to the source code by submitting a request via email.

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