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| RESEARCH ARTICLE

Fuzzy Logic Empowered NetWatch: Revolutionizing Aquaculture with IoT-based Intelligent Monitoring and Management in Bangladesh

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| ABSTRACT
The innovative study "Fuzzy Logic Empowered NetWatch: Revolutionizing Aquaculture with IoT-based Intelligent Monitoring and Management in Bangladesh" is a step towards the dawn of a new era in fish farming techniques that emphasize accuracy and efficiency. Using fuzzy logic controllers in the NetWatch system, stakeholders involved in aquaculture can access a degree of intelligence and adaptability that is not possible with standard management techniques. Fuzzy logic techniques are included in NetWatch, allowing it to make intelligent judgments based on the intricate and frequently unpredictable nature of aquaculture systems, in addition to monitoring and controlling environmental parameters and water quality. Because of its dynamic adaptability, the system can mitigate risks and optimize results in real time while successfully responding to changing situations. Furthermore, NetWatch offers a comprehensive picture of the aquaculture ecosystem by combining pond-specific data with more general environmental insights, facilitating better-informed macro and micro decision-making. With this thorough knowledge, fish farmers can allocate resources more efficiently, reduce waste, and sustainably increase productivity. Moreover, Fuzzy Logic Empowered NetWatch's revolutionary potential offers opportunities for the aquaculture industry, transcending the boundaries of individual fish ponds. Bangladesh can establish itself as a global leader in sustainable aquaculture methods and set new benchmarks for production, efficiency, and environmental stewardship using IoT-based intelligent monitoring and management. Fuzzy Logic Empowered NetWatch catalyzes a systemic shift in how we approach aquaculture management rather than merely technology. Bangladesh may achieve previously unattainable levels of sustainability and productivity by utilizing fuzzy logic and the Internet of Things. This would guarantee a better future for the country's aquaculture sector and the communities it serves.

| KEYWORDS

Aquaculture, IoT, Fuzzy Logic, Fish Farms, Monitoring, NetWatch, Sensor, Sustainability.

| ARTICLE INFORMATION

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1. Introduction

According to FAO, Bangladesh ranks fifth globally in aquaculture production in Fiscal Year 2022. Fish farms are the most extensive aquaculture production unit employed in Bangladesh. Farmed fish production was 7.54 (0.7 million) lakh tonnes in the 1983-84 fiscal year. Department of Fisheries research shows that in 38 years, the yield of cultured fish has climbed to 4.7 million tonnes in the 2021-22 fiscal year. This means that, in this timeframe, the total fish production increased by nearly 6.72 times. In addition to production, the demand for aquaculture goods is rising daily. Bangladesh's daily fish consumption has climbed to 62.58 grams, requiring intensive fish farm management to sustain high production levels. Overproduction has led to water imbalance, fish illnesses, and diminishing aquatic product quality. The lack of frequent observation makes it tough to mitigate these challenges. The principal hurdles include a lack of farm labourers, rising ammonia levels in the water, declining oxygen levels, expensive fish feed, poor nutrition in feed, employing artificial growth hormones, etc. Verma et al.,2022 noted that for aquaculture cultivation to be fruitful, four crucial water quality parameters must be maintained appropriately: salinity, pH, dissolved oxygen (DO), turbidity, CO_2, ammonia, primary productivity and water temperature. The perfect content of these characteristics varies with the type of aquaculture and the species to be cultivated.

The rise in pollution can be linked mainly to the operations of industries and the expansion of the population, necessitating the fast adoption of appropriate pollution control measures. Employing a live environmental pollution monitoring system is commonly recognized as the ideal way to monitor and assess toxins' impact on the environment. Monitoring systems equipped with many sensors have been deployed to determine pollution levels, alongside releasing statistical data on the Internet in a well-organized manner for public access. Water pollution and climate change stand out as vital aspects impacting fish farming activities, which are crucial for sustaining the food supply for a growing populace. Challenges encountered by fish farmers comprise regular feeding, operational expenses, and the loss of fish owing to pollution-induced diseases. As a result of these issues, authors have been inspired to combine modern computer and communication technology into systems for monitoring and regulating water quality as a reaction to the degradation of aquatic environments. The pervasive integration of Internet of Things (IoT) technology across varied sectors is predicated upon its improved paradigm of environmental interaction. The usage of Internet of Things (IoT) technologies has proven to be vital in water quality surveillance in aquaculture environments, notably in the context of fish farming and aquaculture. In fish farming, the lack of viability in engaging labourers for everyday activities requires adopting Internet of Things (IoT) sensors. These sensors acquire real-time data on air quality, water parameters, weather conditions, and air quality while giving valuable statistics through mobile devices and web platforms.

The preservation and enhancement of water quality are crucial for the vitality and development of fish. Recent research attempts have focused on inventing controllers to govern water quality parameters, supporting a conducive aquatic habitat for fish. Basuel and Reyes introduced an Internet of Things (IoT) system that monitors surface temperature, water pH, dissolved oxygen concentration, and pH levels to analyze aquaculture water quality. Additionally, the system facilitates the frequent recording of water quality data for analysis, which substantially benefits fish producers in readily comprehending the information. An additional element of the system is a brief messaging service, which rapidly informs stakeholders of any breaches that may occur regarding water quality regulations. A real-time monitoring approach for fish farming has been suggested, using a sensor array to gauge crucial parameters for analyzing water quality. Some implementations integrate a smartphone application enabling farmers to observe fish ponds remotely for optimal pond management. The incorporation of IoT technology into fish aquaculture control systems has been validated by current literature and studies. These studies stress the potential for novel technology to boost productivity, scalability, and the expansion of enterprises. The Internet of Things (IoT) is one of the most recent technical advances with massive potential for establishing dependable industrial and household applications. Remote measurement, monitoring, warning, and control are mentioned among these applications. Fish aquaculture includes building multiple facilities in water ponds or deep-sea areas, which are furnished with necessary sensors and control mechanisms. Extensive studies have been undertaken to monitor and manage pond water quality to maintain a safe habitat. Research has suggested implementing an IoT-centered system for checking water quality in fish farming facilities, permitting farmers to remotely watch units and manage water circulation using a mobile application. Alternatively, another study has explored employing artificial intelligence, machine learning, and the IoT to supervise water quality and ascertain fish growth by measuring characteristics like pH, water level, temperature, odour, and turbidity. Artificial intelligence is helpful in real-time environmental monitoring and control systems within the fish farming industry. Numerous studies have leveraged soft-computing methods such as fuzzy logic and artificial neural networks to regulate water quality, monitor fish size in ponds, and diagnose fish diseases. This work introduces an IoT-driven system for streamlining fish farm administration and facilitating the remote monitoring of fish habitats.

2. Monitoring and Control System for Fish Ponds in Bangladesh

The fundamental purpose of this work is to create a complex control mechanism to govern essential water quality elements necessary for the sustenance and growth of aquatic creatures, mainly fish. This system will use sensors to supervise important indications, including Dissolved Oxygen (DO), pH levels, Total Dissolved Solids (TDS), ammonia, and temperature. This will enable rapid responses to uphold appropriate water conditions and produce a hospitable habitat for fish. Additionally, stakeholders will be updated about the condition of each pond, which will assist in timely interventions when necessary. In Bangladesh, ensuring water quality control in fish ponds is crucial to prevent infections and sustain competitiveness in global markets. Climate variations, for example, significantly affect chemical processes, stress factors, mobility, microbial actions of the surrounding environment, and fish growth, where rapid alterations might imperil fish health. The pH levels, controlled by elements such as carbon dioxide, demand careful treatment to reduce ammonia and H_2S toxicity. Salinity, detected indirectly using conductivity sensors, influences fish density and development, underlining the significance of maintaining balanced water conditions. Similarly, DO levels are crucial for fish farming and are regulated by temperature, pH, and conductivity. The transparency of water serves as an indicator of biological balance and algal presence, which is vital for monitoring pond health.

Environmental research undertaken for Tilapia fish in Bangladesh underlined specific water quality needs, underlining the need for accurate monitoring and management techniques. To handle oscillations in water quality, the suggested system defines measures to be performed based on expert suggestions adapted to the unique conditions of Bangladeshi fish farms. Each pond, typically sized 3×6 m with a depth of 1.5 m, will be fitted with sensors and actuators for independent control. The modular design enables compatibility with diverse pond sizes and configurations often seen in Bangladesh's aquaculture sector.

In principle, this project intends to improve aquaculture practices in Bangladesh by installing an intelligent control system adapted to the region's demands. This would boost the quality of water management and encourage sustainable fish farming methods.

Table 1. A comprehensive overview of the necessary water quality standards for cultivating Tilapia fish (Makori et al., 2017 and others).

Water Quality Parameter	Unit	Tilapia Fish Range
Water (pH)	Level	6-8
Water temperature	°C	24-34
Dissolved oxygen (DO)	(mg/l)	5-10
Water salinity (for pond)	(mg/l)	0
Ammonia (NH3)	(mg/l)	0-0.7
Transparency (Tr)/visibility	cm	30

Table 2. Actions to be taken to control water quality in ponds

Metric	State	Measures
Water acidity (pH)	If the pH is low, potentially caused by fish waste, food scraps, and dirt, it's essential to assess the quality of the food. If the pH is high, the probable cause might be overapplying calcium carbonate for pond preparation or reducing existing acidic conditions.	- Perform pond cleaning and water replacement (both for high and low pH). - Establish a structured schedule for fish feeding (low pH). - Ensure a proper pond design meets all basic and proper requirements (both for high and low pH).
Water temperature (T)	Adjustments may be necessary if the water temperature (T) exceeds optimal levels, with 25°C being the recommended temperature for growth.	- Implement environmental cooling measures such as closing curtains to block sunlight. - Take urgent action to cool the water in the pond. - Manage water sprinkle and blower for instant solution. - Change the water and maintain the proper amount of trees around the pond.
Oxygen saturation (OS)	If the oxygen saturation (OS) level is low	- Activate oxygen pedals or an air bubble pump. - Provide additional oxygen to the water promptly in urgent situations. -Agitate water immediately by any means, like boating. - Stop feeding and control the temperature.
Water salinity (WS)	If the water salinity (WS) is high (Considering the salinity tolerance levels of different fish species)	Before initiating the project, it is advisable to analyze a water sample. Additionally, it is discouraged to employ a desalination plant due to its expensive nature.
Ammonia (A)	In case of elevated levels of ammonia (A) (Typically indicated by changes in pH)	-Implement a partial water replacement regimen, typically 10% to 30% daily. -Consider introducing a controlled quantity of ammonia-consuming phytoplankton into the pond. -Alternatively, introduce a measured amount of nitrifying bacteria as an alternative to phytoplankton. - Harvest all fish and immediately change the water.

Transparency Test	The Transparency Test is influenced by both temperature and feeding quantity. If transparency is below 30 cm, it is too compact for survival. If transparency is more than 30 cm, it is low in productivity and nutrition.	-Utilized in organic fertilization procedures. (In case of low, dense water). -Stop feeding and add fresh water. (In case of dense water).

3. System Design

Figure 1 depicts the planned layout for "Fuzzy Logic Empowered NetWatch: Revolutionizing Aquaculture with IoT-based Intelligent Monitoring and Management in Bangladesh." Each fish pond functions as a node in the wireless sensor network, with an embedded microprocessor connecting several sensors fitted with a wireless communication module. Data is collected in real-time, and each measurement's date and time are logged. These data are stored in the cloud and available for instant analysis and control.

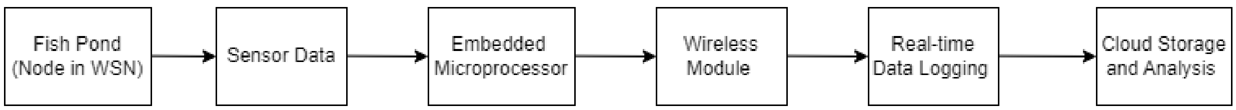

Figure 1. An outline of the general layout proposed for a monitoring and control system

Power transistors and solid-state relays will be utilized to regulate the functioning of the actuators within the proposed systems. These actuators will include water input and drain mechanisms, oxygen pedals and oxygen bubble pumps, fans, exhaust systems, air conditioners, and lights. A selection of sensors will be curated to gather data regarding water quality within the pond and to monitor environmental conditions. These sensors will include:

- A gravity analog pH sensor (SEN0161-V2) will be used for pH detection and water quality evaluation.
- By identifying suspended particles in the water, the Tur sensor (SEN0189) will determine the Tur level.
- A DS18B20 water temperature sensor will be used to measure the water's temperature.
- The DO sensor will measure the dissolved oxygen in water (SEN0237).
- The TDS sensor (SEN0244) will serve as a benchmark for water quality. TDS is measured in milligrams per liter of water. Significant soluble solids dissolved in the water are indicated by higher TDS values, which suggests lower water quality.
- An electrical conductivity sensor (DFR0300) may test a liquid's electrical conductivity to assess water quality.
- The water level in the pond will be determined using the pressure sensor (SEN0257).
- The endpoint, which is the pond's highest water level, will be found by the float level sensor (B16003).
- The air quality sensor (SGP40) will simplify indoor air quality measurement by providing a complete sensor system in one chip. The sensor's data can be used immediately; calibration is not necessary.
- The air temperature sensor (LM35) will determine the ambient temperature.
- The light sensor module (GL5528 LDR) will determine the percentage of light in the surroundings.

4. Proposed Hardware Design

Three central units comprise the suggested design for Fuzzy Logic Empowered NetWatch: Revolutionising Aquaculture with IoT-based Intelligent Monitoring and Management in Bangladesh. These elements are a central control unit, an environment control unit, and a local controller specific to each pond. In Figure 2, this architecture is illustrated. The central control unit and the local controller in each pond can transmit data wirelessly since each pond is seen as a node in a wireless sensor network.

4.1 Primary Control Mechanism

The central control unit will feature an ATmega328 microcontroller serially interfaced with another microcontroller, an Esp8266, for wireless communication. This primary microcontroller will be connected to the local server via Ethernet, as Figure 2 depicts. The local server will be further linked to the cloud server, enabling farmers to monitor farm data remotely from any location via the Internet.

4.2 Pond Management Apparatus

A local control unit comprising an ATmega2560 microcontroller will be installed in the ponds, and it will be coupled to eight sensors to monitor various parameters such as pH, TDS, Tur, DO, electrical conductivity, pressure, and water level. Solid-state relays will be attached to the controller's output to control the water intake, drain, oxygen pedals, and oxygen bubble pump.

4.3 Control Unit for the Environment

The environment controller, a single-chip microcontroller (ATmega2560) with three environmental sensors (air quality, temperature, and light), will be linked to solid-state relays to control the fan, exhaust system, air conditioner, and lights. Wireless communication will be enabled.

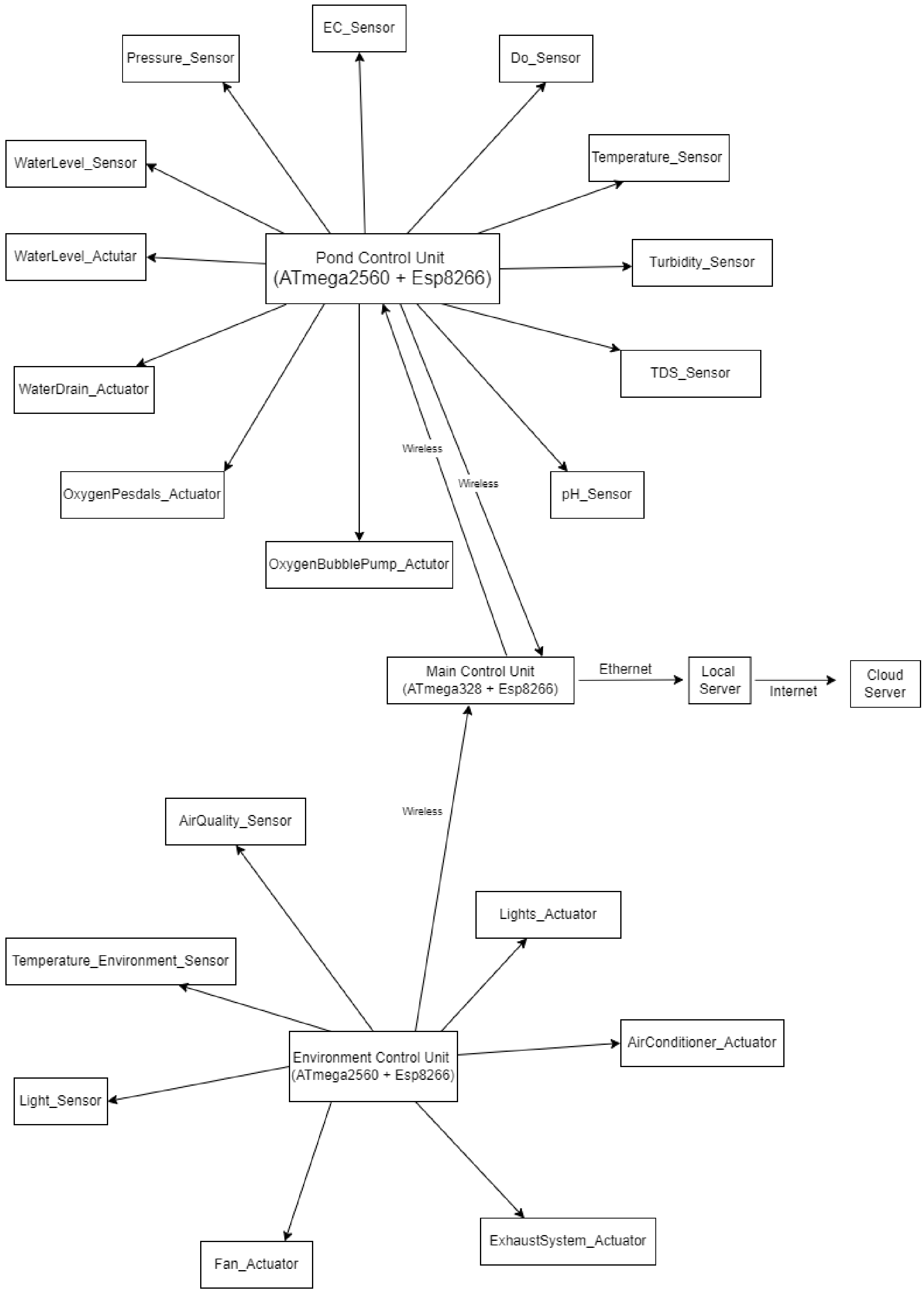

Figure 2: Proposed Hardware Design of the System - Main Control Unit, Pond Control Unit, and Environment Control Unit

5. Proposed Software Design

The NetWatch initiative intends to revolutionize aquaculture in Bangladesh via IoT-based automated monitoring and management. The environment controller will consist of a single-chip microcontroller (ATmega2560) coupled to sensors and actuators, with an Esp8266 controller for wireless communication. The controller will control air quality, temperature, and light and be connected to solid-state relays for the fan, exhaust system, and air conditioning. The software design will handle duties including initializing the system, updating the display, and reading commands. Background chores include scanning all sensors and evaluating signal levels to create control and alarm signals. Fuzzy controllers for each pond will be constructed using MATLAB.

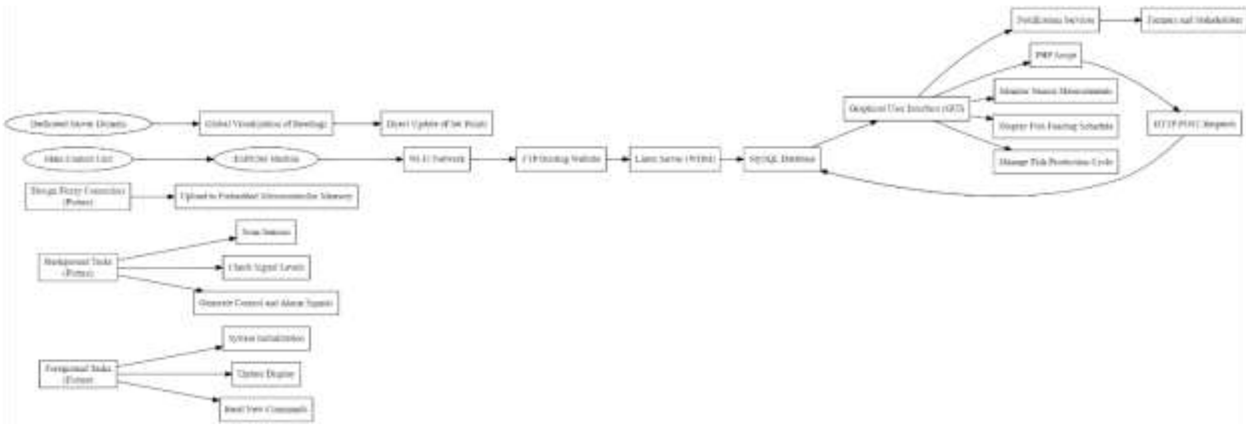

Figure 3: Proposed Software Design Layout for the System, Encompassing Foreground Tasks, Background Tasks, and Remote Connection

The central control unit will be connected to the Internet via the ESP8266 module. This item will connect to a Wi-Fi network and commence data transfer via a Linux server (WHM) to an FTP hosting website. All pond data readings will be recorded in a MySQL database. A graphical user interface (GUI) with PHP and CSS will provide easier data interaction. The ESP8266 will serve as a client, performing HTTP POST requests to a PHP script to insert data (sensor readings, user input, and device state) into the MySQL database. This user interface, designed to be user-friendly, will aid farmers in monitoring sensor measurements, presenting the fish feeding schedule, and managing the fish production cycle. The system would warn farmers and others when water quality indicators stray from standard norms. This element will try to visualize readings from anywhere internationally by accessing our server domain on the Internet. Farmers or specialists will have the potential to adjust set points to improve the fish farm scenario directly.

6. Proposed Fuzzy Logic-Based Control System for Fish Farm Management

Variations in water quality and weather impact fish growth, which can cause problems for fish farms. When translating human rules into fuzzy language, fuzzy logic is a helpful tool for decision-making. A fuzzy controller is needed to regulate the water quality and the surrounding environment in every pond. Fuzzification, reasoning, and defuzzification are the three modules that comprise the controller. In the fuzzification stage, the fuzzy controller transforms the measurable variables into linguistic variables. The Mamdani-style inference procedure uses the centre of gravity defuzzification technique to convert the fuzzy output into a crisp value. The five input variables that the pond fuzzy controller uses are pH, turbidity, TDS, DO, and WC. It produces three control signals, and the illumination, air temperature, and air quality inputs provide three actuating signals that the environment controller produces.

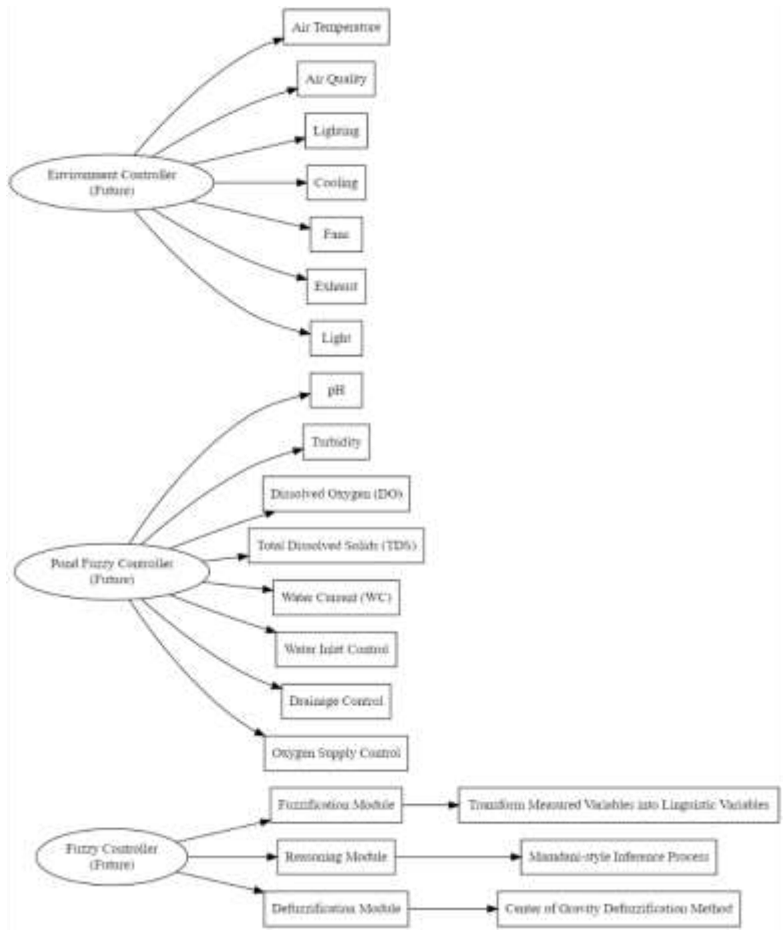

Figure 4: Proposed Fuzzy Logic-Based Control System for Fish Farm Management with Pond and Environment Controllers

The water current, pH, dissolved oxygen, turbidity, total dissolved solids, temperature, air quality, air conditioner, fan, exhaust, and change water and oxygen supply are just a few input and output variables the pond and environmental fuzzy controllers can handle. Each variable has three sets; the total dissolved solids, temperature, air quality, air conditioner, fan, and exhaust have four sets.

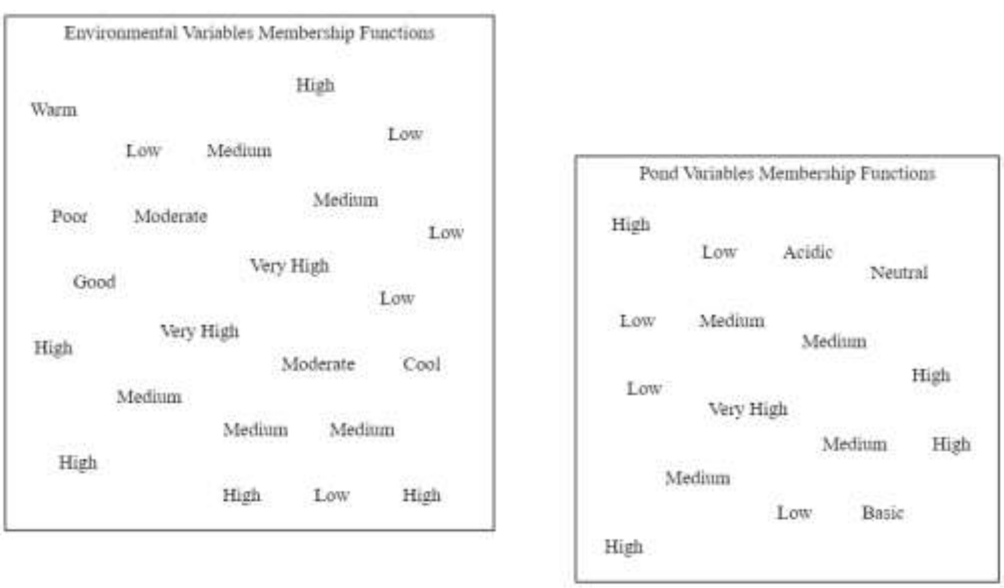

Figure 5: Membership Functions for Fuzzy Controllers' Input and Output Variables in Pond and Environmental Control

Four factors will be controlled by the pond controller: temperature, turbidity, pH, DO, exhaust, fan, air conditioner, exhaust, total dissolved solids (TDS), water current (WC), and variations in the water and oxygen supply. The four fuzzy sets that define the output variables are the maximum, medium, low, and middle. The number of fuzzy sets is determined by the significance of the variable in fish growth and how it affects other indicators.

For Instance:
EPA's Water Quality Control

- Influences WC by dissolved substances.
- Recommended pH range for freshwater: 6.0-9.0.
- Protects aquatic life.

- TDS levels may vary based on the materials added to the pond, with some fish species thriving in near-zero TDS environments while others require levels between 300 and 400 ppm.

- DO levels must be maintained between 5-9 mg/l for optimal fish health, with concentrations below two mg/l leading to potential fish fatalities.

- Turbidity, which measures the relative clarity of liquid, should ideally fall within the 45-75% range.

Fuzzy rules will, therefore, be created to specify how each controller's input and output variables relate to one another. The pond controller will employ 32 fuzzy rules, while the environmental control will utilize seven fuzzy rules. These fuzzy rules will assist the intelligent monitoring and administration of the aquaculture system, assuring optimal conditions for fish development and overall farm production.

Table 3: Fuzzy Rules for Pond Controller

Rule	WC	pH	DO	TDS	Tur	Output
1	Low	Acidic	Low	Low	Low	Low
2	Middle	Acidic	Low	Medium	Medium	Middle
3	Middle	Acidic	Medium	Medium	High	Middle
...	...	...	...	...	...	...
32	Maximum	Basic	High	Very High	Moderate	Maximum

Table 4: Fuzzy Rules for Environmental Controller

Rule	Temperature	Air Quality	Air Conditioner	Fan	Exhaust	Change Water	Oxygen Supply
1	Cool	Poor	Low	High	Low	Low	Medium
2	Warm	Moderate	Medium	Low	High	Medium	High
3	Moderate	Good	High	High	Medium	High	Very High

These tables outline the fuzzy rules for each controller based on the specified input variables (sensors) and their respective fuzzy sets. Each rule defines the relationship between the input variables and the corresponding output variable, enabling the controllers to make intelligent decisions for optimal system management.

7. Results and Discussion
The study validates the effectiveness of fuzzy controllers in creating appropriate control signals based on input signal fluctuations. The controller's response to changes in dissolved oxygen and water levels in a pond demonstrates its adaptive nature, which modifies output signals by changes in air temperature and quality indicators.

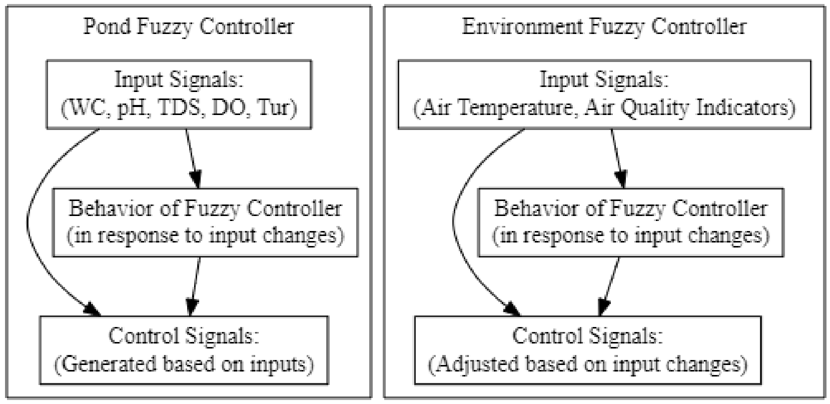

Figure 6: Behavior of the Pond's Fuzzy Controller and Environment Fuzzy Controller

The proposed system will undergo testing to validate real-time sensor measurements and verify wireless data transmission. Farmers can monitor readings and control system operations via smartphones or the Internet. Parameters will be automatically updated every 10 seconds, and readings will be compared with certified gauges at the fish farm.

The comparison results will indicate the measurement system's accuracy and ability to transmit data wirelessly between units. The environment will be assessed to document the highest and lowest temperatures in June 2024, characterized by anticipated temperature variations in the 20-35 °C range.

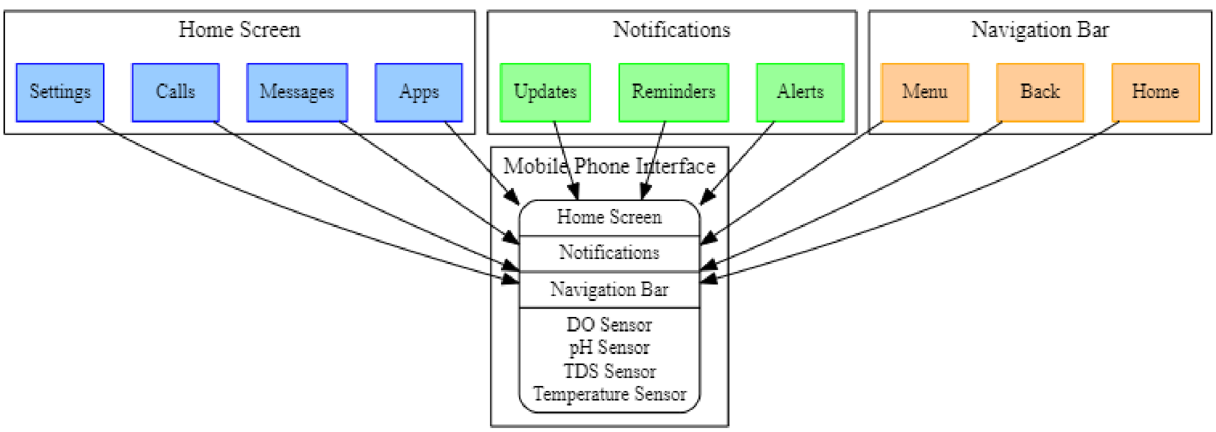

Figure 7: GUI of the Proposed Model

The IoT-based system's water temperature comparison with the approved DS18B20 sensor reveals the system's accuracy. The well's water temperature differs from 6-8°C from the surrounding environment but reduces to 2-3°C after the pump works. These experiments suggest that the well's temperature is suitable for Tilapia fish, which require an 8-38°C environment and are easy to achieve at the lowest cost. The temperature difference is reduced to 2-3°C after the pump starts working.

8. Limitations of the Present Study

The study on integrating the NetWatch system into Bangladeshi fish farming faces several potential limitations. Firstly, its focus might be limited to specific scales or types of fish farming, reducing the generalizability of results. Secondly, the study may not have captured seasonal variations or long-term trends due to a short observation period. Thirdly, the system's performance in extreme environments like extreme temperatures or severe weather may not have been adequately explored. Technological constraints such as battery life and compatibility issues may not have been thoroughly examined. Cost and accessibility concerns could also limit adoption, especially among small-scale producers. The validation methods used might have limitations, impacting the reliability of results. Moreover, regulatory and policy implications may not have been fully considered. Addressing these limitations through further research and innovation can strengthen the evidence base for integrating IoT technologies like the NetWatch system into fish farming, ultimately enhancing industry sustainability and productivity.

9. Future Research

Future research integrating the NetWatch system into Bangladeshi fish farming should prioritize system development to overcome existing limitations. Efforts should focus on refining the system's design for scalability across various farming scales and types. Field trials need to be extended to capture seasonal variations and long-term trends. Assessing performance under extreme conditions and addressing technological constraints are crucial. Moreover, efforts should be made to reduce costs and improve accessibility, validate data rigorously, and engage policymakers to address regulatory considerations. By focusing on these priorities, future research can strengthen the evidence base for integrating NetWatch, ultimately enhancing industry sustainability and productivity.

10. Conclusion

Integrating Internet of Things (IoT) technology through the NetWatch system represents a significant step forward in modernizing fish farming techniques in Bangladesh. The system has shown that it can continuously monitor, regulate, and manage fish farming operations, demonstrating its potential to raise aquaculture industry productivity and sustainability. Through empirical validation, authors have observed the precision and exceptional performance of the NetWatch system compared to traditional manual methods and commercial devices. Integrating fuzzy controllers for overseeing water quality and environmental parameters further enhances the system's adaptability and effectiveness in responding to dynamic conditions within fish ponds. Nevertheless, despite the encouraging outcomes, it is important to recognize certain constraints and aspects that require further investigation. Although the NetWatch system has demonstrated efficacy in enhancing aquaculture management, additional study is needed to improve its performance and scalability for more giant fish farming enterprises. In addition, it is necessary to focus on improving the strength and dependability of wireless sensor networks in difficult environmental circumstances, such as varying temperatures and probable signal disruption. Moreover, future research could investigate incorporating sophisticated data analytics and machine learning methods to facilitate predictive modeling and decision assistance functionalities within the NetWatch system. This would allow for proactive management of fish farming activities and early detection of potential issues, ultimately contributing to further improvements in productivity and sustainability. To summarise, the NetWatch system offers a promising alternative for modernizing fish farming in Bangladesh. However, additional study and innovation are necessary to overcome current limitations and fully exploit its potential in aquaculture. Tackling these obstacles and harnessing cutting-edge technologies can create opportunities for a stronger and more prosperous future for fish farmers in Bangladesh and other regions.

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