Embedded System for Aquaculture Water Quality Management

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Declaration

I certify that this proposal/thesis does not incorporate without acknowledgement any material previously submitted for a degree or diploma in any university, and to the best of my knowledge and belief, it does not contain any material previously published or written by another person except where due reference is made in the text.

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Contents

List of Figures

List of Tables

Abstract

Breeding of ornamental fish is a significant industry segment of Sri Lanka's aquaculture sector. However, most small and medium-scale breeders rely on unskilled, time-consuming and faulty manual monitoring systems of water parameters such as temperature and turbidity. These methods are unskilled, time consuming and error prone, often resulting in fluctuating water conditions which are stressful for fish. Monitoring at night and manpower shortages even exacerbate this issue.

This project provides a low-cost automatic aquarium ornamental fish tank water management system. The system was designed using an Arduino Mega 2560 as the primary controller with the inclusion of DS18B20 (temperature), TS-300B (turbidity) and HC-SR04 (ultrasonic water level) sensors. On detecting abnormal conditions, the system takes the corresponding actions: heating, partial change of some water or robotic cleaning via a motorized arm. The NodeMCU module provides Thing Speak monitoring support. Temperature and water level regulation were consistent and functioned as intended.

While the system effectively maintained stable environmental conditions autonomously, a key limitation was the periodic insensitivity of the turbidity sensor, which occasionally failed to detect slight changes in visual clarity. As a workaround, a manual input mechanism was added, slightly reducing automation.

All components were selected by price considerations as well as compatibility with local support. The system was built within a $100 budget with off the shelf and 3D-printed hardware which made it suitable for budget conscious breeders. This single-component solution is comparable to commercial systems with single functionality in that it treats monitoring, cleaning and basic decision making as the single unit.

The terminal design is scalable for small-scale implementation with prospects for further development. The system offers a practicable alternative for breeders to improve water quality management, reduce labor demands and maintain fish health, especially under conditions of limited supervision.

1. Introduction and Background

The aquaculture freshwater fish breeding industry is a fast-growing sector in Sri Lanka. Being a country close to the equator, the climate is ideal for breeding fish year-round. According to the Sri Lanka Export Development Board (EDB) in 2022, the Sri Lankan ornamental fish industry achieved impressive annual export revenue of USD 22 million (EDB, Sri Lankan Universities and Associations Join Forces with to Strengthen Ornamental Fish Industry and Boost Exports, no date). Therefore, improved efficiency and increased productivity of ornamental fish breeding operations have a direct positive influence on the national economy.

The need for an automated water quality management system in the ornamental fish breeding sector in Sri Lanka arises from the critical role that water quality plays on the health and survival of fish. Fish farmers often face challenges related to maintaining water quality. Poor water condition is the main reason for growing diseases and parasites on the water. If the poor water quality is maintained for a few hours on the tanks continuously it will lead to causes of mortality in fish farming. Farmers often face these problems at nighttime. Because farmers are struggling to expand their farms, if they expand the farm, they need more human power to maintain optimal water quality. As for solutions for nighttime farmers, they remove some amount of water each tank and refill it because they can’t decide what will happen in the nighttime. If we think about reducing mortality factor it is good practice, but this practice leads to increasing water consumption significantly. In this project we are focusing on small to medium size fish farmers who are using glass fish tanks as their fish environment. Because some large scale farmers used swimming pool cleaning robots for cleaning their large scale tanks. Without the implementation of automated systems like the one proposed in this study, Sri Lankan breeders face several significant challenges. Such as the reliance on manual monitoring, Given the tropical climate of Sri Lanka, pH and turbidity fluctuations and other environmental changes can occur rapidly, and time and human power required to consistently monitor and adjust water quality parameters are significant.

An automated water quality management system is inserted to handle continuous real time monitoring for key water quality parameters, such as temperature, pH and turbidity. The system automatically conditions water by turning on the heaters or making water changes at every step. It reduces the chance of human error and minimizes the probability of failures. It helps to increase survival rates, reduce stress, and increase overall breeding success by ensuring water conditions are always optimal. This makes the system profitable and productive for the breeder, growing the ornamental fish industry. Therefore, it can impact to growth of national GDP of Sri Lanka.

1.1 Project scope

The proposed project is aimed for developing an automated water quality management system customized to the ornamental fish-breeding industry of Sri Lanka. The core functionality of this system is to help eliminate problems in maintaining water conditions for the health, growth and survival of ornamental fish. Through the automation of monitoring and controlling key parameters of water quality, temperature, pH and turbidity among others the system will significantly enhance the efficiency and productivity of fish breeding. The industry encounters several issues about water quality management which are currently done by manual methods. Because these ways are time-consuming and labor-intensive, they sometimes lead to human error, creating inconsistencies in water condition that may cause high mortality in fish. The project's scope encapsulates design, development and implementation of the system that embeds sensor technologies with automation and cloud-based monitoring to provide real-time data with control over the water condition within fish tanks.

This project scope also further envisions system being cost-effective and accessible to the small- to medium-sized fish-breeding operations, which are in the majority in Sri Lanka. The system would design considering the use of off-the-shelf hardware like Arduino boards and sensors, which would result in a reduction of costs associated with infrastructure. Further, the project will investigate Thing speak to move forward enabling remote monitoring web application to increase breeder flexibility and control.

At the end of this project, there will be a prototype of an automated system for fish tank water quality management that will be fully operational. The success of the system will be measured by its ability to maintain stable water conditions, reduce the mortality rates of fish and generally improve breeding success. The insights derived from these projects could also serve as a basis for future research and development in the field of automation of aquaculture.

1.2 Motivation for the study

The motivation for this study comes from both personal and industry-wide experiences. One of our team members runs a fish breeding center and faces daily challenges in maintaining optimal water quality for her ornamental fish. Water quality is a basic factor that directly affects the health, growth, and survival of fish. Fluctuations of key parameters such as temperature and turbidity would have an almost instant and adverse effect on fish, making them stressed, diseased and perhaps dead. However, traditional methods of monitoring and managing water quality are labor-intensive, time-consuming and prone to human error. This creates a significant burden on breeders, especially those managing small to medium-sized operations.

The fact that our team members struggle daily with these issues reemphasizes the need for an efficiency upgrade and a more reliable solution. Almost constant attention to adjustments from the manual methods in use demands time hardly available for much else at the breeding center, which otherwise takes a good amount of human labor and expertise.

From this study, not only will it ease the daily burdens of breeders, including our team members, but it will also help in overall efficiency for commercial breeding in ornamental fish. We hope to develop a solution that will incorporate the new technology with traditional fish-breeding practices and thus benefit individual breeders as well as the industry at large.

1.3 Rationale and Justification

While some products are on the market already, monitoring water quality parameters in aquaculture, they leave much to desire in important aspects. Most of these systems will have their values shown in a local screen and offer the feature of sending notifications to the user in case the parameters go out of the desired limits. But there’s no real time action taking for sudden fluctuations, delay that may result in harm to the aquatic environment and financial loss to the breeder. More importantly, such systems generally do not come with the capability to automatically act on the corrective measures, say by adjusting the temperature or initializing a water change when needed.

Furthermore, the inability to control and monitor these systems remotely is a significant limitation, especially for breeders who need to manage multiple tanks or operate in different locations. Thus, the proposed smart aquaculture monitoring system tries to fill this gap through automatic corrective actions and providing remote access and control with cloud integration. In this way, this comprehensive approach ensures better proactive and effective management of water quality, reduces risks, and enhances the productivity of the aquatic culture operation overall.

Furthermore, inability to take automative correcting action is a significant limitation, especial for breeders who maintain several dozen tanks in different locations. The proposed smart aquaculture monitoring system tries to fill this gap through automatic corrective actions and providing remote access and control. This comprehensive approach ensures better proactive and effective management of water quality, reduces risks, and enhances the productivity of the aquatic culture operation overall.

1.4 Research problem

The basic research problem of the study is found out how well the water quality parameters can be maintained in ornamental fish breeding operations when traditional, manual means are employed. Ornamental fish are sensitive to changes in temperature, pH and turbidity. These parameters must be within certain ranges for the good health and survival of the fish. However, for monitoring such parameters the conventional approach is to be done mostly manually and periodically. It is not only time-consuming and labor-intensive but also likely cause human errors. In most cases, it does not generate data in real-time to respond to rapid changes in water quality, which makes it lag in the application of interventions that can lead to fish stress, diseases or even death.

Moreover, available solutions on the market are rather expensive and not designed to satisfy the particular needs of ornamental fish breeders, requiring a system that is rather cost-effective while, at the same time, providing high-precision real-time control over important parameters regarding water quality.

1.5 Research objectives

1.5.1 Main objective

- The research aims to develop an automated system that handles bottom cleanup and monitors essential water quality indicators, including temperature and turbidity in ornamental fish tanks through sensor and microcontrollers and cloud-based services.

1.5.2 Specific objectives

- The system combines temperature and turbidity sensors with an Arduino Mega microcontroller to achieve continuous water quality monitoring.
- The mobile application provides farmers with real-time information about water quality parameters and system status through its user-friendly interface.

1.6 Expected outcomes

The major output of this project will be a much more effective automated water management system that will significantly improve the monitoring and maintenance of various water quality parameters in an aquaculture system. It will monitor such important factors as temperature and turbidity continuously. It will automatically make corrective action to bring them back into line so that continuous optimal conditions are maintained and fish mortality reduced, hence resulting in higher breeding success.

The technology of clouds will make the system an IoT one, which can help breeders to monitor or control their aquaculture systems from a remote location. It is really good for people who manage multiple tanks or those breeders who have to look over things in multiple areas.

The system would reduce the labor needed to manually look out for and adjust water quality, thereby saving time and human resources used in managing aquaculture operations. The project can contribute positively to the national economy by improving efficiency and success rates of ornamental fish breeding operations.

2. Literature Review

2.1 Introduction

The management of water quality in aquaculture particularly in ornamental fish farming, is crucial for ensuring optimal fish health and sustainable production And Ornamental fish breeding is expanding rapidly in Sri Lanka due to its favorable climatic conditions and significant economic contribution. As reported by the Sri Lanka Export Development Board In 2022 the Sri Lankan ornamental fish industry achieved impressive annual export revenue of USD 22 million (Export Development Board, 2022). This growth highlights the need for efficient water quality management to sustain and enhance productivity in the sector (FAO, 2022). The Internet of Things has altered water quality monitoring by combining new sensor technology, real-time data processing, and remote monitoring capabilities. This literature review examines cutting-edge techniques and new developments in IoT-based automated aquaculture water management systems, focusing on their potential benefits and existing challenges.

2.2 Using Bottom Siphoning in Conjunction with Controlled Water Replenishing

Bottom siphoning is one of the most used processes in aquaculture where waste and uneaten feed is removed from the bottom of the tanks. After the siphoning is done, a pre-calculated volume of fresh water is added to balance the water levels. Compared to full water exchanges, bottom siphoning provides greater control over the nutrient balance and water quality. Bottom siphoning facilitates the removal of concentrated organic waste while preserving most of the tank's original water composition. The gradual removal of water aids in the reduction of stress experienced by aquatic creatures due to abrupt fluctuations in temperature, pH, or hardness, which are otherwise noticed during large water exchanges (Tom *et al.*, 2021).

With reintegrating siphoning with distributing water, the bottom siphoning methods allows for the removal of settled organic material like fish feces and unused feed (Tom *et al.*, 2021). The removal of these components assist in reducing the level of toxic compounds such as ammonia and nitrites. Unlike full water replacement methods that tend to disturb the aquatic environment, siphoning requires minimal water replacement which helps maintain the stability of the system. This approach is further developed in the Bottom Clean System (BCS) using sedimentation tanks that contains biofilters, and micro/nano bubble aeration to guarantee continuous waste degradation and oxygenation at the substrate level (Roy, 2024).

2.3 Traditional Water Quality Monitoring and Its Limitations

Normally the monitoring of water quality in aquaculture has relied on manual sampling and laboratory testing methods. These traditional approaches while effective in ensuring compliance with water quality standards present significant limitations (Boyd *et al.*, 2020). The process involves the collection of water samples from various locations within the aquaculture system followed by laboratory analysis. This approach is labor intensive, time consuming, and costly. Commercial aquaculture has faced many challenges due to different environmental conditions will alter the water quality parameters. Like currently, aqua culturists use manual verification strategies to find out the parameters of water may change longer and not exactly because of water quality parameters change over time. And Manual testing will take more time and water quality parameters may vary additional IT time to take proactive measures before causing any damage (Dilli Kumar V *et al.*, 2023).

Research by K. Preetham says, farmers use manual check strategies for knowing the parameters of water (Amale, 2024). This will take longer and not be correct since water quality parameters could change with respect to time. To avoid this downside, innovation should be involved in aquaculture that improves the potency and limits the losses by constant checking of water quality parameters. The labor required by conventional fish farming techniques increases the cost of production because workers are needed to supervise the farms. Aquaculture production will be challenged by a manpower shortage since agriculture workers' average ages are rising in various parts of the world (Aquarium Coop, 2020). To resolve this issue, major changes are required that automated operations should be managed remotely.

Moreover, the reliance on periodic sampling means that real time changes in water quality are often missed potentially leading to adverse impacts on fish health and economic losses. Traditional methods are inadequate in addressing the dynamic nature of water quality, especially in large-scale aquaculture operations where rapid changes can occur (Chiu et al., 2022).

2.4 Emergence of IoT-Based Solutions

Recent advancements have led to the development of IoT-based water quality monitoring systems that address the shortcomings of traditional methods. These modern systems leverage wireless sensor networks (WSNs) and real-time data analytics to provide continuous monitoring of multiple water quality parameters. This project is to design and execute a distributed system called IOT BASED AQUACULTURE MONITORING AND CONTROL SYSTEM (IAMCS) for aquaculture water quality care through remote observation of turbidity, temperature and pH. This work will contribute to remote monitoring framework through IoT to screen water quality in ponds. The system is portable, modular, low cost, versatile and permits sharing of data through cloud that can be used for the advancement and improvement of aquaculture related activities (Amale, 2024).

The capabilities of IoT-based systems to monitor critical parameters such as temperature, pH, turbidity, and dissolved oxygen with high accuracy (Saha, Rajib and Kabir, 2018; Zhu *et al.*, 2019). By employing microcontrollers like Raspberry Pi and Arduino, these systems facilitate real-time data collection and remote access, thus significantly improving response times and management efficiency. The integration of IoT technology not only enhances the precision of monitoring but also streamlines data management and analysis. To ensure an optimal water quality in the fish breeding tank, an automatic and IOT based monitoring system is essential to replace the conventional monitoring which is done manually. In this paper, Jade Smart 1.0 was developed as a IoT based monitoring system of water quality in the breeding tank which consists of three identical boxes equipped with ESP32 as microcontroller, pH sensor, water temperature sensor and water turbidity sensor. This smart monitoring system is capable of digitally collecting, storing and displaying water quality data in real-time through web and mobile phone applications (Ghazali et al., 2023).

In this research an IoT-based intelligent water quality management system for aquaculture was designed and developed to monitor temperature, pH, and turbidity (Olanubi, Akano and Asaolu, 2024). ESP32 Microcontroller programmed with the C programming language was used to implement the smart control module which received data from the sensors and transmitted to a cloud database. A web application was also developed which enabled real-time monitoring and control of the system by a user from anywhere in the world, via any internet-connected device. Alarms and notifications could be received via WhatsApp Messenger. The system demonstrated capacity to improve the efficiency and productivity of aquaculture production. In this research an IoT-based fish monitoring system for aquaculture has been developed to address the shortcomings of existing systems (Pateriya *et al.*, 2023). This new system allows fishermen and aquaculture professionals to measure water quality parameters and monitor fish health. An Android mobile application has been developed to provide real-time measurements of these parameters. By reducing costs and measuring crucial water quality factors, the system aims to enhance production levels in aquaculture.

This research proposes a smart aquaculture monitoring system to address existing concerns regarding aquaculture through the design of a prototype of a smart fish farm system based on the internet of things and artificial intelligence. The proposed system is equipped with various sensors controlled by the Arduino Mega2560 with an integrated Wi-Fi module to assist in making different management decisions (Chiu *et al.*, 2022). To enable real-time data collection; so that fishpond water quality conditions and other system parameters can be readily monitored, adjusted, and assessed remotely. The development of science and technology has developed rapidly at this time and will have a positive impact to facilitate human activities, including aquarium ornamental fish hobbyists. The problems encountered are ornamental fish sellers who have difficulty monitoring all aquarium conditions and feeding and for people who are very busy and even indifferent to monitoring and feeding their ornamental fish. This tool has a water heater as well as a water temperature and pH sensor that can directly monitor the conditions in the aquarium.

Arduino Uno is the mainboard that is used to control all sensors with Internet of Things (IoT) including water temperature sensors, water turbidity sensors, water level sensors, water pH sensors, automatic lights, water heaters that will automatically turn on when the temperature is low and will automatically turn off when they reach the specified temperature and ESP8266-01 which functions to communicate between the Board and the smartphone, as well as the components of the tool and its uses are in accordance with requests from users obtained through Requirement Elicitation (Junaedi and Ki, 2022).

2.5 Advancements in Sensor Technology and Data Integration

The integration of advanced sensors with IoT technology has markedly improved monitoring capabilities within aquaculture settings (Abid et al., 2024). Demonstrate the effectiveness of combining static and dynamic monitoring nodes for achieve comprehensive real time monitoring (Zhu et al., 2010).

The systems in the previous paragraph utilize different sensors to track the pH and turbidity levels, the volume of oxygen in water, and transmit this data to a central server for analysis using wireless connectivity. The advancement of these systems has been boosted further by the implementation of cloud computing technologies which allow for data analysis and visualization through sophisticated software (Yang *et al.*, 2021).These improvements facilitate timely actionable intelligence for managing aquaculture systems thereby improving water quality management strategies (Chen *et al.*, 2022). Improvements for these challenges can be found in the enhancement of IoT technologies. Water quality monitoring systems based on IoT technology are equipped with sensors for the continuous monitoring of water quality parameters and real-time data transfer to cloud solutions (Adu-Manu *et al.*, 2017).With this approach, equipment can be designed to promptly make appropriate changes to ensure conditions are optimal for organisms that live underwater.

The integration of sensors for measuring pH, temperature, ammonia, and turbidity has also been demonstrated to enhance water quality monitoring. Such systems provide ingrained feedback mechanisms which enable aqua culturists to take proactive measures (Abid *et al.*, 2024). Additionally, storing data on the cloud and analyzing enables better data sharing as a result, aids in improved decision making.

2.6 Innovations in Automated and Mobile Monitoring

In 2015, Shuo shared an Advanced Research Proposal concerning real-time water quality monitoring and sensing, proposing the use of unmanned autonomous ships equipped with sensors. This approach is novel in that it enables monitoring to be achieved continuously while avoiding the need for human presence. Furthermore, there is a development of mobile water quality bionic underwater robot fish (Zhu et al. 2019) that mechanically collect data with little disruption, therefore providing easy access towards the data needed. According to Zhu 2019 and Danh, these systems are installed in smartphones and have Wi-Fi that allows users to log in and observe the conditions of water remotely which improves convenience and operational efficiency. Water quality monitoring system innovations further demonstrate how far IoT in aquaculture is still untapped as these innovations allow for increased flexibility and responsiveness to be implemented into monitoring systems. In 2023, Chee Han shared an Automatic Aquarium Water Change System With Real Time Monitoring Through IoT, this system was able to control water changing due to the over feeding.(Chee Han *et al.*, 2023)

2.7 Existing Product Comparison

Seneye Pond

Figure: 1 Seneye Pond & Slides

Seneye Pond is a small device, which measures the temperature, pH and ammonia levels in tanks. It connects to either a computer or a web server for real-time monitoring. This device sends alerts to any sudden changes in pH, ammonia or temperature. To monitor parameters using the Seneye Pond system, special "slides" are required and must be inserted into the device (Cichlids, 2022). Drawbacks of Seneye Pond, slied need to change monthly and one slide cost around 13 to 18 dollars. Additionally, for continuous 24/7 monitoring, the device must either remain connected to a dedicated laptop or be paired with the Seneye Web Server and Wi-Fi module, which costs around $299. The initial cost of the Seneye device itself is $199, bringing the total initial setup cost to approximately $515.

MOAI Cleaner

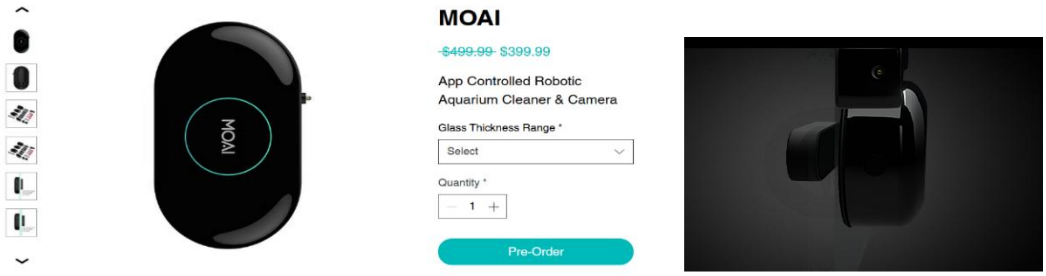


Figure: 2 MOAI Glass Cleaner

MOAI is a robotic glass cleaner used to clean fish tanks glasses. The system consists of two main components a scrubbing sponge that operates inside the tank and a robot unit that stays outside the tank and handles navigation. These two parts are connected through magnetic force. This robot is specifically designed to clean the glass surface of the tank, removing algae or debris stuck to the glass, but it does not remove dirt or waste from within the tank itself. This is a plug and play device after the basic installation and scheduling for cleaning it will work without any human intervention. This only cost $400 for a lifetime.(MOAI, 2024)

Pool robot cleaners

Figure: 3 Robot Bottom Pool Cleaners

Pool cleaners are primarily designed to clean human swimming or large gardening ponds; however, farmers use these robots to clean large aquaculture tanks. These automated devices can clean the bottom surfaces and walls of tanks or ponds by removing debris, algae and sediment (Swimming Pool Tips, 2016). These robots are equipped with brushes and suction mechanisms to collect dirt ensuring a cleaner environment for fish. However, the size of these robots are around 20*20*20 inches which means they may be larger than some glass tanks used in ornamental fish breeding.

This is one of the reasons smaller, more compact cleaning solutions are preferred in such cases. These devices are not able to monitor the water quality, but these cleaning processes are handled automatically according to schedules. AquaVac Automatic Cleaner and Maytronics Wave are some of the popular brands. Prices typically range from $500 to $1,500, offering a reliable and hands-free solution.

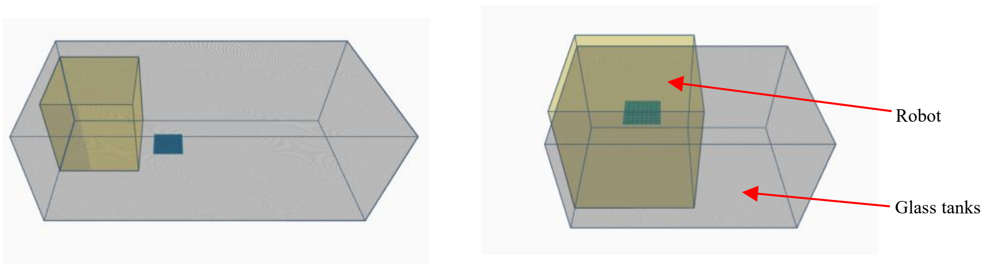


Figure: 4 Glass Tanks and Pool Cleaners' Comparison

Aquarium Vacuum Gravel Cleaner and Fish Tank Cleaner

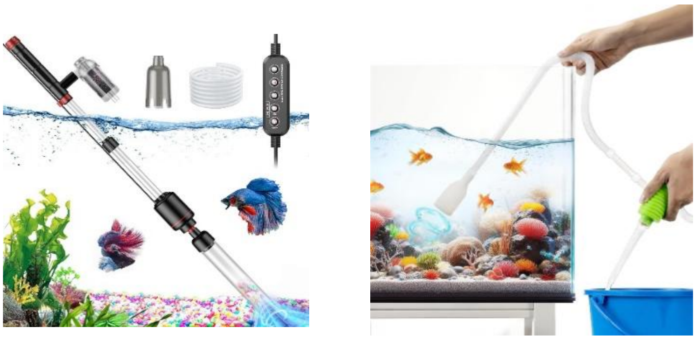


Figure: 5 Aquarium Vacuum Gravel Cleaner & Fish Tank Cleaner

These cleaners operate using vacuum effect. Once the vacuum effect starts, they suction out dirt and uneaten food in the tank (Centre, 2015). However, the device must be manually guided across the tank using a tube which requires human effort. Additionally, these cleaners do not have the capability to monitor water quality. Farmers have around 80-90 tanks so manually cleaning the bottom of each tank is a time-consuming and labor-intensive task. While these devices are cost-effective, typically priced between $20 and $50 they are not ideal for large-scale operations due to the significant human effort required.

While existing commercial products offer various degrees of automation and monitoring, none provide an integrated solution tailored for ornamental fish breeding environments, especially at scale. For example, Seneye Pond offers water parameter monitoring (pH, ammonia, temperature) but lacks automation in water management or waste removal. Its recurring consumable costs and dependence on external computing equipment add to operational expenses, making it less ideal for breeders with multiple tanks.

The MOAI Cleaner effectively automates algae removal from glass surfaces but does not manage internal tank waste or monitor water quality—critical tasks in ornamental fish farming. Similarly, pool robot cleaners, though capable of cleaning large ponds, are oversized for typical ornamental tanks and cannot monitor or control water parameters. Aquarium vacuum gravel cleaners, while affordable, are entirely manual, unscalable, and labor-intensive, especially for breeders managing dozens of tanks.

In contrast, our prototype combines real-time monitoring of pH, turbidity, and temperature, with partial automation of water renewal via siphoning, and includes remote control and data visualization features. It is scalable, low-cost, and compact, addressing key gaps such as real-time responsiveness, turbidity-aware intervention, and system-wide integration—features largely absent or cost-prohibitive in current commercial offerings.

3. System Design and Methodology

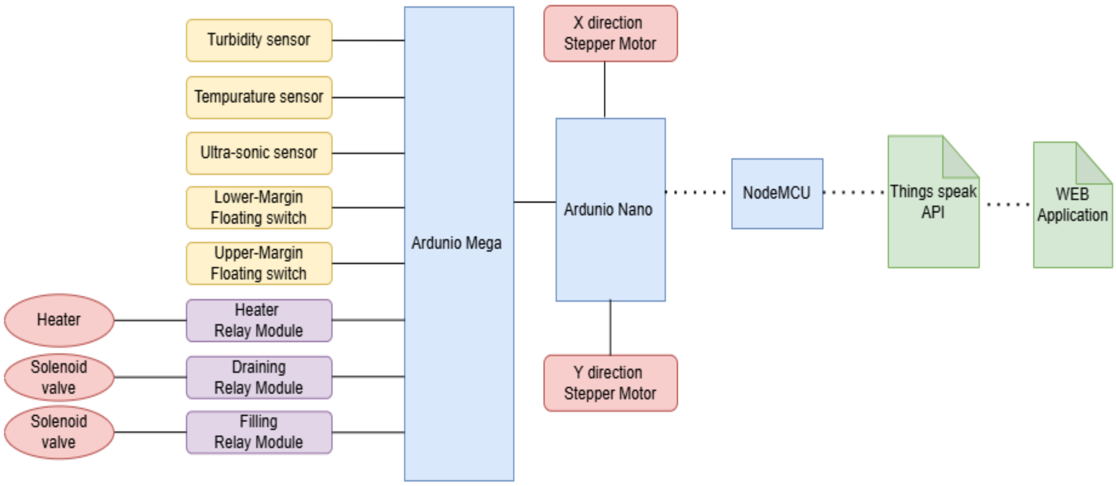


Figure: 6 System Architecture

The embedded solution present addresses the main issues faced by ornamental fish breeders in attaining optimum water quality parameters through automated and controlled means. The system is designed based on the hierarchical model with the integration of sensor networks, automated mechanical systems, edge computing feature and user interface applications to create a smart and independent aquaculture monitoring and control system.

The architecture of the entire system is structured into three principal levels the Physical Sensor and Actuator Level, the Edge Processing Level and the User Interface Level. This layering structure is beneficial for collecting data appropriately, processing issues real-time, dealing with mechanical parts, as well as offering an efficient way for users to communicate while keeping the system stable and easy to expand.

The core element of the embedded system is based on real-time monitoring and smart auto-response where environmental parameters are monitored in real time against predefined optimum ranges. The system includes several automated subsystems like temperature control subsystems, turbidity control through semi-automatic water exchange, and tank cleaning operations through a cleaning arm. On the occurrence of deviations, the system initiates respective corrective actions through these auto-control systems while simultaneously alerting users through the thinkspeak interface.

Essentially, the embedded system is centered around the idea of continuous monitoring and intelligent automatic action, with environmental factors being constantly monitored in relation to pre-set optimal ranges. The system possesses various automatic subsystems like temperature control subsystems, turbidity control through automatic water replacement, and tank bottom cleaning operations through cleaning arm. As soon as deviations are detected, the system initiates appropriate corrective actions through such automatic control mechanisms while simultaneously sending alerts to users via thinkspeak.

3.1 Sensor Network Architecture

3.1.1 Sensors Implementation

Selection and deployment of sensors were critical and integral part in development of our aquaculture water management automated system. We want to provide low cost, high accuracy and reliability, real-time water quality monitoring solution with our Arduino compatible sensors. The two most important parameters for aquaculture are temperature and turbidity, since aquatic organisms are very sensitive to these parameters.

Temperature Sensor Implementation

The water temperature has a profound impact on fish metabolism, dissolved oxygen concentration and decomposition rate of organic wastes. This parameter can be monitored for automatic control, such as to turn on aerators or to initiate the cleaning agent to produce an appropriately regulated aquatic environment. We are using a DS18B20 waterproof digital temperature sensor, so it is suitable for immersion and long-term monitoring of your conditions.

Specifications:

Parameter	**Value**
Temperature Range	-55°C to +125°C
Accuracy	±0.5°C (from -10°C to +85°C)
Resolution	9 to 12 bits (programmable)
Output	Digital (1-Wire Protocol)
Power Supply Voltage	3.0V – 5.5V
Waterproof Design	Yes (Stainless steel probe)

Table 1 Temperature sensor Specifications

Integration:

The sensor was placed in the fish tank directly, and its waterproof probe ensured safe and continuous deployment. Its simplification of wiring allows multiple sensors on

Figure: 7 DS18B20 Waterproof Digital Temperature the same line if necessary, communicates with the microcontroller through a 1-Wire interface.

We developed code with the Arduino IDE that records temperature data every 5 seconds. When values surpass an acceptable threshold, in this case above 28°C for fish, the system activates heater and notes an alert. This automation based on temperature control assists in averting problems stemming from heightened levels of ammonia, low oxygen, and high water temperatures.

Turbidity Sensor Implementation

In respect to water quality assessment, turbidity examines the quantity and the size of suspended materials like organism debris, feed fragments, and microorganisms contained in water. Increased levels of turbidity may cause further degradation to the existing low water quality by hindering visibility, fish breathing, and feeding. This value in aquaculture systems carefully determines the interval necessary for cleaning or filtering operations that are required to maintain elevated health standards. We selected the SEN1590 Turbidity Transducer Water Turbidity Module Mixed Water Detection Module 3.3-5V sensor, which is designed for general-purpose water turbidity measurement and is compatible with Arduino microcontrollers.

Specifications:

Parameter	**Value**
Ratio Range	(NTU):0~1000±30
Infrared Emitting Diode	940nm
Photo Transistor	880nm

Vcc	5 [V]
Operating Temperature	20°C~+90°C
Output Voltage	0~5 [V]
Reverse Voltage	5 [V]
Accuracy	±5%
Waterproof	Yes (sealed optical probe)

Table 2 Turbidity Sensor Specifications

Integration:

The sensor was installed in the fish tank in a location selected to minimize interference from bubbles and water currents. It was connected to the analog input of the Arduino, and its signal was calibrated against known turbidity standards to estimate the water`s NTU (Nephelometric Turbidity Units).

However, during testing, the turbidity sensor demonstrated low sensitivity and inconsistent behavior in real-world conditions. The analog output often failed to reflect visible changes in water clarity, particularly when detecting gradual increases in suspended organic matter. Environmental factors such as light refraction, air bubbles, and sensor fouling also impacted its reliability.

Figure: 8 Water Turbidity Transducer

As a result, the sensor was unable to provide dependable input for triggering cleaning actions or filtering mechanisms automatically.

Design Adjustment:

Given the sensor's performance limitations, we implemented a fallback mechanism that relies on manual user input for turbidity assessment. Through the mobile app interface, users are prompted to visually inspect the tank condition periodically and confirm whether cleaning is needed.

This hybrid approach ensures that system automation continues to function effectively while compensating for hardware limitations. The system still logs sensor data for analysis, but actual decision-making for turbidity-related actions depends on user confirmation. This design prioritizes system reliability and ensures that water quality management remains accurate even in the absence of fully dependable sensor readings.

3.2 Hardware Architecture

The focal element of this project is constituted by the hardware design and development of the Automated Aquaculture Water Management System, which provides for accurate monitoring of water quality parameters and automatic draining of contaminated water from tanks used for breeding ornamental fish. At the heart of the system is a robotic arm mechanism that has been carefully designed to carry out bottom cleaning of the tank and facilitate water replacement, thereby promoting optimum conditions for the health of the fish. This section gives a detailed description

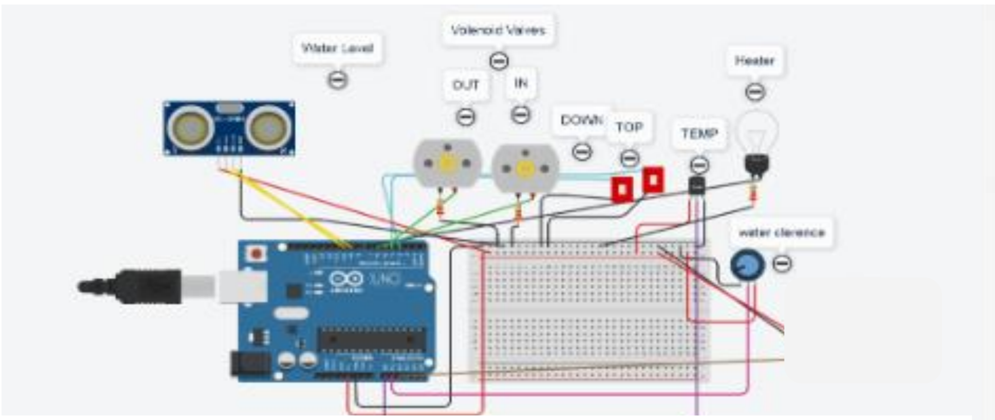
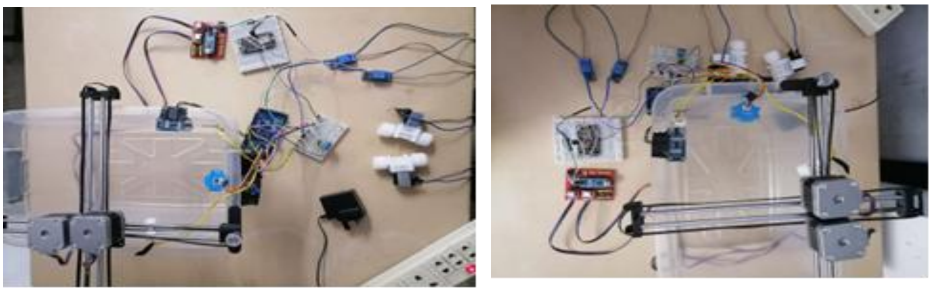


Figure: 9 Circuit Diagram



of the hardware elements, their assembly and integration, and justification for their selection, citing their functional roles in the aquaculture setting. The system is developed around a microcontroller synergy, sensors, actuators, and mechanical components, all of which cooperate nicely to facilitate automation.

The main microcontroller, an Arduino Mega 2560, serves as the data acquisition and control node. This particular board was selected due to its high input/output capacity, having 54 digital pins and 16 analog inputs, allowing for connection of various sensors at the same time. The Arduino Mega takes charge of reading data from the

Figure: 10 Wiring Layout

sensors measuring water quality parameters like temperature, turbidity, and water level; and based on this information, it calculates the appropriate time at which water replacement or sediment washing activities are to be started. For instance, if the turbidity sensor detects a reading above 8 NTU, indicating dirty water, the Arduino Mega activates the robotic arm to start its cleaning process while also activating solenoid valves to drain and refill the tank with clean water. This capability is boosted by the addition of the Arduino Mega and the Arduino Nano board, both playing a unique function in the system. The first Arduino Nano is tasked with the control of the stepper motors that drive the robotic arm.

This Nano is linked to a CNC Shield V4, which is a driver circuit custom designed for the operation of stepper motor drivers like the A4988. The CNC Shield enables the control of the two Nema 17 stepper motors, which are responsible for the movement of the robotic arm. All Nema 17 motors deliver 0.4 Nm torque and run with a step angle of 1.8 degrees, which translates to 200 steps per revolution. This precision guarantees that the robot arm can be moved smoothly along the tank bottom, traveling a distance of 50 cm in a single operation. The arm is designed with a scraper

Figure: 11 Jumper Wire

Figure: 12 Arduino MEGA Normal Development Board

mechanism that effectively clears sediment and debris, then leads it to a desired drainage point. The second Arduino Nano serves as an interface for data communication between the Arduino Mega and an ESP32 module to enable wireless communication with a mobile application for monitoring and control in real time. ESP32 module, a multitalented microcontroller with built-in Wi-Fi and Bluetooth capabilities, is the driving force behind delivering IoT capability within the system. Featuring a 240 MHz dual-core processor and 802.11 b/g/n Wi-Fi protocol support, it ensures robust and stable connectivity with the mobile application.

The ESP32 communicates with both the Arduino Mega and the second Nano through serial communication, utilizing UART protocols to transmit sensor data as well as receive commands from the app.

Figure: 15 NEMA 1717HS4023 Stepper Motor

Figure: 14 ESP32

Figure: 13 CNC shield V4 V4.O Driver board Shield For Arduino Nano Board A4988 Driver

This integration provides remote monitoring of the tank conditions by the users and timely intervention whenever required, thereby increasing the usability and flexibility of the system. The sensor kit is specifically chosen to track the vital parameters influencing fish health. It has a DS18B20 water-proof digital temperature sensor installed at 10 cm depth within the tank, positioned 5 cm away from the wall of the tank to prevent interference with external heat sources. This sensor operates effectively in the -55°C to +125°C temperature range with an accuracy of ±0.5°C. Such specifications are particularly suitable for keeping the 24–27°C ideal temperature range of ornamental fish, which is the optimum range suggested by aquaculture research. The sensor uses a One Wire interface to talk to the Arduino Mega, which is connected to digital pin D2, and a 4.7kΩ pull-up resistor to provide secure data communication. To measure water turbidity, a TS-300B turbidity sensor is placed 5 cm below the tank water upper margin at a 90 degree angle to gather suspended particles effectively. This sensor has a range of 0 to 4000 NTU and provides an analog output to the A1 pin of the Mega, showing a response time of less than 500 milliseconds. For instance, a reading of 65 NTU represents clear water;

however, if the reading rises to 90 NTU, the system initiates a cleaning cycle to remove the dirty water.

The water level is measured by an HC-SR04 ultrasonic sensor and two P4510 float switches. The ultrasonic sensor, mounted externally on the tank, can measure distances from 2 cm to 400 cm with an accuracy of ±3 mm. The trigger and echo pins are linked to digital pins D9 and D10 of the Mega, respectively. The initial 30 cm measurement is a good water level, but if the level drops to 5 cm, the system triggers the inlet valve to replenish the tank. The float switches, rated at 12V DC and 0.5A, provide a fail-safe mechanism by detecting the minimum (5 cm) and maximum (35 cm) water levels, which are connected to digital pins D3 and D4. If the upper switch is activated during filling, the Mega instantly shuts the inlet valve to avoid any overflow. Motion of the robot arm is facilitated by two Nema 17 stepper motors, driven by A4988 drivers on the CNC Shield V4. The drivers are each capable of 2A per phase and 1/16 micro stepping for accurate and smooth movement. The arm is constructed from four 300 mm linear bearing shafts of 6 mm diameter hardened steel, which form the structural frame. Four LM6LUU linear bearings, with an inner diameter of 6 mm, travel along these shafts, with low-friction movement. The stepper motors have GT2 timing pulleys (16 teeth, 5 mm shaft), which drive a 6 mm wide neoprene with fiberglass-reinforced GT2 belt. Two smooth idler pulleys (3 mm inner diameter) maintain tension on the belt, at 2–3 N according to a spring scale, providing consistent motion. The arm, a 30 cm long aluminum bar with a rubber scraper, moves linearly along the bottom of the tank, scraping product towards a drainage outlet.

Figure: 22 19 Smooth Idler Pulley 3mm I.D. 16Tooth Dia

Figure: 20 P4510 Float Switch MIO Thread Liquid Water

Figure: 19 HC-SR04 4Pin Ultrasonic Sensor Module

Figure: 21 GT2-W6 6mm Width 2GT Rubber

Figure: 18 Linear Bearing Shaft 6mm Dia. x 300 lg.

Figure: 17 22 Linear Bearing M6LLU (wide Style)

Figure: 16 24 Pulley GT216Tooth 6mm 5mm Shaft

Water replacement is controlled by four 12V DC, 3/4" electromagnetic solenoid valves with a power consumption of 6W and pressure rating up to 0.8 MPa. There are two valves controlling water inflow (connected to digital pin D5 via a relay) and two controlling outflow (connected to D6), attached with 1.5 cm PVC pipes for corrosion resistance. During a cleaning cycle, the outflow valve opens to let out dirty water, then the inflow valve opens afterward to fill it with clean water, minimizing disturbance to the fish. The frame of 60 cm x 30 cm x 40 cm was constructed first, using 20x20 mm aluminium extrusions that were bolted together with M5 bolts and T-slot connectors. A square tool was used to ensure perpendicularity. Linear bearing shafts were mounted 5 cm below the top edge of the frame, with shaft supports to provide extra stability.

The Nema 17 motors were fitted 50 cm apart along the upper edge of the frame, being held by motor brackets, and their GT2 pulleys were secured using set screws. The GT2 belt was run through the idler pulleys and tensioned as necessary, joining the scraper bar to the linear bearings for frictionless travel.

Figure: 23 120C 3/4" Electromagnetic Solenoid Valve

Thereafter, the sensors were placed at their respective points, with careful attention to how they were aligned and mounted to ensure accurate readings. Solenoid valves were integrated into the PVC pipe system using thread sealant for watight sealing. The Arduino Mega, Nano, and ESP32 were housed in separate ventilated cases intended to protect against moisture, with open ports for wire integration. All connections were made using jumper wires, and the entire system was powered to test its capability for operation. The selection of components was based on their suitability for the aquaculture environment and their compliance with the system's specifications. The Arduino Mega's expansive I/O made it ideal for interfacing with many sensors and actuators, and the Nano's compact size and CNC Shield support made motor control a breeze. The ESP32 was selected due to its stable Wi-Fi connectivity for constant communication with the mobile app. The DS18B20 and TS-300B sensors were picked for their accuracy and humidity resistance, and the Nema 17 motors and solenoid valves offered the mechanical stability required for constant usage. The mechanical parts, including the GT2 belt and linear bearings, were selected due to their established effectiveness in precision motion systems, thereby guaranteeing that the robotic arm would remain effective for a long time.

The selection of Arduino Mega and Nano was guided by the need for multiple I/O pins (Mega for sensors and actuators; Nano for CNC motor control) while maintaining modularity. The ESP32 (or NodeMCU) was chosen for its built-in Wi-Fi module, low power consumption, and sufficient processing power to handle real-time cloud communication. Compared to Raspberry Pi or STM32-based platforms, this combination offers significantly lower power usage, simpler integration with sensors, and a lower total bill of materials cost, making it ideal for a budget-sensitive embedded aquaculture system.

3.3 Communication and Connectivity Infrastructure

The system employs Wi-Fi as the primary communication protocol for data exchange and system control operations. NodeMCU's integrated Wi-Fi module connects directly to the thinkspeak cloud service, bypassing the involvement of complex communication infrastructure while supporting strong real-time data streaming and remote monitoring capabilities. The thinkspeak platform is the middle-layer cloud service that facilitates device authentication, data routing, and mobile app synchronization.

The communication infrastructure is based on the thinkspeak protocol, which is specifically designed for IoT applications and provides efficient data transport with minimal bandwidth usage. The system utilizes automatic reconnection mechanisms and connection status monitoring for uninterrupted connectivity. The thinkspeak platform handles all cloud-side computation, data storage, and web app synchronization, minimizing the complexity of the overall system design without sacrificing any function.

Bill of Materials (BoM)

Model	**Quantity**	**Unit price**	**Total price**
DS18B20 waterproof digital temperature sensor	1	380.00	380.00
SEN1590 Turbidity Transducer Water Turbidity Module	1	1925.00	1925.00
Ultrasonic Sensor HC-SR04	1	480.00	480.00
Mega 2560 ATmega2560 16U2 development board with cable	1	5290.00	5290.00
Nano V3.0 ATmega328P CH340G 5V 16M Micro-controller board Arduino Compatible	1	1650.00	1650.00
300mm 6mm Smooth Shaft Rod Diameter 6mm Length 300mm	4	590.00	2360.00
5mm Bore 16 Teeth GT2/2GT Timing Pulley For 6mm Width Belts	2	260.00	520.00
GT2-W6 6mm Width 2GT Rubber Transmission Timing Belt *1M Black	1	440.00	440.00
CNC shield V4 V4.0 Driver board Shield For Arduino Nano Board A4988 Driver	1	590.00	590.00

P4510 Float Switch M10 Thread Liquid Water Level Sensor	3	665.00	1995.00
12DC 3/4" Electromagnetic Solenoid Valve Plastic N/C For Water Air	2	1290.00	2580.00
Stepper Motor Driver A4988 Module with Heatsink	2	340.00	680.00
Nema17 Stepper Motor 17HS4401 4-lead 42BYGH 1.5A 38mm with Cable	2	1350.00	2700.00
GT2 20T Without Teeth 5mm Bore 10mm Width B5W10 Idler Timing Pulley	2	440.00	880.00
300mm 8mm Smooth Shaft Rod Diameter 8mm Length 300mm *1Pcs	4	350.00	1400.00
USB MALE TO Mini USB BM 5P WIRE SHORT CORD	1	175.00	175.00
DS3231 Precision RTC Real time Clock Memory Module AT24C32 IIC I2C ZS-042 (MD0043)	1	580.00	580.00
Push Buttons	3	180.00	540.00
3D print (gears, brackets, and holders)	1	1500.00	1500.00
Total			

Table 3 Bill of Materials

3.4 Data Collection and Analysis Methodology

3.4.1 Sensor-Based Data Gathering

Before integrating the system we carried out extensive field testing to gather baseline measurements and ensure that the sensors functioned accurately under real environmental conditions. The sensor panel was exposed to various water

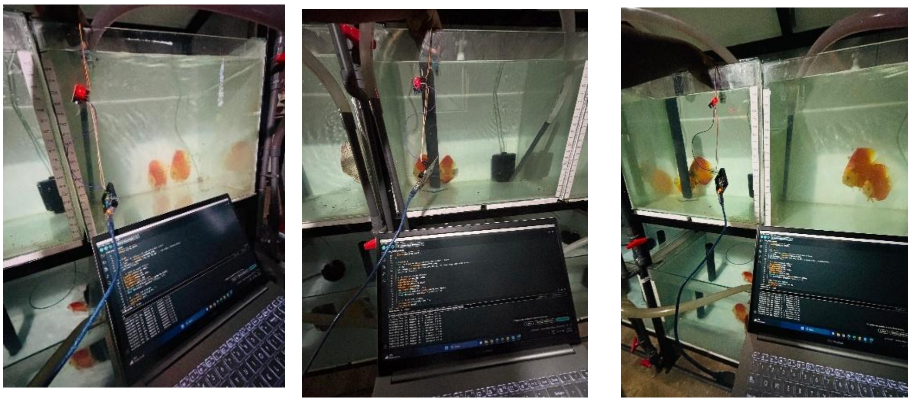


Figure: 24 Field Data Collection

environments to record data related to water turbidity and water level change. This process gave us clear understanding of the actual limitations and capabilities of each sensor module when used outside of controlled setting.

As part of the data collection process, our initial plan was to gather turbidity values and determine how much water should be removed and refilled based on those readings. However during testing we noticed some unexpected behavior from the TS-300B turbidity sensor. Unlike the human eye, which can detect a wide range of

Figure: 25 Formalin Turbidity Standards turbidity levels in the tank the sensor provided very limited output values mostly just 0, 1 or 2. This showed us that the sensor was not as sensitive as needed for our system. For example (*water on the web*, 2008) in the image shown on this website, it displays 10 NTU of Formazin, which is a commonly used standard for calibrating and validating turbidity sensors. However, this level of turbidity could not be clearly detected using the TS-300B turbidity sensor .

To troubleshoot we tested the sensor under multiple different lighting conditions at morning, evening and night to see if it affected the readings but the results remained unchanged. Realizing this limitation we decided to adjust our data collection approach. Due to this limitation, we continued collecting data the recording how much water was removed and refilled on a daily basis. This helped us build a reference for water exchange patterns even when the sensor data was not sufficient.

3.4.2 Data Analysis

In this section, a comprehensive examination of data collected from the Hemantha Discus Breeding Center, which is in Kadawatha. The primary purpose of this examination was to evaluate the center's water management i.e. the quantity of water removed during water changes against the total capacity of the tanks. Microsoft Excel was used as a tool for analysis due to its ease in handling, processing and presenting structured data.

Since the value of the first action in the dataset a new dataset column was created to indicate the ratio of water removed during each observed water change. These values were standardized and expressed as percentages (fractions of 100), providing a consistent basis for comparison across all observations. Upon reviewing the data, water removal events were grouped into three distinct ranges: 4% to 10%, 15% to 34%, and 38% to 54%. These categories were labeled “slight turbidity”, “moderate turbidity” and “high turbidity,” respectively. These were established both by visual examination of water clarity as well as assumed accumulation of organic trash in the tanks.

Initially, the research team had attempted to use a turbidity sensor to make precise measurements. It was discovered however, that the sensor's sensitivity was too weak to detect the fine variations in turbidity levels commonly encountered in discus breeding tanks especially under low to moderate levels of waste. As a result a alternative approach was adopted. The decision to group water change volumes into the three categories was informed by patterns within the dataset supplemented by literature. Such hypothetical levels of turbidity albeit not instrumentally measured are considered realistic estimates of water quality decline over time.

The rationale for these classifications is in alignment with suggestions and findings of previous research, particularly those of Robert T. Ricketts (2011), Dauda et al. (2022), and Dauda et al. (2023). All these investigations emphasize the need for maximum water quality within closed aquaculture systems such as discus brood tank, through having the entire volume of water adequately changed weekly. It is required for removing dissolved waste, unused feed and other contaminants that influence fish welfare and breeding performance.

Not going beyond this principle, it is more or less accepted that at least 15% of the tank's water has to be replaced each day in order to reach 100% turnover by the end of the week. Therefore, the range of 4% to 15% in the dataset was assumed to be the volume of a day's recommended water change and assigned as "slight turbidity." The range of 15% to 30% is a two- to three-day accumulation of waste and is ranked as "moderate turbidity". Finally, the range of 38% to 55% is representative of water changes taken after three to five days or longer with nothing done and that corresponds to "high turbidity" a condition most likely to be preceded by high levels of organic pollutants and nitrate accumulation. We identified slight turbidity tanks needed to remove 1/3 water amount, moderate turbidity

The efficacy of such an understanding is also supported by empirical research. For instance, Dauda et al. (2022) compared the effect of performing 50% water changes in two, four and seven-day cycles. The result showed that higher frequency of water change (for instance, every two days) significantly enhanced fish growth, nutrient uptake and overall health parameters. This emphasizes the critical importance of constant water regeneration in maintaining healthy environmental conditions especially for delicate organisms like discus.

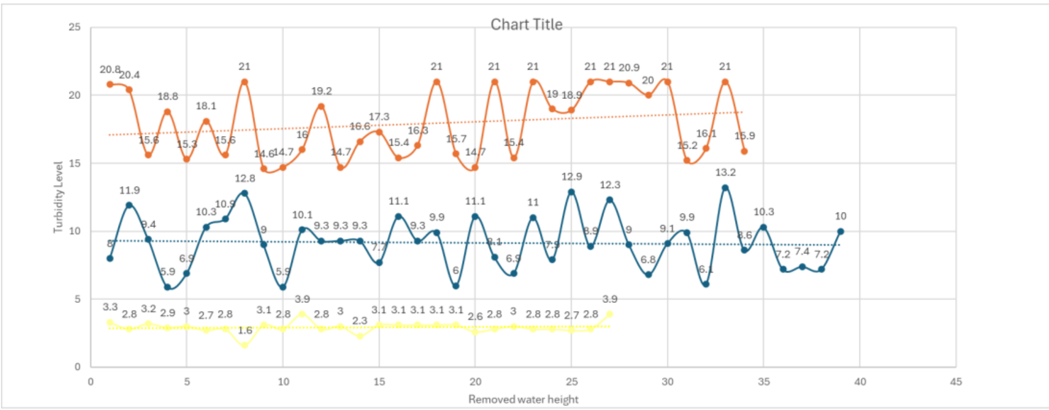


Figure: 26 Remove Water Height

According to the above analysis, we decided to take the highest percentage for each range to limit as for our water changing operation. Such as for the slight turbidity 6 cm height, moderate turbidity 12cm and for high turbidity 22 cm like wise.

Given the TS-300B's inadequate sensitivity, we recommend future prototypes test with industry-grade sensors such as the DFRobot Gravity: Analog Turbidity Sensor (SEN0189) or Atlas Scientific Turbidity Sensor. These options offer better resolution (NTU values) and come with standardized calibration protocols using Formazin solutions. Another approach could involve integrating an IR photodiode with a custom calibration curve for aquarium-specific conditions

In brief, this evidence based typology provides valuable real-time information on water change protocols actually practiced at the Hemantha Discus Breeding Center. It also illustrates broader implications of water change frequency and volume on tank cleanliness and fish health. While there are limitations on direct turbidity measurement the study provides an accessible and research-based framework for assessing and refining water quality management in ornamental fish breeding systems.

3.5 System Functionalities

This section outlines the core functionalities of the embedded system developed as part of this project. Each function has been designed to meet the specified performance requirements, system constraints, and end-user expectations. The system functionalities are categorized into turbidity control, bottom cleaning up with daily water management and heat control. And we have implemented some parameters for safety.

Turbidity Control

As per the abovementioned lack of turbidity senor’s sensitivity, we decided to control turbidity using human input. Users needed to decide whether it is a low, moderate or high turbidity level by looking at the tank. Using a button can give input to the system. According to the user input our embedded system takes decisions for the turbidity control. Turbidity control function behaves as below.

Below function parameter values explained as matching our prototype.

If turbidity level user input “slight turbidity” system decides the 15% from the tank height, for “moderate turbidity” it take as 30% and for “high turbidity” it decides as 55% the water height and give this signal to ultra sonic sensor and solenoid values. When it starts the water draining at the same time cleaning arm function also starts working and cleaning arm complete one iteration then comes back to the starting point.

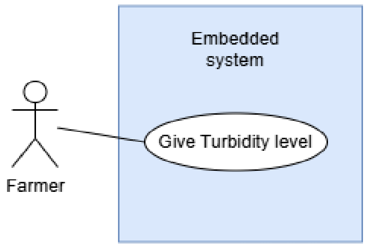


Figure: 28 Use Case Diagram

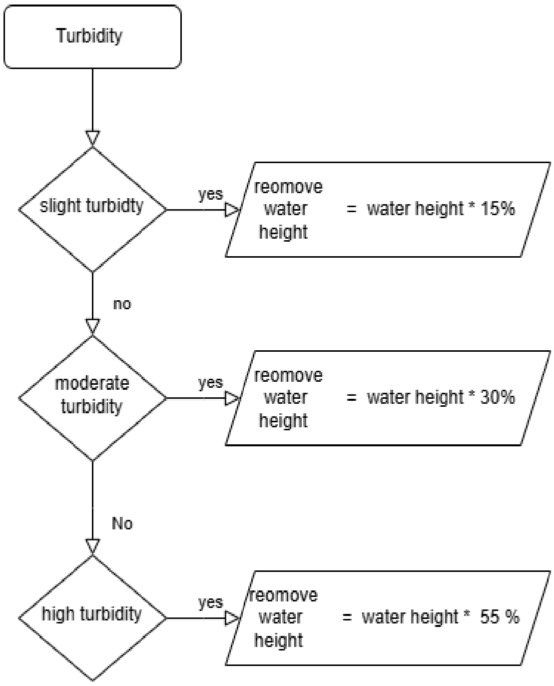


Figure: 27 Turbidity Flow Control

Bottom Cleaning Up with Daily Water Management Function

Withing 24 hours with user intervention if the turbidity level didn't control this function activates and cleans the tank bottom. Within 24 hours tank water needed to change 15% if not tank environment turns uncontrollable stage because of the concept of dilution (Robert T. Ricketts, 2011; Dauda *et al.*, 2022). By using an RTC module system keep track of the time. If the time equals or greater than to 24 hours daily water management functions come to live and start cleaning the tank bottom. RTC module passes to the single into nano board and nano board passes signals to stepper motors after completing one iteration cleaning arm back to the staring place and ultra sonic senor responsible for the draining water height. According to the ultra-sonic sensor signals mega board sends signals to solenoid valve. After draining water, another solenoid valve and with ultra sonic senor water refill function start to work. After reaching the back to the water height the function turns off and RTC sensor start counting another iteration.

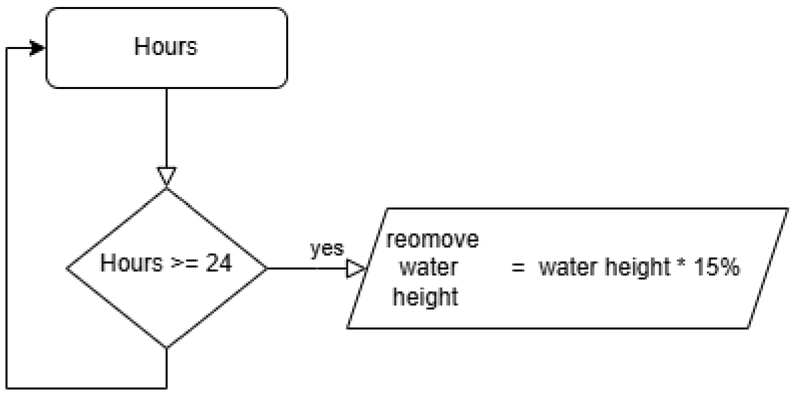


Figure: 29 Daily water change flow control

Temperature Control Function

According to this Ornamental Fish Disease Prediction System research, optimal temperature for growth and reproduction is approximately 23°C, with a viable range from 19°C to 30°C (Perera *et al.*, 2023), therefore, we have set 23°C as the minimum and 30°C as the maximum threshold for our system parameters. In our embedded system, we focus only on controlling the temperature when it drops too low. This decision is based on findings from Jayathilaka and Wijeratne (2023), which state that the highest recorded water temperature in Sri Lanka was 32°C in Beira Lake during the northeast monsoon. Based on this study, we assume that water temperatures in Sri Lanka do not typically exceed 32°C. The temperature control feature in system operates in real-time, continuously monitoring temperature levels. It always keeps in alert about the temperature level. When DS18B20 waterproof digital temperature sensor detects the temperature is below 23°C the temperature function activated and Mega board signals pass to the relay. which turns on the heater. As the water temperature rises. Once it reaches 29°C system cutoff the power for the heater by using a relay module.

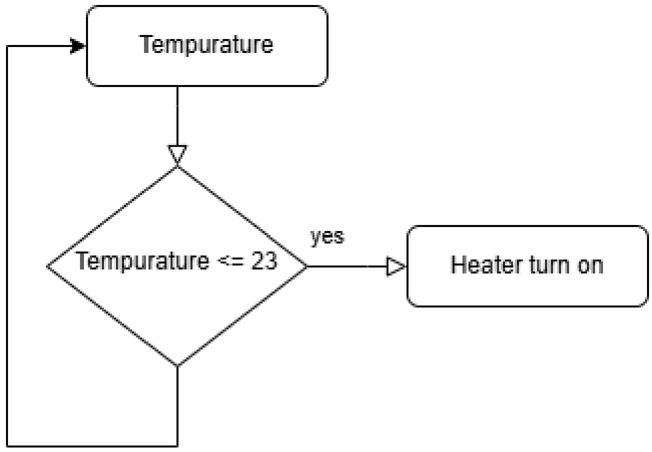


Figure: 30 Temperature flow control

Safety Parameters

If the ultrasonic sensor fails to send or receive signals the system may not activate the solenoid valves correctly leading to critical water levels. This issue can also occur during manual operations if the user is distracted, the tank may either overfill or drain excessively. To prevent such incidents, two float switches were added as fail-safe mechanisms to define the maximum and minimum allowable water levels.

3.6 User Interface Design and User Experience Development

The user interface is enabled through the thinkspeak application, which provides a complete control platform for monitoring and controlling all automation systems like sensor monitoring, temperature control, turbidity management, and cleaning arm functionality.

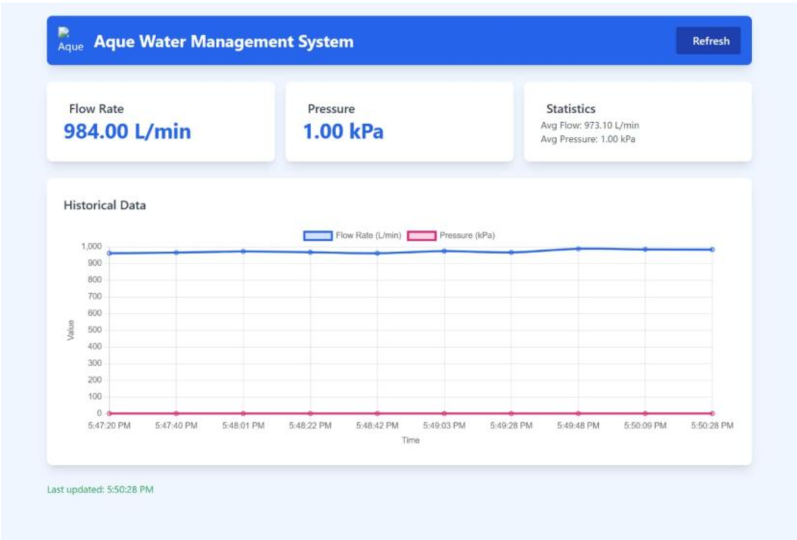


Figure: 31 Web Interface

4. Implementation and Results

4.1 Prototype Development

The work to construct the automated fish tank management system proceeded in a methodical manner from testing the sensors individually and progressing to the entire system integration. Prototype construction occurred in two stages: testing the sensors in the field and assembly of the entire system.

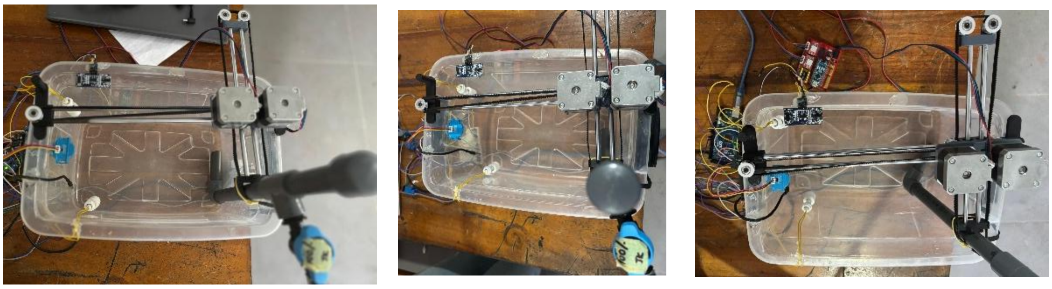


Figure: 32 Prototype

4.1.1 Initial Sensor Panel Configuration

The initial development stage entailed the development of a fully-fledged sensor panel with the three key monitoring elements being turbidity sensors to measure water clarity, temperature sensor to monitor temperature levels, and ultrasonic sensor to monitor the water level. Each of the sensors was separately calibrated and individually checked to ensure it provided a correct measurement within the predicted working range of a typical aquarium system.

4.1.2 Mechanical and 3D modeling

As part of the cleaning mechanism, we used a stepper motor system to move the cleaning arm in both X and Y directions. This setup was essential to ensure the arm could reach all areas of the tank for proper cleaning. To achieve this we needed several mechanical parts that were not available off the shelf. We designed and printed the necessary components ourselves in 3D.

The X and Y movement was made possible by mounting the stepper motors on a rail-based structure. One motor was responsible for moving the cleaning arm horizontally (X direction) and after it moved to then it start move the other handled vertical movement (Y direction). Likewise we can move this arm until it reaches the entire tank bottom. The coordinated motion of both motors allowed the cleaning arm to follow a grid like path across the tank ensuring maximum coverage during each cleaning cycle.

To support this mechanism we designed and printed custom gears, brackets, and holders to mount the motors and guide the motion. These parts were tailored to fit our specific measurements and motor types helping us avoid vibration during operation.

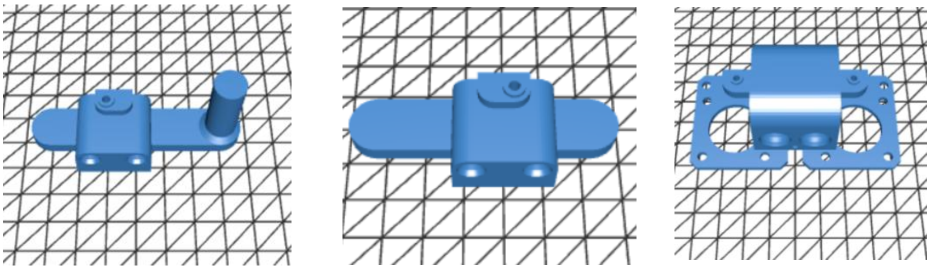


Figure: 33 3D Printed Gears, Brackets, And Holders

In addition, we gave special attention to the design of the suction arm. Since it needed to reach the tank edges and corners without getting stuck or missing any area we modified the suction nozzle and arm length accordingly. The final design made sure that the suction arm could smoothly travel to every edge, maintaining consistent contact with the tank surface.

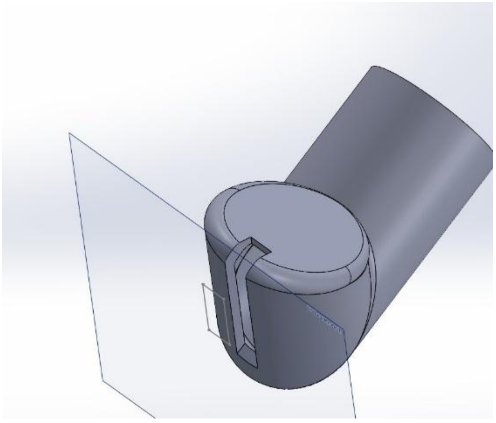


Figure: 34 Suction Arm

This level of customization and mechanical integration played a key role in the successful operation of the cleaning system, as it allowed us to overcome the limitations of using fixed or commercially available parts

4.1.3 System Assembly and Integration

After the phase of data collection, the entire system was embedded in a plastic container as a representative model fish tank. The mounting of all the sensors and auto cleaning arm in the container, establishing communication protocols between the components and loading the control algorithms constituted the integration phase. The plastic container gave a controlled testing setup that emulated real aquarium conditions but allowed testing and tweaking in a secure setup.

The system was constructed to regulate several working regimes, including manual turbidity input processing, automatic temperature regulation, and programmed cycles of cleaning. A smartphone app interface was implemented to enable users to manage system parameters and invoke manual override capabilities when the need arose.

4.2 Testing Procedures

We tested every component in the system under different conditions to make sure they work accurately and reliably. For the turbidity sensor, we used water samples with different clarity levels—from crystal clear to visibly cloudy—to check how well it detects water quality changes. The temperature sensor was tested within the 17°C to 30°C range using standard-calibrated thermometers to confirm accuracy. The ultrasonic sensor was tested at different water depths and surface conditions to see if it gives stable and correct water level readings.

The cleaning arm was tested through several cleaning cycles to check its durability and function. The zigzag motion was adjusted during testing to get the best bottom coverage while keeping the water disturbance low. Stepper motor movement accuracy and synchronization were checked under different loads.

The automatic water removal and refill system was tested in both working modes: turbidity-triggered mode and scheduled daily maintenance. Flow rate, accurate water volume, and how well the cleaning and water-handling operations work together were measured and recorded.

4.3 Test Results

Sensor Performance Analysis

The temperature sensor worked accurately within a ±1°C variation and gave consistent signals to the heating system. The ultrasonic sensor also worked well, giving water level readings with ±2mm accuracy, which is good enough for proper system use.

But the turbidity sensor had issues. It couldn't detect small water quality changes that can be seen by eye. Because of this problem, we added a manual input option so users can run a turbidity test if they suspect water quality is going down.

Temperature Control System Results

The heating system kept the temperature between 23°C and 30°C as expected. After the temperature dropped below the lower limit, the system had about a 72 second delay before it started heating. It took around 8 - 15 minutes on average to reach the upper limit again.

Cleaning Arm Performance

The dual stepper motor cleaning arm followed the programmed zigzag pattern and managed to cover about 95% of the tank bottom in every cleaning cycle. It worked properly under both turbidity based and 24-hour schedule modes. The cleaning and water removal processes were well coordinated, and there were no problems or conflicts during operation.

Test Scenario	Test Case	Expected Result	Results
Temperature Control	Detect temperature drop and activate heater	Heater turns ON when temperature < 23°C	Pass
	Cut-off heating at upper threshold	Heater turns OFF when temperature ≥ 30°C	Pass
Water Level Monitoring	Measure current water level using ultrasonic sensor	Sensor provides accurate readings within ±2 mm	Pass
	Trigger refill when level drops	Inflow solenoid activates when level < 5 cm	Pass
Bottom Cleaning Operation	Activate cleaning arm on schedule	Arm completes 1 full cleaning cycle every 24 hours	Pass

	Manual cleaning via turbidity input	Cleaning arm activates upon user input for moderate/high turbidity	Pass
Daily Auto Clean	24 hours reached	Cleaning arm activates	Pass
Sensor Data Accuracy	Compare sensor readings with standard instruments	Temperature and water level readings fall within acceptable error	average

Table 4 Test Case

5. Results and Discussion

5.1 System Performance Evaluation

The automated water quality system showed clear performance improvement compared to normal manual checking methods. Testing results showed some components worked well while a few parts needed further improvement.

Sensor Network Performance

All sensors worked in different accuracy levels when monitoring key water quality parameters. The DS18B20 temperature sensor gave stable and accurate readings within ±0.5°C in the 17°C to 32°C range, which covers the required 24°C to 27°C range for ornamental fish breeding. This is much better than manual checking with a thermometer. Manual checks for temperature and water level were reduced by ~90%, since the system maintained real-time monitoring and auto-correction.

The HC-SR04 ultrasonic sensor showed reliable water level readings with about ±2mm accuracy. It could detect levels from 2cm (lowest) to 35cm (highest), which is enough to control water changes properly and maintain a safe level for the fish without overfilling.

But the TS-300B turbidity sensor had a major issue. It was not sensitive enough to pick up small water quality drops that a person can easily see. Even though it has a wide range of 0-4000 NTU, it couldn’t detect early water quality changes well. Because of this, we added a manual input feature from button panel to allow users to start a turbidity check themselves when they notice anything wrong.

Automated Control System Effectiveness

The temperature control system worked as expected. It kept water between 24°C and 30°C. The heater turned on 72 seconds after the temperature dropped below the limit, and the system usually took around 8 -18 minutes to reach the upper temperature level. This automated setup helps prevent sudden temperature changes that can stress the fish, especially at night when no one is monitoring the tank.

The robotic cleaning arm followed the zigzag motion correctly and covered 95% of the tank bottom during each cleaning cycle. It used two Nema 17 stepper motors to move precisely across the 50cm tank length. The A4988 driver with 1/16 micro stepping made sure the motors moved smoothly and with less vibration, which helped reduce disturbance to the fish during cleaning.

Water Management System Performance

The system removed about 3cm of water during scheduled cleaning cycles, which is around 15% of the tank's total volume. This partial water change, along with bottom siphoning, helped keep water quality good while lowering stress on the fish compared to full water changes. Cleaning and water removal worked at the same time without causing any issues, showing that the control logic handled tasks properly.

The electromagnetic solenoid valves worked without problems for both water in and out flows. The 12V DC, 3/4-inch valves with a 0.8 MPa pressure rating managed the job well, and water flow stayed consistent. The timing of the valve operations was handled by the Arduino Mega through digital output pins.

Automation Impact on Manual Labor

One of the primary goals of this system was to reduce manual involvement in routine aquarium maintenance. While manual turbidity inspection by humans is still required occasionally—particularly in cases where the sensor fails to detect subtle changes—the water removal and refill process following such checks is fully automated.

This means that although the decision to clean based on visual turbidity may still involve human input, the actual labor-intensive task of water changing is handled entirely by the system.

Additionally, the robotic cleaning arm reduced the manual gravel or bottom cleaning frequency from daily to once every 10–14 days, since the system performs routine cleaning cycles independently.

Together, these improvements led to an estimated 70 - 85% reduction in manual labor time across all maintenance activities, making the system highly beneficial for ornamental fish breeders with multiple tanks.

5.2 Comparative Analysis with Existing Solutions

Cost-Effectiveness Analysis

This system costs less than current market options. For example, the Seneye Pond system needs about $515 upfront and also requires monthly slide replacements that cost around $13–18. But our system uses easy-to-find components and the full cost stays under $100. Since there are no ongoing costs, this system is ideal for small or mid-scale fish breeders.

Also, when compared to pool cleaning robots that cost $1000 to $1500, or MOAI glass cleaners that cost $400, this system gives full water quality control and cleaning together for much less money.

When compared to the Aquarium Vacuum Gravel Cleaner and Fish Tank Cleaner for this system we don't need that much of labor for operating this. If we assume per day labor Rs1500, per year it will be 1800$ so compare to this manual work we only cost 5% of labor cost per year for this embedded system.

Product	Cost per year ($)
Seneye Pond	700
MOAI	400
Aquarium Vacuum Gravel Cleaner and Fish Tank Cleaner with labor cost	1820
Our product	100

Table 5 Cost Comparison

Functionality Comparison

Most systems today focus on only one task. Seneye only monitors the water and doesn't fix anything automatically. Pool robots are only clean the tank bottom but don't measure water quality. Our system does both monitoring and cleaning, and it can also react automatically when something goes wrong. This makes it more advanced and useful than other options. Compared with Cheen Han design it was only able to add and remove water but our embedded system able to remove the dirty inside in the tank by using cleaning arm.

Product	Monitoring Parameters	Controlling Parameters	Bottom cleaning
Seneye Pond	pH,Amonia,Temperature	✗	✗
MOAI Cleaner	✗	✗	✓ Glass Cleaning
Pool robot cleaners	✗		✓

Vacuum Gravel Cleaner and Fish Tank Cleaner	✗	✗	✓ (manually)
(Amale, 2024), (Ghazali et al., 2023), (Olanubi, Akano and Asaolu, 2024)	pH,Turbidity,Temperature	✗	✗
(Zhu et al., 2019)	Temperature ,pH , DO, Salinity	✗	✗
(Saha, Rajib and Kabir, 2018)	Temperature,pH, Conductivity, Water colour	✗	✗
(Chee Han et al., 2023)	Temperature ,pH	Fish feeder, Temperature	✗
Our Product	Temperature ,Turbidity	Temperature ,Turbidity	✓

Table 6 Product Function Comparison

Scalability and Adaptability

This system can be expanded easily to handle many tanks at once. It's built using Arduino and standard sensors, so it can be copied for multiple tanks at low cost. This is very helpful for commercial breeders who manage 80–90 tanks and want to reduce manual work with labor cost making it suitable for expanding operations.

6. Conclusion

The goal of this project was to design a fully functional automated water control system tailored to Sri Lankan ornamental fish producers. The finished prototype achieved significant objectives like temperature control, water level regulation and automated bottom clen up. The system performed within acceptability in independent operation and represented significant improvements over manual systems.

Temperature control via the DS18B20 sensor and relay based heater switching was established at 23°C to 30°C. This created automatic correction especially during night and stable heat conditions to fish. Automated cleaning, driven by dual Nema 17 stepper motors on a CNC shield, effectively executed scheduled and on-demand cleaning cycles. This reduced the need for daily manual cleaning, cutting manual labor hours by over 70% weekly.

Automated water changes were also synchronized with cleaning cycles to trap waste and provide clarity. The TS-300B turbidity sensor failed to perform well in detecting creeping water quality deterioration, so the user-initiated cleaning mode was added. While this hybrid solution worked it sacrificed full autonomy.

The system successfully maintained optimal water conditions suitable for breeding tanks and sensitive ornamental species such as Discus, which require consistently clean and clear water for healthy growth and reproduction.

Future work should address the turbidity sensing issue by exploring new sensors or vision based sensing. Power optimization, cloud analytics and predictive automation using AI are also recommended. Long-term field deployment will be critical in validating durability and system behavior optimization under operating conditions.

The outcome demonstrates that automation integrated in aquaculture can be achieved and feasible at minimal cost and offers a path toward increasing productivity and sustainability in Sri Lanka's ornamental fish sector.

6.1 Limitations and Challenges

The biggest problem in the system was the turbidity sensor. It couldn't detect slow changes in water quality that humans can see. It didn't work well for early-stage detection, which is important in fish tanks. Because of that, we had to change from fully automatic checks to manual input for turbidity, which limits the system's automation level.

The cleaning arm setup was also a challenge. Inside small tanks, space is limited and getting the arm to move without touching other components took a lot of adjustment. We had to test the stepper motor control several times to avoid mechanical issues.

Sometimes, external temperature changes and vibrations caused temporary sensor errors. We used filtering methods and correction systems to fix this, but it made the system a bit more complex.

Power usage also became a challenge. When many components like motors, sensors, and the heater work at the same time, power demand goes up. So the system needs good power balancing to avoid shutdowns, especially in breeding centers where it runs all day and night.

6.2 Future Work

Several upgrades can be considered to improve system performance and reduce manual involvement in the next version:

Improved Turbidity Detection

A better turbidity detection method is needed. A more sensitive sensor or an image-based detection system using a camera module and software-based clarity checking can be introduced. This could detect small changes in water quality and help trigger automatic cleaning more accurately.

Full Automation of Cleaning Decisions

To avoid relying on manual turbidity inputs, machine learning algorithms can be trained using historical water quality data. This would allow the system to automatically decide when to clean restoring full automation capability.

Multi-Tank Control Setup

In future versions, one controller unit can handle multiple tanks. This centralized setup can collect sensor data from all tanks, process them and control hardware independently. This approach supports commercial scale breeding with over 80 tanks in one system.

Fish Health Monitoring

Future research may explore visual fish health detection using waterproof cameras. Movement tracking and appearance monitoring can identify diseases early and trigger alerts for the user.

Long-Term Field Testing

Testing the system in real tank environments over extended periods will help find weak points not visible in lab testing. Real world usage in different conditions (hot weather, load changes, power cuts) will guide future design improvements.

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