Original Research Article

A Low-Cost Embedded System for Continuous Water Quality Monitoring in Aquaculture Ponds

ABSTRACT

Aim: This research focuses on the development of an embedded system designed for real-time monitoring and control of water quality parameters in aquaculture ponds. The system aims to provide an efficient and cost-effective solution for managing critical water quality factors such as temperature, turbidity, and pH levels, which are essential for maintaining a healthy aquaculture environment.

Methodology: The system integrates temperature, turbidity, and pH sensors with an Arduino Mega board, an LCD, and other electrical components to detect and display water quality parameters. Input data from the sensors are processed and analyzed using an Arduino program installed on a computer system, and the results are directly displayed on the LCD. The performance of the developed system was validated by comparing its readings with those obtained from traditional instruments, including a pH-cum-temperature meter and a Secchi disc for turbidity.

Results: The comparison revealed an error margin of 0.9% for pH, 1.2% for temperature, and 1.9% for turbidity when using the embedded system compared to traditional methods. The total cost of developing the system was approximately Rs. 7000.

Conclusion: The experimental results demonstrate that the developed embedded system is a viable and cost-effective tool for monitoring and improving water quality in aquaculture ponds, contributing to the betterment of the aquaculture environment.

Keywords: Water quality monitoring, Embedded system, Aquaculture, Arduino, sensors

1. Introduction

Aquaculture encompasses a broad set of activities, knowledge, and techniques dedicated to the breeding of aquatic plants and various species of animals, playing a crucial role in global food production and economic development. In India, the aquaculture industry has shown significant growth, with fish production reaching 359 thousand million fry and 17,545 thousand tonnes in 2022-23 (1). Additionally, shrimp and prawn production was reported at 757.2 thousand metric tonnes and 438 thousand tonnes, respectively, in 2019-20 (2,3). As the global demand for fish is projected to rise substantially by 2050, aquaculture presents a promising option for providing sustainable fish meat, contributing to food security, and supporting economic growth.

Maintaining the health and productivity of aquaculture systems requires continuous monitoring of key physical, chemical, and biological parameters of pond water. Monitoring variables such as oxygen levels, temperature, turbidity, and pH are essential to ensure optimal conditions, prevent environmental damage, and avoid the collapse of production processes (4,5). Fish performance is influenced by a variety of factors, including environmental, production, and biotic factors, many of which can be controlled or mitigated within aquaculture facilities. Water quality is frequently neglected in the management of ponds and lakes, leading to prevalent issues such as excessive algal blooms, overgrowth of aquatic vegetation, the emergence of noxious odors, and the mortality of fish. For example, halogen lights can be used to adjust photoperiods, improving fish behavior and performance (6), while filters can reduce turbidity, enhancing water quality (7). Stress is a significant factor that can negatively impact fish performance, with factors such as temperature and water conductivity playing critical roles in feeding behavior and overall health. To enhance the sustainability and profitability of fish farms, it is vital to monitor these parameters closely. Recent advances in technology, particularly in wireless and wired sensor networks, have enabled more efficient and real-time monitoring of these critical variables. These networks, consisting of numerous self-organized sensors, collect, transmit, and process information in a coordinated manner, significantly improving the efficiency of monitoring and analysis in aquaculture environments (8). Conversely, sensor networks have emerged as highly effective tools for efficiently processing information in laboratory settings, significantly reducing the time required for sample analysis (9).

The rapid development of electronics, microelectronics, digital systems, microcontrollers, telecommunications, and information technologies has facilitated the creation of sophisticated information systems and mobile applications for control and supervision in various agricultural fields, including aquaculture (10,11). Embedded systems, which are programmed to perform specific functions within larger mechanical or electrical systems, have become invaluable tools in this context, particularly for real-time monitoring under various environmental conditions (12,13).

This study focuses on the development of a low-cost embedded system designed for real-time monitoring of key water quality parameters, specifically pH, turbidity, and temperature, using a variety of sensors. The proposed system is modular, portable, cost-effective, and versatile, offering significant potential for enhancing aquaculture practices and improving the sustainability and efficiency of aquaculture operations.

2. Materials and methods

a. Description of the experimental site

This study was conducted at the Agricultural and Food Engineering Department of IIT Kharagpur, utilizing two experimental ponds located at geographical coordinates N 22° 18' 52.3584" and E 87° 18' 32.6448", with an elevation of 54 meters above mean sea level. The experimental setup involved pond. Water quality parameters, including temperature, pH, and turbidity, were measured at three specific times each day: 8 AM, 1 PM, and 6 PM. For each parameter, readings were taken from pond at these intervals for five continuous days, and the average of the three recorded measurements at each time point was used for further analysis.

b. Development of embedded system

The low-cost embedded system developed for water quality monitoring comprised several key components, including a temperature sensor, pH sensor, turbidity sensor, microcontroller (Arduino Mega), LCD display, and integrated circuit (IC) boards. The specifications of each electronic component are detailed in Table 1. To monitor water temperature, the DS18B20 digital temperature sensor was employed. The DS18B20 is a compact, digital sensor that operates using a bandgap temperature sensor and a 12-bit analog-to-digital converter (ADC) to measure temperature. The sensor's functionality is based on the principle that the voltage of a semiconductor material varies with temperature. The bandgap temperature sensor generates a voltage proportional to the temperature, which is then converted into a digital signal by the ADC. This digital data is transmitted serially to the microcontroller using the 1-Wire protocol. The DS18B20 sensor was connected to the Arduino Mega microcontroller via a 4.7 KΩ pull-up resistor (Fig. 1).

Turbidity, a measure of the cloudiness or haziness of a fluid caused by total suspended solids (TSS), is quantified in Nephelometric Turbidity Units (NTU). High turbidity can substantially diminish the aesthetic quality of lakes and streams and pose serious threats to aquatic life. Elevated turbidity levels can impair fish and other aquatic organisms by reducing available food sources, degrading spawning habitats, and disrupting gill function, ultimately impacting their health and survival. In this study, a turbidity sensor was employed to measure the turbidity levels of water. The sensor consisted of a plastic-covered circuit, ensuring it was waterproof to prevent water ingress. Inside the housing, the sensor featured a probe circuit, which included a photo-emitting diode and a phototransistor. The phototransistor detects the amount of light transmitted through the water, with the intensity of received light indicating the turbidity level. As the concentration of suspended particles in the water increases, the amount of light received by the phototransistor decreases, allowing for the quantification of turbidity. The turbidity sensor was interfaced with the Arduino Mega microcontroller using an LMV358 IC-based module. This module provides a three-pin interface for connection and includes an analog/digital selector switch, enabling the selection between analog and digital output modes. The turbidity probe and its connection setup are illustrated in Fig. 1, and the detailed specifications of the sensor are provided in Table 1.

pH was a critical chemical parameter in this study as it directly influenced the metabolism and other physiological processes of cultured organisms. The pH meter used operated by measuring the difference in electrical potential between a pH electrode and a reference electrode, with this potential difference indicating the acidity or alkalinity (basicity) of the solution. The pH probe employed consisted of several key components: a measuring electrode (also known as the active electrode), a reference electrode (standard electrode), a glass membrane, and a protective housing. The measuring electrode, made of glass, was responsible for detecting the pH levels, while the reference electrode received the supplied voltage, enabling accurate pH measurement. The pH probe was connected to the microcontroller via a BNC connector, which linked the pH circuit to an available analog input on the microcontroller, allowing for real-time pH readings (Fig. 1). The pH sensor was firstly calibrated with different known pH solutions. The detailed specifications of the pH probe and its components are provided in Table 1. This setup ensured precise and reliable monitoring of pH levels in the aquaculture environment. The developed embedded system was shown in Fig. 2.

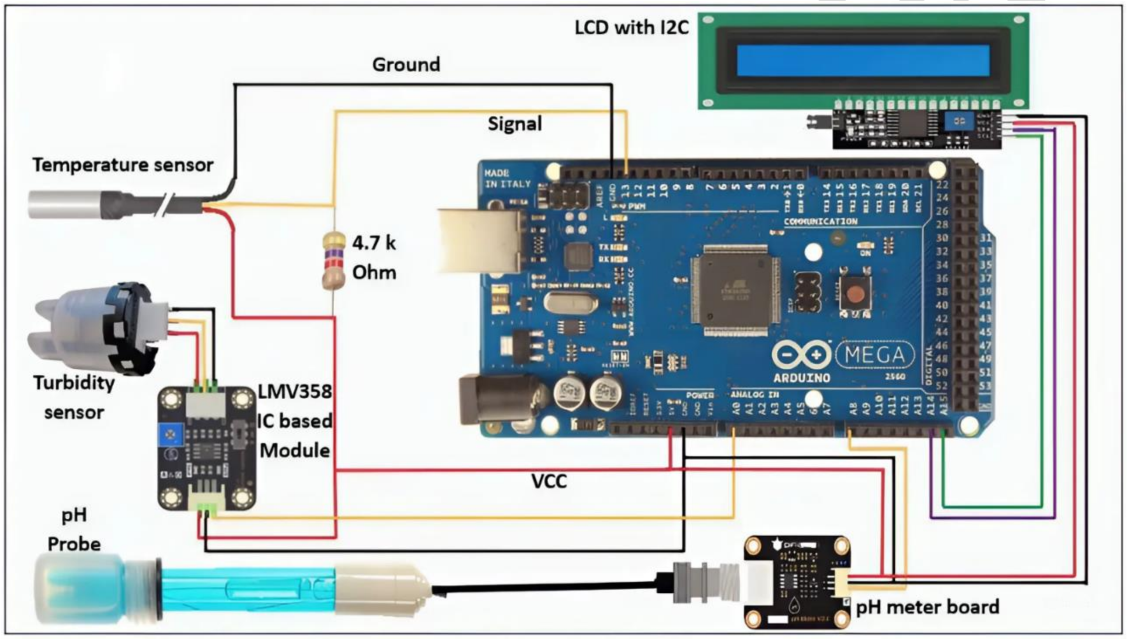

Fig.1: Circuit diagram of the developed embedded system

Table 1: Specifications of the different components of embedded system

S. No.	Transducer	Specifications
1.	Temperature sensor	Range: -10 to 85°C; Working precision: up to +/-0.5°C
2.	Turbidity probe	Power: DC 5V max. 30 mA; Operating temp: -30 to 80°C
3.	pH sensor	Power: DC 9V 1A; Range: 0-14; Accuracy: +/-0.1 pH
4.	Microcontroller	ATmega 2560, Flash memory 256 KB, Clock speed 16 MHz
5.	Display	16×2 LCD

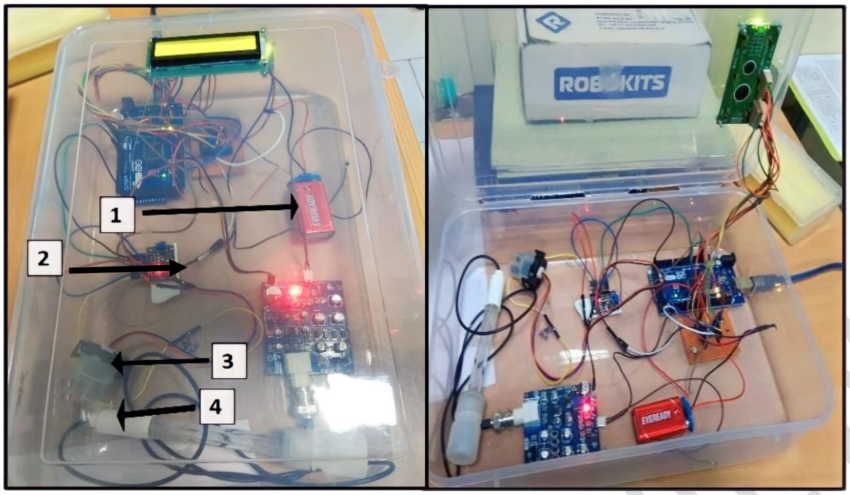

Fig.2: Developed embedded system (1: 9 volts battery; 2: temperature sensor; 3: turbidity sensor; 4: pH probe)

c. Comparison of the developed system with existing methods

The embedded system was designed, fabricated, and constructed to monitor water quality parameters. To validate its performance, the system was compared with established instruments. For pH and temperature validation, the HI98127 pH and temperature tester, with a resolution of 0.1, was utilized (Fig. 3a). Turbidity was validated using a Secchi disk (GABY Instruments) featuring black and white quadrants (Fig. 3b). The Secchi disk was used to measure turbidity in terms of depth, recorded in centimeters or millimeters. To enable a meaningful comparison between these measurements and the NTU values provided by the developed sensor, a calibration curve was employed. This curve facilitated the conversion of the Secchi disk depth readings into corresponding NTU values, allowing for a direct comparison between the traditional method and the sensor-based measurements. Measurements for pH, temperature, and turbidity were taken from Pond at three specific times: 8 AM, 1 PM, and 6 PM for five continuous days. For each parameter, three readings were recorded at each time point using both the developed system and the reference instruments. The average of the three readings at each time was calculated for comparison purposes, allowing for an accurate assessment of the system's performance against the standard instruments. A statistical analysis was conducted to evaluate the accuracy of the developed embedded system by comparing its measurements with those obtained from existing instruments. This comparison was performed using a two-sample t-test, assuming equal variance, to assess the differences between the two sets of data. The significance level for the t-test was set at 5%, providing a robust measure of whether the discrepancies between the measurements were statistically significant.

Fig. 3: (a) pH and temperature tester (b) Secchi disk

3. Results and discussion

a. pH

The results demonstrated that the pH values varied throughout the day (Fig. 4). This variation was attributed to the photosynthetic activity of aquatic plants and algae, which consumed carbon dioxide (CO_2) during daylight hours, thereby increasing the pH of the water. At night, photosynthesis ceased, and respiration dominated, releasing CO_2 back into the water and subsequently lowering the pH (14). Additionally, temperature influenced the pH of the water, with warmer midday temperatures potentially causing changes in the dissociation of water and other dissolved substances, leading to slight fluctuations in pH. The pH measurements yielded average values of 6.96 using the tester and 7.02 using the developed system. The variation between the measurements obtained from the tester and the developed system was found to be 0.9%. Statistical analysis, performed using a two-sample t-test (assuming equal variances), revealed no significant difference between the values measured by the tester and the developed system [-0.539 (28) = 0.593, $P > 0.05$] at a 5% level of significance. This lack of substantial difference in the means of the values, coupled with the high p-value, indicated that the observed difference was not statistically significant, thereby supporting the acceptance of the null hypothesis.

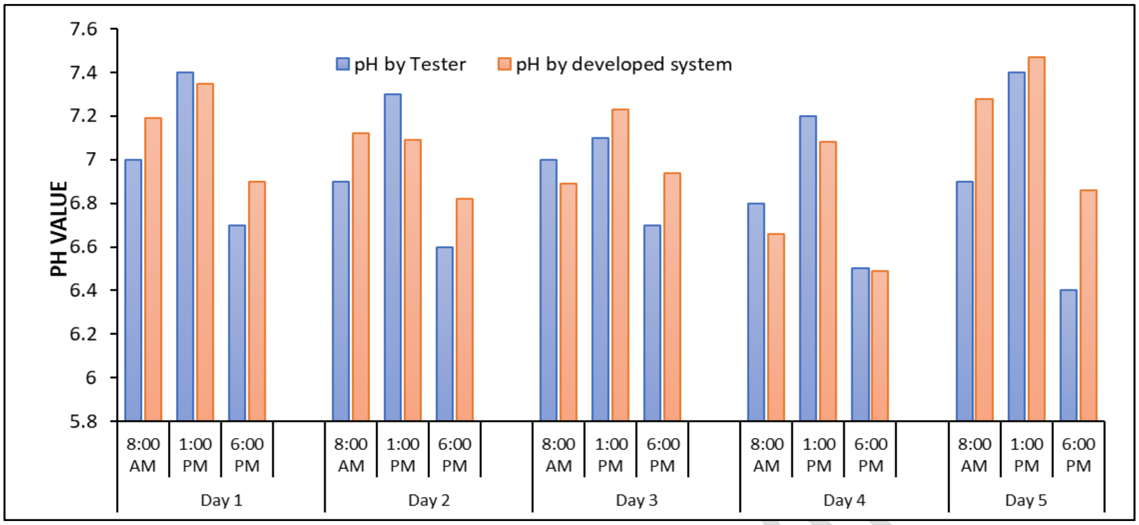

Fig. 4: Comparison of pH values with both methods

b. Temperature

The results revealed a distinct pattern in temperature values throughout the day (Fig. 5), influenced by greater sunlight exposure at noon compared to the morning and evening. The temperature measurements showed average values of 29.14°C using the tester and 29.48°C using the developed system. The variation between these measurements was calculated to be 1.2%. Statistical analysis, conducted using a two-sample t-test (assuming equal variances), indicated no significant difference between the temperature values recorded by the tester and those recorded by the developed system [-0.542 (28) = 0.592, $P > 0.05$] at a 5% significance level. This minimal difference in mean values, along with the high p-value, suggested that the observed difference was not statistically significant, thereby supporting the acceptance of the null hypothesis.

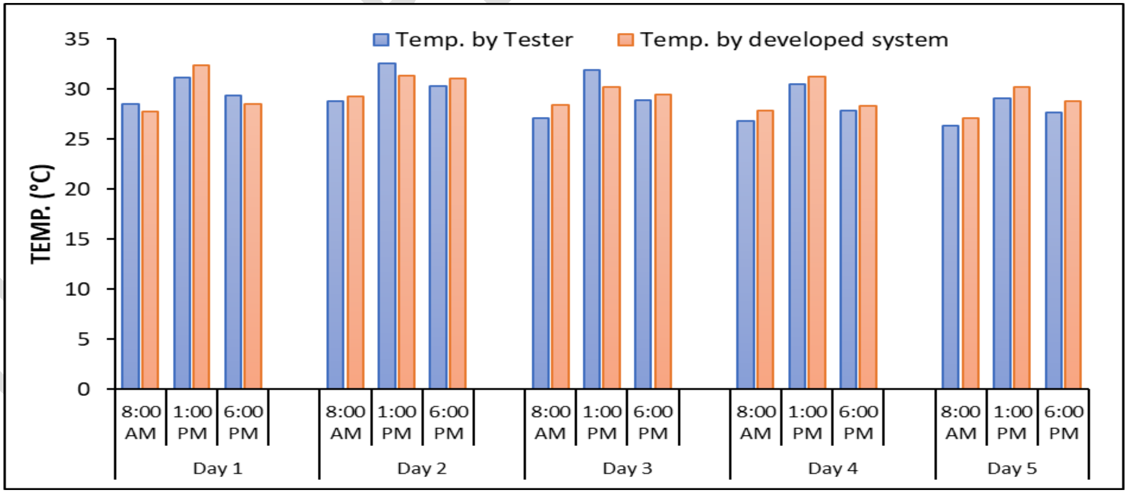

Fig.5: Comparison of temperature values with both methods

c. Turbidity

The results indicated a distinct pattern in turbidity values throughout the day (Fig. 6), primarily due to the activity of aquatic organisms, such as fish, which increased turbidity by stirring up sediments during feeding or movement. This activity tended to be higher at certain times, leading to fluctuations in turbidity levels. Additionally, wind-induced waves and water movement resuspended particles from the bottom of the pond, further increasing turbidity. As wind patterns varied throughout the day, so did the turbidity levels. The turbidity measurements yielded average values of 17.46 NTU using the Secchi disk and 17.14 NTU using the developed system, with a variation of 1.9% between the two methods. Statistical analysis, conducted using a two-sample t-test (assuming equal variances), revealed no significant difference between the turbidity values measured by the Secchi disk and those recorded by the developed system [0.438 (28) = 0.664, $P > 0.05$] at a 5% significance level. The minimal difference in mean values, combined with the high p-value, suggested that the observed variation was not statistically significant, thereby supporting the acceptance of the null hypothesis.

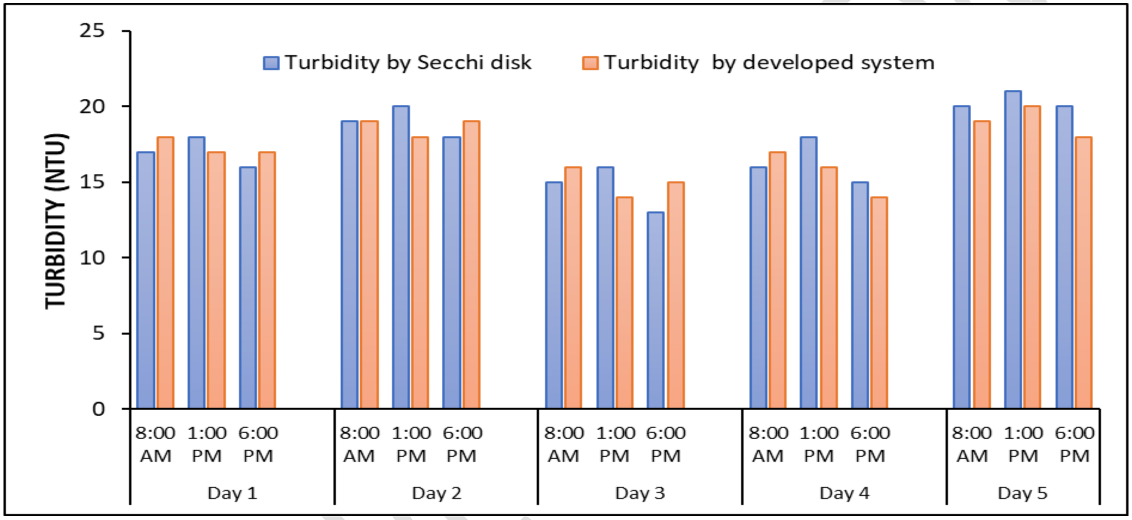

Fig.6: Comparison of turbidity value with both methods

4. Conclusion

This study successfully developed and validated a low-cost embedded system for real-time monitoring of key water quality parameters—pH, temperature, and turbidity—in aquaculture ponds. The system was tested against traditional measurement instruments, showing minimal variation in readings, with statistical analysis confirming no significant differences between the two methods at a 5% significance level. The embedded system demonstrated reliable performance, offering an accurate, portable, and cost-effective solution for continuous monitoring of water quality in aquaculture environments. By enabling real-time data collection, this system can significantly enhance the management of aquaculture ponds, leading to improved fish health, increased productivity, and more sustainable aquaculture practices. The results underline the potential of such embedded systems to replace or complement traditional methods, providing a valuable tool for both researchers and aquaculture practitioners. Future work could focus on integrating additional sensors and expanding the system's application to different aquatic environments.

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