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AI-Powered IoT Platform for Edge-Based Aquaculture Water Quality Monitoring

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ABSTRACT

Proposed work here presents integration of artificial intelligence (AI) with Internet of Things (IoT) technologies to automate the Aquariums and aquiculture ponds, in this presented research discloses Usage AI algorithm to predict of the critical water quality parameters in real-time such as temperature, pH levels, salinity though IoT sensor integration for signal acquisition. Here the Integrated system ensures optimal aquatic conditions, enhancing the health and productivity of aquatic life. Additionally, the AI component enables predictive maintenance timely by analyzing sensor data to detect abnormal issues and prevent it by supporting intervention. The results with proposed methodology is cost-effective, scalable, and userfriendly, making it accessible for remote monitoring. Presented method Experimental results demonstrate the system's efficiency in maintaining water conditions is accurately and also minimizes the manual intervention. This work highlights the potential of AI-driven IoT solutions in advancing aquarium management and sets a foundation for future innovations in smart aquatic ecosystems.

1. INTRODUCTION

The integration of AI and the Internet of Things (IoT) to aquaculture systems is promising way of managing of critical parameters of water quality, It supports more accurate and efficient cultivating practices. Traditional methods of water quality monitoring in aquaculture have often been labor-intensive and time consuming due to it requires manual sampling and analysis. These methods may fail to provide real-time analysis, which can delay timely interventions. To address these challenges, IoT systems have been developed to continuously monitor of essential water quality parameters, such as pH, temperature, dissolved oxygen (DO), turbidity, and salinity, It supports timely to farmers track these parameters in real time and make corrective decisions. Furthermore, the integration of machine learning (ML) models and ensembled approach for predictive analytics has further improves the accuracy of these systems. In Literature there are many approaches are developed to address these issues and designed semi custom-automated systems. One prominent approach is the Machine Learning (ML) Approach, which uses the AImethodologies to optimize the management of water quality in aquaculture systems. Many recent developed aqua systems enhances the precision of pond management with adaptive control decisions by use of the Random Forest algorithms. These algorithms allow optimized parameter adjustments in aquaculture water quality, ensuring that conditions remain ideal for aquatic life [1]. In few cases, activating aerators or filtration systems to maintain optimal conditions uses Decision Tree models and Deep Learning models are employed to predict and automate necessary adjustments in real-time. These ML techniques, employed manily for predictive analysis, It support the the continuous improvement of system efficiency, sustainability, and shrimp health by timely correcting potential water quality parameters before they escalate [7], [11], [15]. Where as in Sensors-Based Approach: IoT-enabled sensors supports continuous monitoring by capturing real-time data on a variety of water quality parameters. Embedded boards, Microcontrollers, Sensors like the DS18B20 for temperature, SEN0161 for pH, and MQ135 for gas detection are commonly used to gather data on parameters such as temperature, pH, dissolved oxygen, turbidity, and salinity. The collected data from various sensors is transmitted to cloud platforms for data analysis and generate decisions to farm managers, quickly detect any abnormalities and take corrective actions [1], [2], [6], [16]. Advanced smart sensors and sensing systems further support in providing complete response on multiple water quality factors simultaneously, allowing for more accurate and real-time control of the aquaculture environment [12]. In Cloud and Real-Time Monitoring Approaches: In this approach make use of the data gathered from IoT sensors, many systems integrate. The transmission of sensor data to cloud platforms, such as Firebase and Blynk, enables farm managers to monitor water quality remotely and in real-time in user selected local language. Many cloud-based solutions allow the centralization of data from multiple farms, facilitates quick understand of water quality changes. these Mobilebased applications and web-based control systems performs the user specific tasks and sends information to farmers about water quality parameters and receive notifications whenever critical thresholds are reached, thereby ensuring immediate intervention when it necessary at times [1], [3], [5], [6], [21]. In Embedded Hardware and Automation Approaches: In this approach often uses the sensors in modern aquaculture systems. Microcontrollers based boards such as Arduino, ESP32, and Raspberry Pi are often employed to process data from sensors and automate actions, such as controlling water pumps, automate feeding systems. That support moitoring real-time fish behavior and environmental conditions, reducing Biowaste and ensuring better fish health [14]. By linking these systems to IoT based sensors, farmers can achieve overall farm productivity [12], [13], [14]. Furthermore, Wireless Communication and Data Transmission Approaches: ensuring that IoT-based systems provide continuous and reliable data transmission. In this approach use Technologies such as GSM modules (SIM800L), Wi-Fi (NodeMCU ESP8266, ESP32), LoRa, and Zigbee for transmit sensor data to cloud platforms in real time [2], [5], [10], [19]. These communication protocols not only ensure data collected from sensors is transmitted efficiently but also allow for remote control of aquaculture systems, enhance the farmers to make decisions regardless of their location [19], [24]. Edge based Energy-efficient and sustainable solutions are essential where power supply may be limited. The use of solar-powered IoT systems and energy-reducing automation can significantly lower the energy consumption of aquaculture systems with resource constrained, making them more costeffective and environmentally friendly [16], [12]. These solutions help farmers monitor and control essential water quality parameters with minimal environmental impact. In conclusion, IoT-based systems, coupled with advanced machine learning models and real-time monitoring, are transforming aquaculture management.

Figure 1. Overview of Ai-Powered Iot Platform For

II. Related Work

The application of Internet of Things (IoT) technologies in aquaculture has gained significant attention due to the need for continuous monitoring and management of water quality parameters critical to aquatic life. Recent studies focus on real-time sensing, remote monitoring, automation, and the integration of intelligent analytics to improve productivity and sustainability.

IoT-Based Water Quality Monitoring Systems

Several researchers have proposed IoT-based systems for real-time water quality monitoring in aquaculture environments. Adriman et al. [1] developed an IoT-based monitoring and notification system for prawn ponds, enabling continuous observation of water parameters and alert generation. Similarly, Olanubi et al. [2], [21] presented an intelligent IoT-based water quality management system that improves monitoring accuracy and decision-making in aquaculture farms. Shete et al. [3], [20] proposed a real-time IoT-enabled water quality monitoring method that enhances responsiveness through continuous data acquisition.

Chen et al. [4], [22] designed an IoT-based fish farm monitoring system that demonstrated improved operational efficiency using sensor networks. Yaacob et al. [5], [24] also presented a fisheries water quality monitoring system using IoT, highlighting the benefits of remote data visualization and reduced manual labor. Abinaya et al. [6] proposed a novel IoT methodology for monitoring and controlling aquaculture water quality, emphasizing automation and scalability.

Embedded and Prototype-Based Aquaculture Systems

Several works focus on embedded hardware prototypes for aquaculture monitoring. Dodda et al. [9] developed an embedded system prototype for fish farm monitoring, validating the feasibility of real-time sensing using microcontroller-based platforms. Selvaganesh et al. [18] proposed a real-time smart aquaculture monitoring system using ESP32, demonstrating efficient sensor integration and wireless communication. Reddy et al. [19] presented an IoT-based water quality monitoring framework for smart aquaculture with reliable embedded implementation.

Automation, Feeding, and Control Systems

Automation in aquaculture, particularly in feeding and control, has been explored by multiple researchers. Adegboye et al. [14] proposed an intelligent fish feeding system that dispenses feed based on fish feeding intensity, improving efficiency and reducing waste. Saha et al. [17] designed an automated fish farm monitoring system using IoT to enhance operational control. These systems highlight the importance of integrating sensing with actuation for intelligent aquaculture management.

Cloud, Mobile, and Remote Monitoring Solutions

Cloud and mobile-based monitoring solutions have also been investigated. Acar et al. [13] presented an IoT cloud solution for aquaculture, enabling centralized data storage and analysis. Jacob et al. [10] developed a mobile application–based IoT system for remote aquarium monitoring and management, allowing users to track water quality parameters from anywhere. Ghobrini et al. [11] focused on cost-effective multi-parameter IoT systems for aquaculture and aquaponics, emphasizing affordability and scalability.

Intelligence, AI, and Advanced Analytics in Aquaculture

The integration of intelligence into aquaculture systems is an emerging research direction. Ma et al. [12] designed an intelligent monitoring system focused on dissolved oxygen control. Rahul et al. [15] integrated IoT with deep learning techniques for smart aquaculture management, demonstrating improved prediction accuracy in freshwater aquariums. Singh et al. [23] proposed a sustainable IoT solution for freshwater aquaculture management, highlighting energy efficiency and long-term sustainability.

Woo et al. [8] provided a comprehensive survey on digital twins–based aquaculture systems, emphasizing the role of advanced analytics and system modeling. Yesankar et al. [7] reviewed the role of IoT in smart agriculture, with relevance to precision aquaculture, sustainability, and efficiency.

Research Gap and Motivation

From the existing literature, it is evident that most works focus on real-time monitoring, basic automation, or cloud-based visualization. However, limited research combines multi-parameter water quality sensing, AI-based predictive analytics, embedded system automation (feeding and alerts), and cost-effective implementation within a single integrated platform. Additionally, many systems lack proactive prediction of abnormal water conditions and rely mainly on threshold-based alerts.

To address these gaps, the proposed work integrates AI-driven prediction, IoT-based real-time monitoring, automated feeding, GSM alerts, and embedded vision support, providing a comprehensive, scalable, and intelligent solution for smart aquarium and aquaculture management.

III. METHODOLOGY

In this presented work, the board developed for aquaculture water quality monitoring uses various sensors, and all the sensors record values continuously in real-time that depict the conditions in the aquarium system. Firstly, the pH sensor connected to the PCB module is designed to measure the pH level of sample solutions by measuring the hydrogen ions present in the solutions. This measurement plays a vital role in determining the acidity or alkalinity of the sample, represented on a pH scale ranging from 0 to 14, where 7 denotes neutrality.

Secondly, the digital temperature sensor DS18B20 used in this work follows a single-wire protocol and measures temperature in the range of -67°F to +257°F or -55°C to +125°C, with an accuracy of ±5. The Keys Studio turbidity sensor is used to detect water quality by measuring the level of turbidity. It works by converting the current signal into a voltage output through a circuit. These sensors operate by emitting light through a liquid sample and measuring the amount of light scattered by the suspended particles. In this work, the greater the scattering of light is observed in many aquafarms during the rainy season and shows less in summer.

The presented work explores the use of the MQ2 gas sensor in close proximity to water for detecting gases like H2, LPG, CH4, CO, Alcohol, Smoke, and Propane. Due to its high sensitivity and fast response time, measurements can be taken almost immediately, and values show a higher correlation with water contamination. Some sensors have analog values that are converted to digital values using an ADC device. Here, the presented board design utilizes the MCP3008, a 10-bit Analogto-Digital Converter (ADC) from Microchip Technology. In this design, microcontrollers and single-board computers like the Raspberry Pi are used to read analog signals from various data sensors. It operates via the Serial Peripheral Interface (SPI) protocol, enabling fast and reliable data transmission. The 10-bit resolution of the MCP3008 provides good precision for most sensor readings. One key advantage of the MCP3008 is its compatibility with low-power devices, operating at a wide range of voltages, typically between 2.7V and 5.5V, making it suitable for integration with both 3.3V and 5V systems.

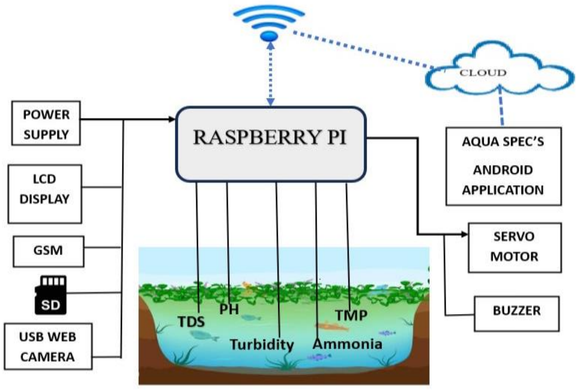

Figure 2. Block Diagram

The sensors in this work are connected to the Raspberry Pi, which features a Broadcom BCM2835 system on a chip (SoC), including an ARM1176JZF-S 700 MHz processor, Video Core IV GPU, with 256 MB of RAM. The presented algorithm tested with Raspbian OS is used to obtain actual values. Raspbian is a free operating system based on Debian, optimized for Raspberry Pi hardware. Using the Python programming language, the output values are retrieved.

Here, the output values are displayed using an LCD (Liquid Crystal Display). A 16*2 LCD means 16 characters can be shown per line, and there are 2 such lines. Each character is displayed in a grid of 5*7 pixels on this LCD. The LCD has two registers: Command and Data. It takes 39-43 μ S for the LCD to place a character or execute a command, and 1.53ms to 1.64ms for other operations, except for clearing the display or returning the cursor to the home position.

Further, the GSM module used is the SIM800C, a Quad-Band GSM/GPRS module in an LCC type, supporting GPRS up to 85.6 kbps data transfer. The SIM800C has strong exten- sion capabilities with abundant interfaces, including UART, USB2.0, GPIO, and more. GSM is used to send notification alerts to the respective mobile number. Finally, the buzzer used in this system can be powered by a DC power supply ranging from 4V to 9V. Here, the buzzer is associated with a switching circuit to turn it ON or OFF at the required time and intervals. Furthermore, the

Astro-Beano 6 LED Webcam with a microphone is used for monitoring. A webcam is a video camera that streams an image or video in real-time.

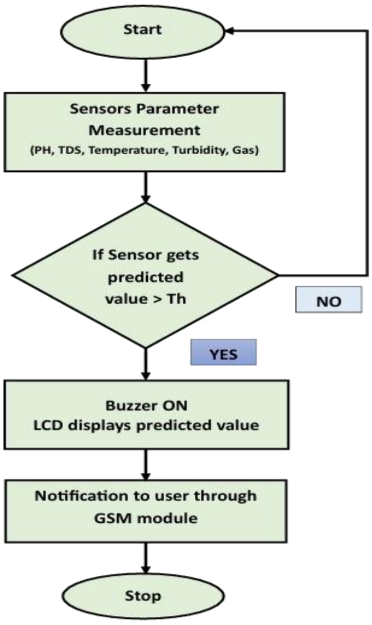

Figure 2. Flow Chart

Pseudocode: Aquaculture Monitoring and GSM Integration

```
BEGIN
1. Import necessary libraries
2. Set serial port = "/dev/ttyS0", baud rate = 9600
3. Try:
      Initialize serial connection
      Print connection status
   Except:
      Print error, set error flag = None
4. Configure GPIO:
      Define LCD, servo motor, buzzer, and sensor pins
      Set PWM on servo pin
5. Function set_servo_angle(angle):
      Adjust PWM duty cycle to rotate servo motor
      Wait for 1 second
6. Set servo to initial angle using set_servo_angle()
7. Define scheduled feeding times:
      Time1 = "10:40"
      Time2 = "10:42"
8. Function check_time():
      Compare current system time with scheduled times
      If time matches, activate servo motor
9. Initialize LCD display
10. Initialize DS18B20 temperature sensor
11. Initialize LDR pin
12. Load dataset and train machine learning model
13. Function predict_from_sensor_data():
      Predict TDS, turbidity, temperature, gas, and pH values
14. Setup GSM module:
      Serial port = "/dev/ttyUSB0"
      Baud rate = 9600
15. Function send_sms(message):
      Send SMS to predefined number "+919912173701"
16. Try:
      Send "AT" command
      Set SMS text mode
      Enable periodic system checks
17. While TRUE:
      Check current time
      Read sensor data
      Display sensor values on LCD
      Perform prediction using trained model
      If abnormal value detected:
         Activate buzzer
         Send SMS alert via GSM
18. Except:
      Handle runtime error
END
```

In this aquarium system all the sensor got different values those values are changed according to the condition in the aquarium system. The pH Sensor PCB module is engineered to measure the pH level of sample solutions by evaluating the activity of hydrogen ions present in the solutions. This measurement is crucial for determining the acidity or alkalinity of the sample, which is represented on a pH scale ranging from 0 to 14, where 7 denotes neutrality. The digital temperature sensor like DS18B20 follows single wire protocol and it can be used to measure temperature in the range of -67oF to +257oF or -55oC to +125oC with +-5The keysstudio turbidity sensor detects water quality by measuring level of turbidity. The principle is to convert the current signal itself into the voltage output through the circuit. Its detection range is 0

The sensors are connected to the Raspberry Pi, which has a Broadcom BCM2835 system on a chip (SoC), including an ARM1176JZF-S 700 MHz processor, Video Core IV GPU, and was originally shipped with 256 megabytes of RAM, later upgraded (Model B & Model B+) to 512 MB. It does not include a built-in hard disk or solid-state drive, but it uses an SD card for booting and persistent storage, with the Model B+ using a MicroSD. By using Raspbian OS to get actual values, Raspbian is a free operating system based on Debian, optimized for Raspberry Pi hardware. Raspbian comes with over 35,000 packages installed on personal computers. By using the Python language, the output values are obtained. Python is easy to learn and use; it is developer-friendly and a high-level programming language. The output values are displayed by using an LCD (Liquid Crystal Display). It is the innovation utilized in scratchpad displays and other smaller computers. A 16x2 LCD means 16 characters can be shown per line, and 2 such lines exist. Each character is shown in a grid of 5x7 pixels in this LCD. There are two registers in this LCD, namely Command and Data. It takes 39-43µS for the LCD display to place a character or execute a command. It takes 1.53ms to 1.64ms except for clearing the display and searching for the cursor to the home position.

Here, the GSM module used is the SIM800C, a Quad-Band GSM/GPRS module in an LCC type that supports GPRS upto 85.6 kbps data transfer. The SIM800C has strong extension capability with abundant interfaces, including UART, USB2.0, GPIO, etc. The SIM800C module provides much flexibility and ease of integration for customer applications. GSM is used to send notification alerts to the respective mobile number. GSM is an open and digital cellular technology used for transmitting mobile voice and data services, operating at the 850 MHz, 900 MHz, 1800 MHz, and 1900 MHz frequency bands. It requires a SIM (Subscriber Identity Module) card, just like mobile phones, to activate communication with the network. Additionally, they have an IMEI (International Mobile Equipment Identity) number, similar to mobile phones, for identification. The MODEM needs AT commands to interact with the processor or controller, which are communicated through serial communication. These commands are sent by the controller/processor.

This buzzer can be used by simply powering it using a DC power supply ranging from 4V to 9V. A simple 9V battery can also be used, but it is recommended to use a regulated +5V or +6V DC supply. The buzzer is normally associated with a switching circuit to turn ON or turn OFF the buzzer at required time and require interval.Astro-beano 6 LED Webcam with Microphone is used for monitoring. A webcam is a video camera that feeds or streams an image or video in real time to or through a computer network, such as the Internet. Webcam software enables users to record a video or stream the video on the Internet. As video streaming over the Internet requires much bandwidth, such streams usually use compressed formats.

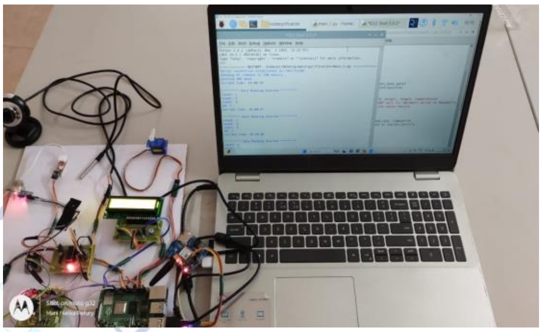

Figure 3. Circuit Implementation

IV. Results and Discussions

In this study, the Android application functioned as intended, providing real-time monitoring of water quality parameters. The sensors operated effectively, generating accurate data for each specific parameter, in alignment with the system's design. The predicted values were computed using the Raspberry Pi microcontroller. The controller module successfully acquired data from the sensors, which was then transmitted via Wi-Fi to the cloud server. The processed data was subsequently displayed on the web application, ensuring seamless monitoring.

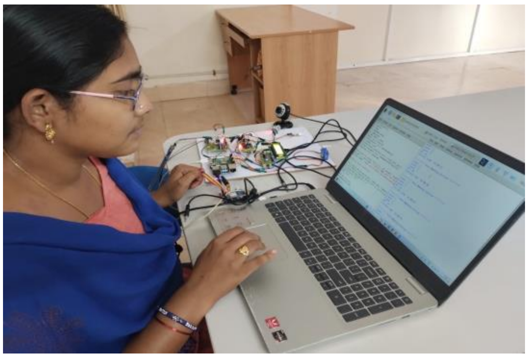

Figure 4. AI Model AND IoT Sensing System Integration

When the system detected abnormal turbidity values, the buzzer was triggered in real-time, and the alert was immediately displayed on the user's Android device. The data was also logged and stored in the database for further analysis.

The system utilizes a Random Forest machine learning algorithm, which integrates multiple decision trees to generate predictions. Experimental evaluation showed that the maximum accuracy achieved for pH value prediction was 1 out of 14. The temperature range was recorded between 20-25°C, and the gas range was 50. The predicted values for temperature and gas were 27.31°C and 1, respectively. Additionally, turbidity and TDS were predicted to be 1 and 0, respectively. All sensor readings were in close agreement with the actual values, and both predicted and measured values were accurately displayed on the LCD.

The system also incorporates a USB webcam, which facilitates the real-time monitoring of color changes in the water. This feature enhances the system's capability for visual monitoring during aquatic operations. The results indicate that the system can effectively display sensor data on the Android application and is sufficiently robust to notify the user when parameter values deviate from predefined thresholds, ensuring timely interventions.

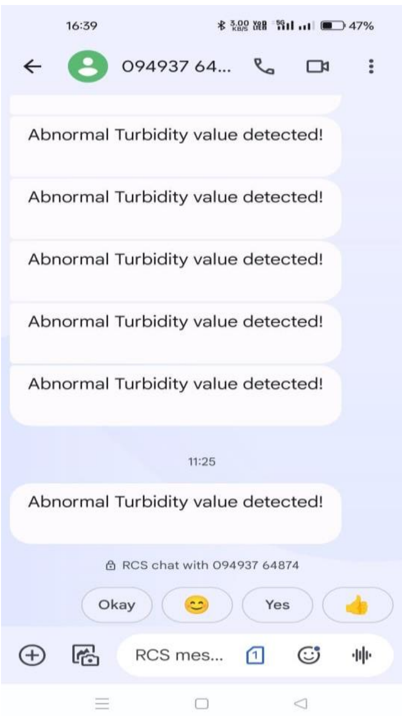

Figure 5. Output on Android application

V. Conclusion

This paper presented a Smart Assistive Communication System for Challenged and Normal People using Embedded Systems and IoT, aimed at reducing communication barriers faced by individuals with speech, hearing, and visual impairments. By integrating flex sensor–based gesture recognition, text-to-speech conversion, and IoT-enabled emergency alert mechanisms, the proposed system enables effective and inclusive bidirectional communication.

The developed prototype successfully translates hand gestures into meaningful text and audible voice outputs, allowing speech-impaired users to convey essential needs. Simultaneously, the text-to-speech module supports visually impaired users by providing clear audio feedback, while the display interface assists hearing-impaired users. The IoT-based emergency alert system ensures user safety by enabling instant communication with caregivers or family members during critical situations.

Experimental results demonstrate reliable gesture recognition, fast system response, and stable IoT communication, confirming the practicality and effectiveness of the proposed solution. The system's low-cost hardware design, portability, and real-time operation make it suitable for deployment in home, healthcare, and assisted-living environments.

In conclusion, the proposed smart assistive communication system provides an intelligent, user-friendly, and scalable solution that enhances independence, safety, and quality of life for differently-abled individuals, while promoting inclusive communication in everyday scenarios.

Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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