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Brackish water parameters monitoring dashboard using Internet of Things and Industry 4.0

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Abstract

INTRODUCTION: Brackish water aquaculture plays a crucial role in meeting the growing global demand for seafood. It offers an opportunity to diversify aquaculture production and reduce pressure on overexploited marine resources.
OBJECTIVES: By harnessing the unique properties of brackish ecosystems, this practice contributes to food security, economic growth, and sustainable resource management, while also promoting the conservation of valuable marine habitats. The development of a cutting-edge Indigenous Water Quality Monitoring Prototype named "Aqua BuoySis" for precision brackish water aquaculture utilizing machine intelligence.
METHODS: The prototype integrates sensors for Dissolved Oxygen (DO), pH, Temperature, Turbidity, and Total Dissolved Solids (TDS). These sensors are calibrated using a dynamic temperature-based machine-learning approach to ensure accuracy in real-time environments. Sensor calibration constants are uploaded to a server for comprehensive data calibration.
RESULTS: The system collects data at 20-second intervals, associating it with specific pond IDs. Data refinement is achieved through Long Short-Term Memory (LSTM) processing. An Android and Web application, available in native languages such as Tamil and Telugu, has been developed to provide live updates to aqua farmers, facilitating informed decision-making.
CONCLUSION: This technology represents a significant step towards enhancing precision in brackish water aquaculture through the fusion of machine intelligence and water quality management.

Keywords: Brackish aquaculture, Machine Learning, Long Short-Term Memory, Water quality management, Web-based application.

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Specifications table

Hardware name	Aqua Buoys(TinyML)
Subject area	• Engineering and materials science Environmental, planetary and agricultural sciences
Hardware type	• Biological sample handling and preparation • Field measurements and sensors
Closest commercial analog	Standalone Wireless Sensor Network will gather data on real-time environmental and weather parameters from the shrimp culture pond. Mobile phone-based advisory system for location-specific and personalized advisories to farmers.
Open source license	https://www.flashforge.com/product-detail/FlashPrint-slicer-for-flashforge-fdm-3d-printers
Cost of hardware	INR.52000
Source file repository	https://115.240.192.141/ShrimpAnalytics/index.php

1. Introduction

1.1. Hardware in context

Several hardware components were used, which were integrated into a single PCB. Then the PCB board was fitted onto a cylinder and made to stay afloat in the ponds using the buoys [1,2]. The components are as follows:

1.2. ESP8266NodeMCU CP2102 Board

A common development board used to create Internet of Things (IoT) projects is the ESP8266 NodeMCU CP2102 board. It is built around the ESP8266 WiFi module and includes a CP2102 USB-to-UART bridge chip that enables simple programming and USB communication with a computer. Farmers may manage water quality more intelligently by integrating real-time pond data through IoT connectivity and using that knowledge to change feed rates, oxygen levels, or treatments. Aquatic creatures' habitats are kept healthy, and aquaculture productivity is optimized using this real-time data. A low-cost WiFi microcontroller for Internet of Things applications that allows real-time data transfer is the ESP8266 Node MCU CP2102 Board. TinyML, a program for machine learning models on embedded devices, is essential for resource-constrained real-time edge AI applications in environmental monitoring systems.

The ESP8266 NodeMCU CP2102 board has the following notable features:

a. Wireless connectivity: The board has an ESP8266 WiFi module installed, allowing it to connect to WiFi networks and communicate with other devices and online services [3,4].

b. GPIO Pins Several General-Purpose Input/Output (GPIO) pins on the board can be used to connect to sensors, actuators, or other components that are located outside of the device

c. USB interface: The board's USB interface, which is included in the CP2102 chip, allows it to be connected to a computer for programming and serial communication.

d. Microcontroller: The board's ESP8266 module has a microcontroller with processing power that you can use to run programs and manage various operations.

e. The Environment for Development: With this board, the NodeMCU firmware frequently provides a user-friendly programming environment for creating and uploading programs.

f. Open Source: Because the NodeMCU CP2102 board is open-source hardware, anyone can use and modify the design files and specs, as shown in Figure 1.

Recursive neural networks (RNNs) are neural network architectures in which hierarchical input structures are subjected to a recursive application of the same set of weights. It is frequently employed for applications like natural language processing and hierarchical data analysis that need tree-like structures or sequences of different lengths. A "memoryless" feature commonly used in modelling systems whose future states are independent of past ones is the capacity of a Markov Process, a stochastic process, to go only to the next state based only on its present state. A sort of recurrent neural network (RNN) called the Long Short-Term Memory (LSTM) RNN Model uses memory cells to retain information over extended periods of time, making it perfect for applications such as speech recognition, natural language processing, and time series forecasting. Recurrent neural networks, or Long Short-Term Memory (LSTM) networks, are perfect for applications like time-series prediction and natural language processing because they can handle sequential input and solve the vanishing gradient problem. Their proficiency in identifying enduring relationships and managing noisy data is impressive, as they provide a harmonious blend of efficiency and adaptability in several fields. Poovendran examines Elliptic Curve Cryptography (ECC), a strong encryption technique for cloud computing, in contrast to more established techniques like AES. According to the report, ECC may improve resource efficiency, boost data security, and provide a scalable, affordable solution [5]. Sri H.G. aims to improve water level monitoring systems by integrating Human-Machine Interface (HMI) display modules with passive IoT optical fibre sensor networks. It uses Fiber Bragg Grating (FBG) sensors for real-time data visualization and advanced feature extraction, aiding in environmental management and flood prevention. The system's robustness is tested and validated for performance metrics [6].

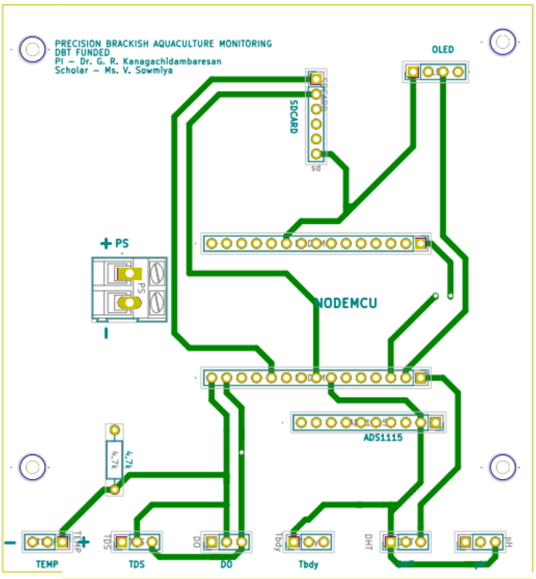

Figure 1. ESP8266NodeMCU CP2102 Board

1.3. OLED display

An Organic Light light-emitting diode (OLED) display is a type of flat-panel display technology that uses organic compounds to emit light when an electric current is applied. OLED displays are known for their vibrant colours, high contrast ratios, and thin form factor. A monitoring system with both an SD card and an OLED display will be more user-friendly since the SD card will allow for comprehensive data logging and storage, enabling long-term trend analysis and system performance assessments. Real-time, easily readable data may be seen on the site. They are commonly used in various electronic devices, from smartphones and televisions to wearable devices and digital signage [7,8].

Key characteristics and advantages of OLED displays include:

1. Thin and Flexible: OLED displays are fragile and can be made flexible, allowing for innovative designs and applications.

2. Vivid Colors: Each pixel in an OLED display emits its own light, resulting in vibrant and accurate colours. This enables OLED displays to achieve deeper blacks and better contrast compared to some other display technologies.

3. Fast Response Time: OLEDs have fast response times, making them suitable for applications with rapid motion, such as gaming.

4. Wide Viewing Angles: OLED displays offer wide viewing angles, ensuring consistent image quality even when viewed from different angles.

5. Energy Efficiency: OLED displays are energy-efficient because they only emit light where needed, leading to potential power savings in devices.

6. No Backlight Required: Unlike LCDs, OLEDs do not require a separate backlight, allowing for thinner and lighter devices.

7. Design Flexibility: OLED technology allows curved and edge-to-edge displays, enabling unique and aesthetically pleasing device designs.

8. High Contrast: OLEDs can achieve very high contrast ratios because they can turn off individual pixels completely, resulting in true blacks.

9. Better Outdoor Visibility: OLED displays perform well under bright sunlight, improving outdoor visibility.

10. Potential for Transparent Displays: OLED technology can create transparent displays, opening up possibilities for augmented reality and unique user experiences.

1.4. SD card read sensor

An SD card reader sensor is a device that allows you to read and write data to Secure Digital (SD) memory cards. SD cards are commonly used for storing and transferring data in various electronic devices, such as digital cameras, smartphones, and embedded systems. With adapters, SD card reader sensors can read regular SD, mini-SD, and micro-SD cards in addition to other card formats. Mini-SD and micro-SD cards are smaller and frequently seen in tiny devices, but standard SD cards have more considerable storage capabilities. Standard SD card slots can be compatible with adapters, and it's essential that the reader supports different speed classes and capacities. The SD card reader sensor facilitates communication between the SD card and another device, such as a microcontroller or computer, enabling data storage, retrieval, and manipulation [14,15].

Key features and functionalities of an SD card reader sensor include:

1. Data Storage and Retrieval: The sensor lets you store and retrieve data on an SD card. This data includes files, images, videos, audio recordings, and more [4].

2. File System Compatibility: SD cards typically use file systems such as FAT16 or FAT32, which the reader sensor can understand and manage.

3. Serial Communication: The sensor interfaces with the SD card using serial communication protocols, such as SPI (Serial Peripheral Interface) or SDIO (SD Input/Output).

4. Data Logging: SD card reader sensors are commonly used in data logging applications, where they record and save data from sensors or instruments onto the SD card.

5. Expandable Storage: SD cards allow devices with limited internal storage to expand their memory capacity to store larger amounts of data.

6. Embedded Systems: SD card reader sensors are used in embedded systems for tasks such as firmware updates, data backups, and configuration storage.

7. Portable Media Storage: The sensor can store and transport media files, making it a convenient option for audio players, digital cameras, and video recorders.

8. Data Security: Some SD cards support hardware-level data encryption and protection, adding a layer of security to the stored data.

9. Versatility: SD card reader sensors are compatible with various sizes of SD cards, including standard SD, miniSD, and microSD cards, making them versatile for different applications.

10. Data Transfer: The sensor facilitates fast and reliable data transfer between the SD card and the connected device, enabling efficient data management.

SD card reader sensors are commonly integrated into development boards and microcontroller-based projects. They provide a cost-effective and convenient solution for adding data storage capabilities to various electronic systems. When using an SD card reader sensor, it's essential to consider factors such as compatibility, data integrity, and power management to ensure reliable and efficient operation.

1.5. Analog to digital converter

An Analog-to-Digital Converter (ADC) is an essential electronic component that plays a critical role in converting analog signals into digital data. It enables the processing and manipulation of real-world continuous signals by digital systems, such as microcontrollers, computers, and other digital devices. ADCs are widely used in a variety of applications, including measurement, control systems, communication, and data acquisition [16,17].

Key features and functions of an Analog-to-Digital Converter include:

1. Signal Conversion: ADCs convert continuous analog signals, such as voltage or current, into discrete digital values that digital systems can process and analyze.

2. Resolution: An ADC's resolution determines the number of discrete values it can represent. Higher-resolution ADCs provide a finer and more accurate representation of analog signals.

3. Sampling Rate: The sampling rate defines how frequently the ADC measures the analog signal. It is crucial for accurately capturing rapidly changing signals.

4. Quantization: Quantization divides the analog signal range into discrete levels, determining the precision of the digital representation.

5. Accuracy: ADC accuracy refers to how closely the digital output corresponds to the analog input. Factors such as linearity, offset error, and gain error contribute to accuracy [18,19].

6. Bit Depth: An ADC's bit depth indicates the number of bits used to represent the digital output. A higher bit depth allows a more accurate representation of small signal variations.

7. Input Range: ADCs have a specified input voltage range within which they can accurately convert analog signals. Signals outside this range might result in distortion or clipping.

8. Single-Ended and Differential Inputs: ADCs can accept single-ended inputs (one signal relative to a standard reference) or differential inputs (the voltage difference between two signals).

9. Digital Interfaces: Many modern ADCs feature digital interfaces, such as SPI (Serial Peripheral Interface) or I2C (Inter-Integrated Circuit), making them easy to interface with microcontrollers and digital devices.

10. Applications: ADCs are used in various applications, including sensor interfacing, audio processing, wireless communication, data acquisition systems, motor control, medical devices, and more.

ADCs are an integral part of the analog-to-digital signal processing chain, enabling the conversion of real-world signals into a format that digital systems can understand and manipulate [20]. The choice of an appropriate ADC depends on factors such as the required resolution, sampling rate, input range, and interface compatibility for a given application.

1.6. DO sensor

A Dissolved Oxygen (DO) sensor is an important instrument used to measure dissolved oxygen concentration in water. Dissolved oxygen is a critical parameter in aquatic environments as it directly affects the health and survival of aquatic organisms and indicates the overall water quality. The SD card storage system on the microcontroller was probably used to log the DO sensor's data continuously.

Maintaining a DO sensor requires routine cleaning and calibration. Hydrogen ion concentration is measured using glass electrodes, and the reference electrode provides a steady comparison.

Key features and functions of a Dissolved Oxygen sensor include:

1. Measurement Principle: DO sensors typically employ either the polarographic or optical method for measuring dissolved oxygen [21,22]. Polarographic sensors use a permeable membrane and an electrode to measure the oxygen diffusion rate, while optical sensors use fluorescence or luminescence to measure oxygen concentration.

2. Calibration: DO sensors require periodic calibration using standardized solutions to ensure accurate and reliable measurements.

3. Units: Dissolved oxygen is measured in milligrams per litre (mg/L) or parts per million (ppm).

4. Temperature Compensation: Temperature significantly influences dissolved oxygen levels. Many DO sensors incorporate temperature compensation to provide accurate readings under varying temperature conditions.

5. Applications: DO sensors are used in various fields, including environmental monitoring, water treatment, aquaculture, research, and industrial processes. Maintaining optimal DO levels in aquaculture is crucial for fish and aquatic plant health.

6. Real-Time Monitoring: DO sensors are often integrated into monitoring systems that allow real-time tracking and data logging of dissolved oxygen levels over time.

7. Probe Types: DO sensors come in various probe designs, including submersible probes for in situ measurements, handheld probes for field sampling, and online sensors for continuous monitoring in industrial settings.

8. Maintenance: Proper maintenance, including regular cleaning and storage, is essential to ensure the longevity and accuracy of DO sensors. Different types of sensors have different cleaning and maintenance requirements. For example, optical sensors need to be cleaned manually or automatically to prevent biofouling; electrochemical sensors need to be cleaned frequently; conductivity sensors need to be cleaned with weak acids; pressure/flow sensors need to be cleaned manually; and acoustic sensors need to be cleaned regularly.

9. Measurement Range: DO sensors have a specified measurement range to provide accurate readings. It is essential to choose a sensor with an appropriate range for the application.

10. Sensor Variability: Different DO sensors may vary in accuracy, response time, and suitability for specific environments. Careful consideration is needed to select the suitable sensor for a given application.

Dissolved oxygen is a critical parameter for assessing the health of aquatic ecosystems, ensuring water quality in various industries, and supporting the growth and well-being of marine organisms. DO sensors are indispensable tools for researchers, environmentalists, and water management and analysis professionals.

1.7. Water Temperature Sensor

A Water Temperature sensor is a device used to measure and monitor the temperature of water in various applications, ranging from environmental monitoring to industrial processes. It provides valuable information about the thermal conditions of water bodies, which is essential for understanding aquatic ecosystems, water quality, and various engineering applications.

Key features and functions of a Water Temperature sensor include:

1. Temperature Measurement: Water temperature sensors measure the temperature of water in degrees Celsius (°C) or Fahrenheit (°F).

2. Accuracy: Sensor accuracy is crucial for obtaining reliable temperature measurements. High-quality sensors provide accurate and repeatable readings.

3. Range: Water temperature sensors have a specified temperature range for accurate measurements. Choosing a sensor with an appropriate range for the application is essential. Temperature sensors play a critical role in determining whether an aquatic organism's environment is suitable since many species are sensitive to particular temperature ranges. These sensors ensure a stable aquatic ecology, aiding in preserving the ideal circumstances for species survival, development, and reproduction.

4. Submersible Design: Many water temperature sensors are designed to be submersible, allowing them to be directly immersed in the water for in situ measurements.

5. Response Time: Response time refers to how quickly the sensor detects temperature changes. Some applications require sensors with fast response times, while others prioritize stability.

6. Calibration: Regular calibration ensures the accuracy of temperature readings. Calibration involves comparing the sensor's output to a known reference source.

7. Environmental Conditions: Consider the environmental conditions in which the sensor will be used. Some sensors are designed to withstand harsh conditions, such as extreme temperatures or corrosive environments.

8. Connectivity: Water temperature sensors may feature analog or digital outputs, making them compatible with a wide range of data acquisition systems and microcontrollers.

9. Applications: Water temperature sensors are used in environmental monitoring of rivers, lakes, oceans, and aquariums. They are also important in industrial processes like water heating and cooling, aquaculture, hydrology, and research.

10. Data Logging: Water temperature sensors are often integrated into data logging systems to monitor and record temperature changes continuously over time.

Water temperature is a critical parameter influencing aquatic ecosystems, water quality, and various industrial processes. By providing accurate temperature measurements, water temperature sensors contribute to informed decision-making, resource management, and scientific research involving water bodies.

1.8. Water quality sensor

A water quality sensor is a versatile device designed to measure and assess various parameters and characteristics of water to determine its overall quality. These sensors play a crucial role in monitoring and managing water resources, ensuring drinking water safety, and maintaining aquatic ecosystems' health. They are used in a wide range of applications, from environmental monitoring to industrial processes [9,10,14].

Key features and functions of water quality sensors include:

1. Multi-Parameter Measurement: Water quality sensors can measure multiple parameters, including but not limited to temperature, pH, dissolved oxygen (DO), turbidity, conductivity, total dissolved solids (TDS), oxidation-reduction potential (ORP), and various ions. Changes in pH and water temperature, necessitating methods like pH and temperature adjustment, calibration, and maintenance, impact the accuracy of ORP sensors. Accurate readings in water bodies with varying chemical compositions are guaranteed by automatic temperature correction and site-specific calibration.

2. Accuracy: High accuracy is essential for reliable water quality assessments. Sensors with precision components and calibration mechanisms provide accurate measurements.

3. Modularity: Some water quality monitoring systems allow the integration of interchangeable sensor modules for flexibility in parameter measurement.

4. Real-Time Monitoring: Many water quality sensors provide real-time data, enabling immediate response to changes in water conditions and rapid decision-making.

5. Remote Monitoring: Water quality sensors can be integrated into remote monitoring systems, allowing data to be collected and analyzed remotely.

6. Environmental Conditions: Sensors may be designed to operate in specific environmental conditions, such as submersible sensors for underwater monitoring or rugged sensors for harsh environments.

7. Data Logging: Water quality sensors often have data logging capabilities, enabling historical data collection for analysis and reporting.

8. Integration: Water quality sensors can be integrated into larger monitoring networks, enabling comprehensive assessments of water bodies and systems.

9. Calibration: Regular calibration ensures accurate measurements over time. Some sensors have built-in calibration mechanisms or can be calibrated externally.

10. Applications: Water quality sensors are used in various fields, including environmental monitoring, water treatment, aquaculture, agriculture, research, and industrial processes.

Water quality sensors ensure safe drinking water, manage wastewater treatment processes, assess the impact of pollutants on aquatic ecosystems, and comply with environmental regulations. They empower scientists, researchers, water managers, and policymakers with essential data to make informed decisions and safeguard our water resources.

1.9. Solar Panel

A solar panel, also known as a photovoltaic (PV) panel, is a device that converts sunlight into electricity using the photovoltaic effect. Solar panels are a vital component of solar energy systems, harnessing renewable energy from the sun to generate electricity for various applications. Photovoltaic cells, conducting wires, tempered glass, encapsulant, back sheet, aluminium frame, junction box, and anti-reflective coating comprise solar panels. Thanks to these parts, sunlight may be converted into power. They have longevity, effectiveness, and dependability.

Key features and functions of solar panels include:

1. Photovoltaic Cells: Solar panels consist of multiple photovoltaic cells made from semiconductor materials like

silicon. These cells absorb photons from sunlight and release electrons, creating an electric current.

2. Electricity Generation: When sunlight strikes the photovoltaic cells, it creates a flow of electrons, generating direct current (DC) electricity.

3. Conversion Efficiency: A solar panel's efficiency refers to the percentage of sunlight it can convert into usable electricity. Higher-efficiency panels produce more electricity from the same amount of sunlight.

4. Types of Solar Panels: There are various solar panels, including monocrystalline, polycrystalline, and thin-film panels. Each type has different efficiencies, costs, and applications.

5. Power Rating: Solar panels are rated in watts (W) or kilowatts (kW), indicating their maximum power output under specific sunlight conditions.

6. Grid-Tied and Off-Grid Systems: Solar panels can be used in grid-tied systems, where excess energy is fed back into the utility grid, or off-grid systems, where energy is stored in batteries when sunlight is unavailable.

7. Mounting and Installation: Solar panels are typically mounted on rooftops, ground structures, or other support systems to optimize their exposure to sunlight.

8. Inverter: Solar panels produce DC electricity, converted to usable alternating current (AC) electricity through an inverter before being used by appliances and the grid.

9. Net Metering: In grid-tied systems, net metering allows homeowners to receive credit for excess electricity they generate and feed back into the grid.

10. Environmental Benefits: Solar panels produce clean, renewable energy, reducing greenhouse gas emissions and dependence on fossil fuels.

11. Applications: Solar panels are used in residential, commercial, and industrial settings to generate electricity for homes, buildings, remote locations, and various appliances.

Solar panels are a sustainable and environmentally friendly energy solution. They offer a way to reduce electricity bills, lower carbon footprints, and contribute to a more sustainable future. They are a critical technology in the transition to renewable energy sources and play a significant role in addressing energy and environmental challenges.

PH Sensor

pH sensors for water are vital instruments used to measure the acidity or alkalinity levels of aqueous solutions. These sensors operate based on detecting the concentration of hydrogen ions present in the water, which determines its pH value. In various industries and applications such as environmental monitoring, industrial processes, and scientific research, pH sensors are pivotal in ensuring optimal conditions. In fields like water treatment and aquaculture, accurate pH measurements are essential for maintaining suitable conditions for aquatic life and chemical processes. A reference electrode is used for stability, and a glass electrode sensitive to hydrogen ions is used for the pH measurement. The potential difference produced by the reaction between the glass and the reference electrodes is translated into a pH value, indicating the solution is acidic or alkaline. Modern pH sensors offer high precision, durability, and the capability to provide real-time monitoring, enabling prompt adjustments to maintain desired pH levels [11]. Their significance in water quality management and diverse sectors underscores their role in ensuring effective and sustainable utilization of water resources. Shown in Figure 2. Real-time pH monitoring in aquaculture and water treatment allows quick modifications to maintain ideal water conditions. It enables operators to respond swiftly to pH variations to avoid hazardous environmental situations, protect aquatic life, and improve water treatment procedures.

Figure 2. pH sensor

1.10. DO Sensor

Dissolved Oxygen (DO) sensors are critical tools used to quantify the amount of oxygen dissolved in a liquid, primarily in water bodies. DO levels are a fundamental indicator of water quality, affecting aquatic life and ecosystem health. These sensors utilize various principles, such as polarography or fluorescence, to measure the water's oxygen molecule concentration. Monitoring DO levels is particularly important in aquaculture, wastewater treatment, and environmental research. In aquaculture, maintaining optimal DO levels ensures the well-being of aquatic organisms by supporting their respiration and growth. In wastewater treatment, DO measurements help assess the effectiveness of biological processes that rely on oxygen-dependent microbes to break down pollutants. In aquatic habitats, pH has a critical role in biological activities as well as the solubility of nutrients and metals. Because aquatic life depends on particular pH ranges to survive, extreme pH values can harm it. Changes may result in detrimental algal blooms or inadequate nitrogen absorption.

Furthermore, understanding DO fluctuations in natural water bodies aids in assessing ecosystem dynamics and identifying potential pollution or oxygen depletion issues. In essence, DO sensors contribute significantly to sustaining healthy aquatic environments and optimizing industrial processes reliant on water quality, as shown in Figure 3.

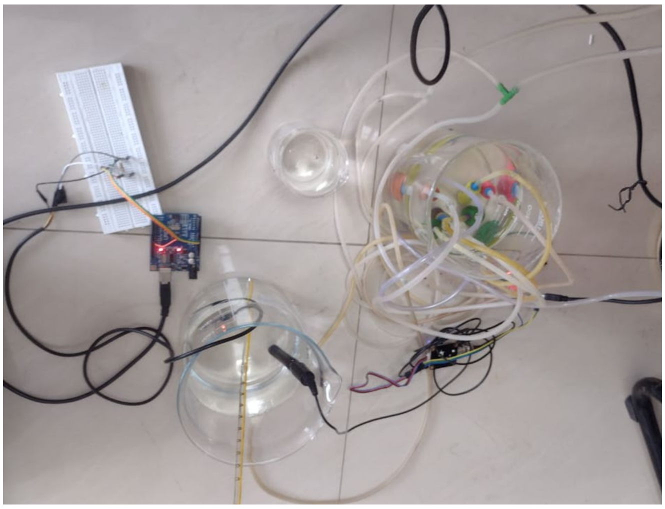

Figure 3. 3DO sensor Calibration in different salinity and temperature
Accuracy = Actual DO ± 0.3

1.11. Temperature and TDS Sensor

Temperature and Total Dissolved Solids (TDS) sensors are pivotal instruments in water quality monitoring, offering valuable insights into aquatic environments. Total Dissolved Solids (TDS) sensors provide more precise measurements of the amount of dissolved particles in water, improving water quality monitoring. This enhances the accuracy and dependability of the system by enabling more accurate assessments of the purity of the water and making it simpler to identify pollutants or quality variations. The temperature sensor measures the thermal state of water, a crucial parameter as it influences chemical reactions, biological processes, and overall ecosystem dynamics. Accurate temperature data helps assess habitat suitability for aquatic organisms and track seasonal variations.

On the other hand, TDS sensors quantify the total concentration of dissolved inorganic and organic substances in water. This metric indicates water purity, reflecting the presence of minerals, salts, and pollutants. TDS meters must be calibrated, their electrodes regularly cleaned, and stored in dry environments. When taken care of properly, they may live up to five years; they can even live longer in pure water or with sporadic use. On the other hand, they do not survive as long in heavy industrial settings or hard or dirty water. Their dependability depends on routine maintenance, including battery inspections. Monitoring TDS aids in assessing water quality for consumption, industrial use, and agriculture. In aquaculture, maintaining appropriate TDS levels is vital for the health of aquatic organisms, while in environmental monitoring, elevated TDS levels might indicate contamination. Together, these sensors contribute to a comprehensive understanding of water conditions, enabling informed decision-making in various sectors such as agriculture, aquaculture, and environmental management. Their integration into monitoring systems facilitates the maintenance of optimal water parameters for both human and aquatic life.

1.12. Turbidity Sensor

A turbidity sensor is a critical tool used to measure the clarity and transparency of water by quantifying the number of suspended particles or solids present in the liquid. Turbidity sensors use light scattering from suspended particles in the water to determine the purity of the water. More particles imply a greater turbidity measurement, which decreases the clarity of the water. This technique makes the accurate evaluation of silt levels and water contamination possible. Turbidity is an essential parameter in water quality assessment as it reflects the level of sediment, silt, or organic matter present in the water column. This measurement is critical for evaluating the health of aquatic ecosystems, water treatment processes, and various industrial applications. Turbidity sensors work based on principles such as light scattering or absorption. Connecting turbidity sensors to real-time data platforms allows for the smooth integration of these sensors into water quality monitoring systems. In addition to helping determine pollution levels in industrial and natural settings, these sensors analyze water quality continuously, guaranteeing prompt identification of particle matter and silt. They emit light into the water, and the sensor then measures the

scattered or absorbed light to determine the degree of turbidity. Clearwater will allow light to pass through with minimal scattering, resulting in a low turbidity reading. At the same time, water with higher suspended particle content will scatter more light, indicating higher turbidity levels.
Nephelometry and other light-based techniques have several benefits, such as non-contact measurement, quick reaction times, and the capacity to identify even minute variations in water clarity. Compared to other procedures, such as gravimetric analysis, these approaches are often less intrusive and more accurate. In environmental monitoring, turbidity measurements help assess the impact of land runoff, erosion, and pollution on water bodies. Reliable turbidity measurements are essential for manufacturing food and beverage medicines that depend on pure water. Turbidity measurements that are accurate and trustworthy ensure that the water utilized is free of impurities, protecting the end goods' quality and safety. In water treatment, turbidity serves as an indicator of filtration efficiency and treatment effectiveness. Additionally, maintaining consistent water quality is crucial for product quality and safety in beverage production. Overall, turbidity sensors significantly safeguard water resources, aquatic ecosystems, and human health.

1.13. 3D Filament

3D filament, also known simply as filament, refers to the material used in 3D printing to create physical objects layer by layer. It is a critical component in the 3D printing process, serving as the "ink" or material that is melted and deposited by the 3D printer to build up the final object. The 3D printer in the system probably supports prototyping materials like PLA, ABS, and PETG. The kinds of flexible or high-temperature materials that may be printed are restricted. Regarding accuracy, most consumer-grade 3D printers provide a resolution of between 0.1 and 0.05 mm, although the degree of precision may differ based on the material and design complexity.

Key features and aspects of 3D filament include:

1. Material Composition: 3D filaments are available in various materials with unique properties and characteristics. Common filament materials include thermoplastics like PLA (Polylactic Acid), ABS (Acrylonitrile Butadiene Styrene), PETG (Polyethylene Terephthalate Glycol), TPU (Thermoplastic Polyurethane), and more.

2. Diameter: Filaments are available in different diameters, with 1.75 mm and 2.85 mm standard sizes. The correct filament diameter must match the specifications of the 3D printer.

3. Colors: Filaments come in a wide range of colours, allowing for creative and colourful 3D prints.

4. Specialty Filaments: In addition to standard filaments, speciality filaments with unique properties exist, such as wood-infused filaments, metal-infused filaments, glow-in-the-dark filaments, and more.

5. Printing Temperature: Different filament materials have specific temperature requirements for melting and extrusion. Proper temperature settings are essential for successful 3D printing.

6. Print Bed Adhesion: Some filaments require specific print bed preparations or surface treatments to ensure proper adhesion during printing.

7. Strength and Durability: Filament materials vary in strength, flexibility, and durability. Some materials are better suited for functional parts, while others are ideal for prototypes or artistic creations.

8. Compatibility: Filament compatibility with a specific 3D printer depends on the printer's extruder type, temperature range, and other specifications.

9. Biodegradability: Certain filaments, such as PLA, are biodegradable and considered more environmentally friendly than non-biodegradable alternatives.

10. Post-Processing: After printing, objects created from 3D filament can be further refined, painted, or modified using post-processing techniques.

3D filament is a fundamental element in 3D printing technology, enabling the creation of a wide range of objects and prototypes. Choosing the proper filament material for a particular project involves considering factors such as intended use, desired properties, and compatibility with the 3D printer. As 3D printing continues to advance, new filament materials and innovative features are continually being developed to expand the possibilities of this technology.

1.14 3D Printing Machine

A 3D printing machine, also known as a 3D printer, is a device that creates three-dimensional objects by adding material layer by layer based on a digital design. It has revolutionized various industries by enabling rapid prototyping, customization, and small-scale manufacturing [12,13]. 3D printers come in various types, each utilizing different technologies and materials to achieve their printing processes.

Key features and aspects of 3D printing machines include:

1. Printing Technology: Different types of 3D printing technologies exist, such as Fused Deposition Modeling (FDM), Stereolithography (SLA), Selective Laser Sintering

(SLS), and more. Each technology has its strengths, materials, and applications.

2. Build Volume: The build volume defines the maximum object size that can be printed in the 3D printer. Larger build volumes allow for larger objects.

3. Materials Compatibility: 3D printers are designed to work with specific 3D printing materials, such as plastics, resins, metals, ceramics, and composites.

4. Layer Resolution: Layer resolution refers to the thickness of each printed layer. Smaller layer resolutions result in finer details but may increase print times.

5. Extruders or Print Heads: FDM printers often have multiple extruders or print heads, allowing for multi-material or multi-colour printing.

6. Bed Heating: Many 3D printers have heated build platforms that help with adhesion and prevent warping of printed parts, especially for materials like ABS.

7. Connectivity: Some 3D printers offer WiFi, USB, or SD card connectivity options, allowing users to send print jobs remotely.

8. Software Compatibility: 3D printers often require specific slicing software to convert 3D models into printable instructions (G-code).

9. Calibration: Proper calibration is crucial for accurate and successful prints. Many 3D printers offer automatic calibration features.

10. Applications: 3D printers are used in various industries, including manufacturing, aerospace, healthcare, automotive, architecture, education, and more.

11. Cost and Budget: 3D printers vary widely in cost, from affordable desktop models to high-end industrial machines.

12. Ease of Use: Some 3D printers have user-friendly interfaces designed for beginners, while others offer advanced features for experienced users.

3D printing machines have transformed how products are designed, prototyped, and manufactured. They enable rapid iteration, reduce lead times, and offer opportunities for customization and complex geometries that traditional manufacturing methods often struggle with. As technology advances, 3D printers evolve, making them more accessible, efficient, and capable of producing high-quality objects for various applications.

Hardware description

The sensors were integrated and mounted with the PCB board, as shown in Figure 4. They were explicitly designed for aqua buoys and interfaced with the battery and solar units. Aqua BuoySis is a real-time prototype system for monitoring water quality in aquatic settings using sensors for temperature, turbidity, and pH. In ponds, lakes, or brackish waterways, it supports the ecosystem's stability and the water's health, facilitating analysis and decision-making. The prototype "Aqua BuoySis" for monitoring brackish water probably includes salinity, temperature, pH, and turbidity. These sensors help with ecosystem management and aquaculture efficiency by offering a comprehensive picture of the water quality in brackish settings. Challenges for the Aqua BuoySis system include sensor calibration, power consumption management, and network connectivity assurance. Some solutions include using energy-efficient protocols like MQTT, optimizing data sampling rates, and using edge computing to lower latency and transmission burden. Sensor calibration, data validation procedures, and sensor reading redundancy are useful strategies to assure the Aqua BuoySis prototype's accuracy and dependability throughout various climatic circumstances. These real-time IoT-based monitoring systems can offer more frequent and instantaneous data updates than traditional monitoring systems, which improves the system's overall responsiveness and efficiency.

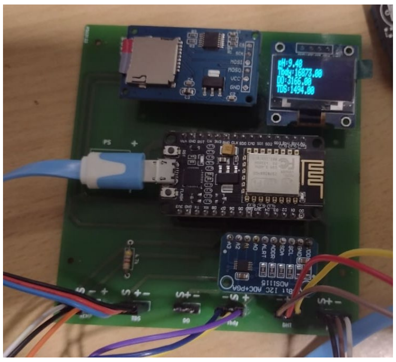

Figure 4. PCB board design and testing

Figures 5 and 6 showcase the Aqua buoys designed and ready for deployment. With the help of an LSTM model, a real-time data streaming architecture can handle live data quickly and effectively. It uses platforms such as Kafka, Apache Flink, and Spark Streaming for data intake, preprocessing, and model serving. The model handles variable data quantities, continuously monitoring performance and security. Because of their capacity to manage long-term dependencies, complicated non-linear patterns, and noise filtering—features that make them perfect for long-term prediction and spotting subtle changes—LSTM networks are the favoured choice for analyzing temporal data from water quality sensors. For the analysis of sensor data for water quality, the LSTM network structure comprises 1-2 layers with 50-200 units, loss functions such as MSE and cross-entropy, and activation functions such as sigmoid. Practical training is achieved with the Adam optimizer, which uses dropout regularisation to avoid overfitting. The range of batch sizes is 32–128. Reducing overfitting, enhancing performance, and finding pertinent variables from water quality sensor data are the steps in the feature selection process for an LSTM model. Data comprehension, domain expertise, correlation analysis, feature engineering, significance techniques, dimensionality reduction, cross-validation, regularisation, and iterative refinement are essential processes.

Figure 5. a) Aqua Buoys ready for deployment b) Testing in a small tub

Figure 6. Site Installation in Mamallapuram and Muttukadu Cultures

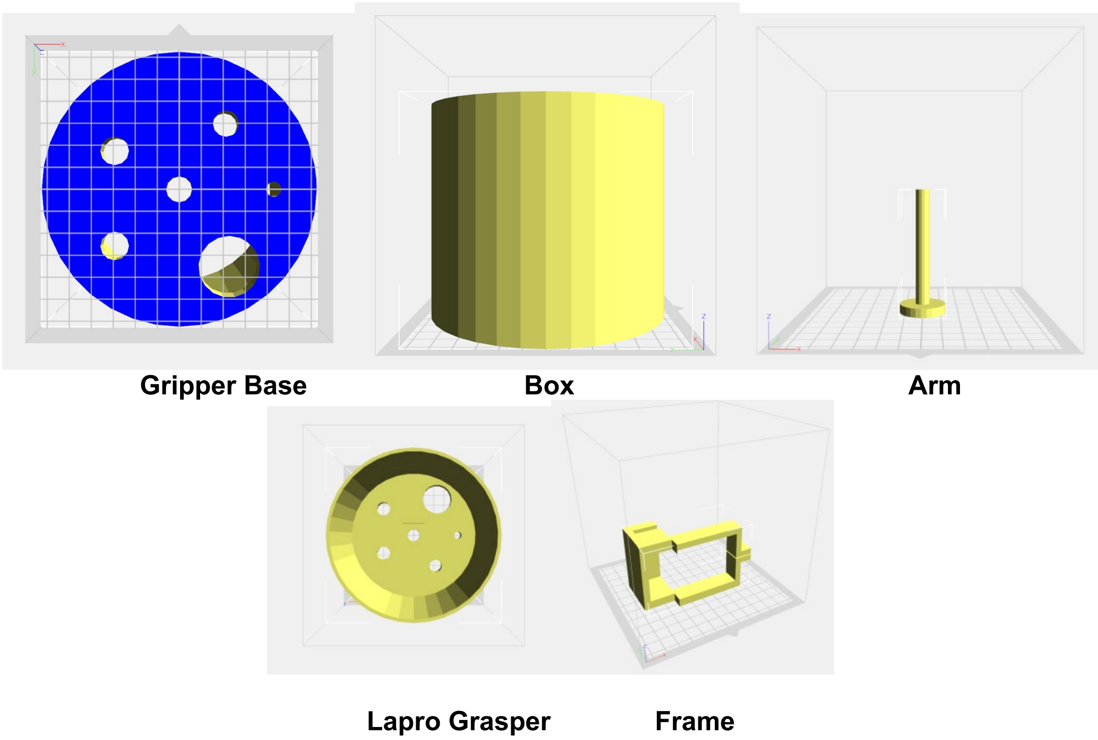

Figure 7. Design models from the CAD

Figure 7 shows 3D printing. Supplementary files that facilitate digital replication of the devices are encouraged, such as STL files for 3D printing components. We recommend uploading CAD files to the [NIH 3D Print Exchange] as Custom Labware and then entering the link here, as shown in Figures 8 and 9.

Figure 8. 3D printing of the component

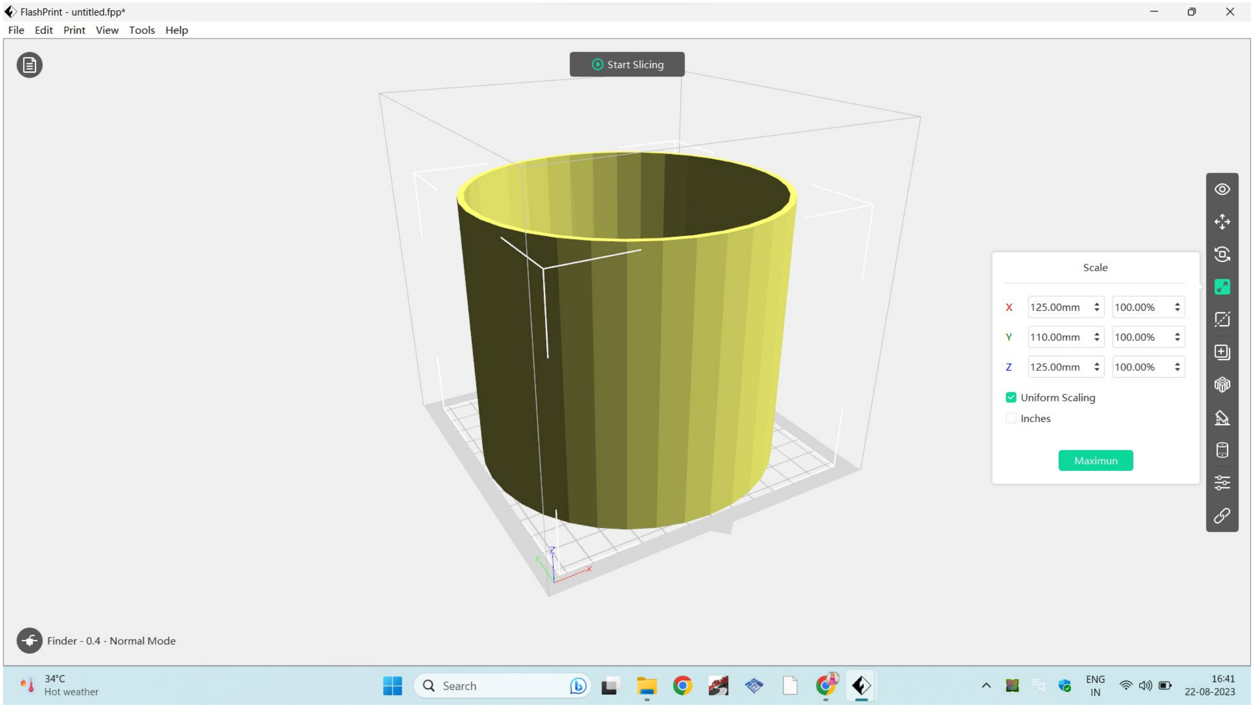

Figure 9. 3D component's surface Dimensions Straight view

The elaborate specifications of the 3D component are given as follows: L-Bend and T-joints are 25mm and 25mm long, and the union is 3/4th of the base. The component is placed on normal water tubes as the base and ventilated by a Pipe hub, as shown in Figure 10 below, with a diameter of 150mm. The whole setup is protected by means of a cap with a diameter of 160mm.

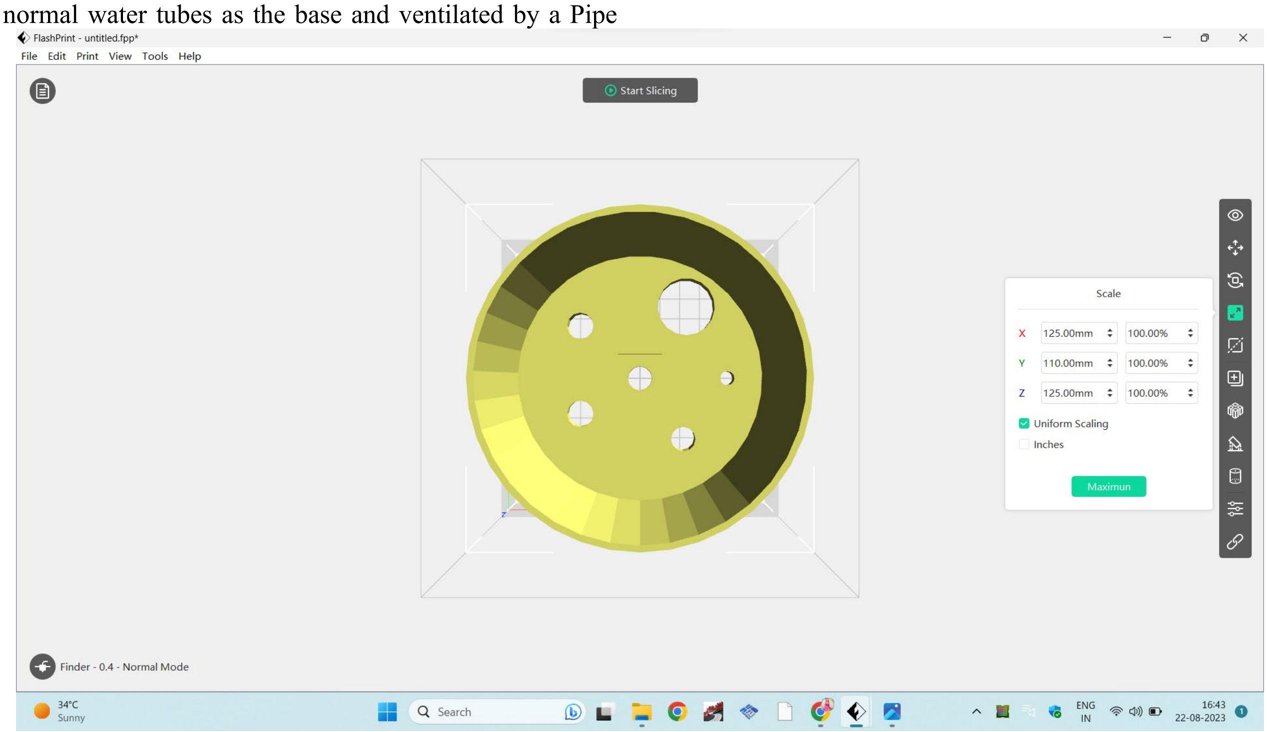

Figure 10. 3D component's surface Dimensions interior view.

Electronics: PCB layouts and other electronics design files can be uploaded to the Open Hardware Repository or other repositories or as supplementary materials. Shown in Figure 11.

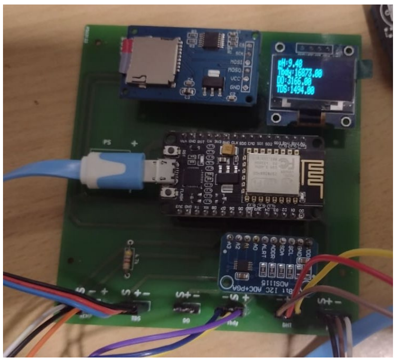

Figure 11. PCB board design and testing

Software and firmware: The repository should include all software files used in the design and operation of the hardware. Describe the software and firmware and use extensive comments in the code.
The PCD board is 10* 9 mm in length and is placed onto the hollow cylinder box, which is 360 mm in height.

1. Design files summary

Complete a separate row for each design file associated with your hardware (including the primary design files). Any empty rows should be deleted.

Design file name	File type	Open-source license	Location of the file
Shaft.gx	gx	CAD Open Source	https://drive.google.com/file/d/1mOw1lDta8Qwz-RKY6ewQCzBcP2NSbh_W/view?usp=drive_link
Solid.gx	gx	CAD Open Source	https://drive.google.com/file/d/1snma2ZDBhc7hVSDHrBS5VrQPuxUvUwh1/view?usp=drive_link
Servomotor.STL	STL	CAD Open Source	https://drive.google.com/file/d/1jqGkm3eRtb0SzBfM3OgVE0cu41mCi8GC/view?usp=drive_link
Brush.STL	STL	CAD Open Source	https://drive.google.com/file/d/1G5Nn8hTHGDLvoOx_440leWebn43A0MtZ/view?usp=drive_link
Housing.STL	STL	CAD Open Source	https://drive.google.com/file/d/1gm8EyG4n02_9E2lQUi7JZVWd_lNZoUfn/view?usp=drive_link
Shaft.STL	STL	CAD Open Source	https://drive.google.com/file/d/10g6Xn_pTCMoxBlU1eVS1ivu3YxWJtllc/view?usp=drive_link

Table 1.

Shown in Table 1. For each design file listed in the summary table above, include a short description of the file below (just one or two sentences per design file).

Bill of materials

Suppose your bill of materials is long or complex. In that case, you can upload the details in an editable spreadsheet, e.g., ODS file type, Excel spreadsheet or PDF file, to an open-access online location, such as the Open Science Framework repository. Include the link here. Alternatively, the bill of materials can be submitted alongside your manuscript as supplementary material.

Bill of materials summary

Complete a separate row for each component of your hardware – all components associated with a cost should be listed, and any empty rows should be deleted.

Designator	Component	Number	Cost per unit - currency	Total cost - currency	Source of materials	Material type
ESP8266Node MCU CP2102 Board(MICRO CONTROLLER)	ESP8266Node MCU CP2102 Board	1	281	281	https://robu.in/product/nodemcu-cp2102-board/	(MICRO CONTROLLER)
0.96-inch Yellow-Blue OLED Display Module	OLED display	1	215	215	https://robu.in/product/0-96-inch-yellow-yellow-blue-oled-lcd-led-display-module/	sensor
Micro SD Card Reader Module	SD card reader sensor	1	39	39	https://robu.in/product/micro-sd-card-module/	sensor
ADS1115 16-Bit ADC- 4 Channel with Programmable Gain Amplifier	Analogue to digital converter	1	870	870	https://robu.in/product/ads1115-16-bit-adc-4-channel-programmable-gain-amplifier	sensor
20CM DuPont Wire Color Jumper Cable 2.54mm 1P-1P Female to Female 40PCS	wire	1	39	39	https://robu.in/product/20cm-dupont-wire-color-jumper-cable-2-54mm-1p-1p-female-female-40pcs/	polymer
Turbidity Sensor with Module	Turbidity Sensor	1	589	589	https://robu.in/product/turbidity-sensor-module/	sensor
DFRobot Gravity Lab Grade Analog Dissolved Oxygen Sensor / Meter Kit For Arduino	DO Sensor	1	17,365	17,365	https://robu.in/product/dfrobot-gravity-lab-grade-analog-dissolved-oxygen-sensor-meter-kit-for-arduino/	sensor
SeeedStudio Grove PH Sensor Kit (E201CBlue)	Ph sensor	1	1649	1649	https://robu.in/product/grove-ph-sensor-kit-e-201c-blue/	Sensor

4.7K ohm Resistor - 1/4 Watt - 5 Pieces Pack	Resistor	1	2	2	https://www.electronicscomp.com/4.7k-ohm-resistance-1-4-watt?gclid=Cj0KCQjwldKmBhCCARIsAP-0rfx_oo4Vax4rcvGu15AOh-POSqc0rxr3RCcNE46T7OO2fCtJ_-PRFnsaAh0xEALw_wcB	Metal
DS18B20 Waterproof Temperature Sensor Probe	Water Temperature sensor	1	64	64	https://www.electronicscomp.com/ds18b20-water-proof-temperature-sensor-probe-india?gclid=Cj0KCQjwldKmBhCCARIsAP-0rfy9a_SGdWK3XgZpnfathNU4WW6g4DbJufl6mn964ra-gwiFGyG1QAQaAvNHEALw_wcB	sensor
Water Quality Sensor TDS Water Quality Testing Probe	Water quality sensor	1	306	306	https://robu.in/product/water-quality-sensor-tds-water-quality-testing-probe/	sensor
DURABLE uPVC Pipe 25mm 10KGF Pressure Class 5, 10KG/SQCM	pipe	1	217	217	https://www.indiamart.com/proddetail/upvc-pipe-25mm-10kgf-pressure-class-5-23927742748.html	polymer
Luminous 330W 24V Polycrystalline Solar Panel, LUM 24330	Solar panel	1	11m,445	11,445	https://www.moglix.com/luminous-330w-24v-polycrystalline-solar-pv-module-panel-with-25-years-warranty-lum-24330/mp/msn2km1x430x9v	Semiconductor
WOL 3D Flashforge PLA 3D Printer Filament - 1.75mm, Red	3d filament	1	1299	1299	https://www.amazon.in/WOL-3D-Flashforge-Printer-Filament/dp/B00J8WB4EM	Thermoplastic polyester
Red And Black Flashforge Finder 3D Printer, Flash Print, Model Name/Number: 700355100638	3D printing Machine	1	40,000	40,000	https://www.indiamart.com/proddetail/flashforge-finder-3d-printing-machine-13478469755.html?pos=2	3D Printing Machine

Table 2.

As shown in Table 2, you can use this space to provide additional descriptions of the materials used.

Build instructions

The farmers may obtain real-time pond information because the entire system is connected to the Internet. A Reconfigurable PCB board was created to house all the necessary OLED displays, memory cards, and water-quality sensors. The board has a Node MCU microcontroller with several water quality sensors, including a DHT 11 sensor, a pH sensor, a TDS sensor, a temperature sensor, a humidity sensor, a DO sensor, an SD card for storing sensor data, and an OLED for showing farmers the sensor data. This system now has a little ML (Machine Learning) component that can forecast sensor values in the future and alert the farmer. Real-time data processing at the edge is made possible by TinyML, or "Tiny Machine Learning," which is a technique that uses microcontrollers and other small, resource-constrained devices to execute machine learning models. This eliminates the need for powerful computers or cloud services. The main obstacles to using machine learning in water quality systems are the requirement for big datasets for precise predictions, fluctuation in water conditions, and data quality. Furthermore, combining predictive models with real-time data may require a lot of processing power and knowledge. When the board is turned on, it connects to the Google Sheet. The dashboard updates the Google Sheet with data from the live sensor, as shown in Figure 12.

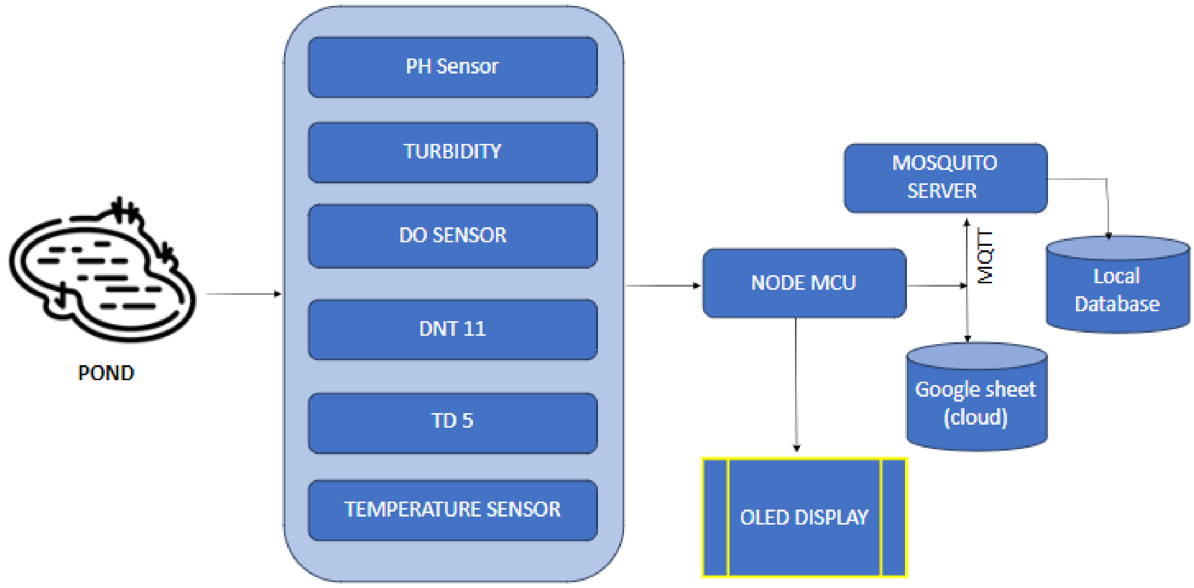

Figure 12. Architecture of TinyML Processing Framework

The spreadsheet is updated every second. Users can view the sensor data in the Google sheet by opening it. Additionally, they receive notification messages if the data crosses the threshold value. The turbidity sensor value may change if there are more sediment particles in the water, which causes warnings to be sent to the user in the form of alert messages. The farmer should then change the water, which is a good agricultural practice. The user dashboard was created with easy monitoring in mind.

Operation instructions

The first task is to discover sliding pH values from the datasets holding sensor dates; the second is to forecast values using machine learning. The algorithm's task is to get the predicted values and plot them in a live graph with Python. The kit was designed with a PCB board that contains NodeMCU, OLED Display, and Sensors like Ph, turbidity, DO, DHT 11, Temperature, and solar power supply. Sensors are immersed into the pond to get the water quality information. In the meantime, acquired data is displayed in the OLED display. The SD card stores the sensor data. If an internet service is lost, then live data notification is not possible at that time. This memory card acts as a backup data collection. OLED displays live sensor data that could be utilized to find the current pond condition for the healthy growth of shrimp. NodeMCU uses the I2C protocol for communication. (See Figure 13.)

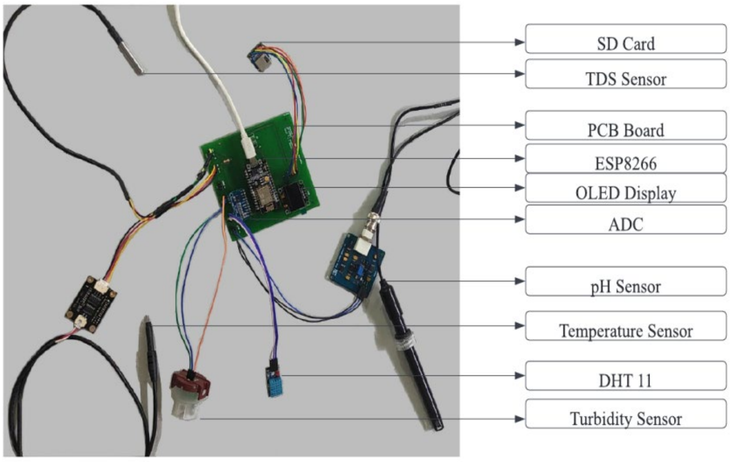

Figure 13. PCB Board Design for Brackish Water Aquaculture

Validation and characterization

The essential step is to get the required data from the Google sheet to train those values using the Recursive Neural Network and LSTM principle. The vital concept applied here is the Markov process. The Markov process runs on the principle that future behaviour depends only on the current state. It is self-reliant of the past state. It is a random process that works only when grounded in the current state. They are designed to avoid long-term related problems. All RNN networks have a chain of repeating modules of the neural network. Also, LSTMs have a chain of repeating modules, but the chain of LSTM structure is slightly different from that of the common RNN. Here, 1000 pH values are obtained, 67% of which equals 670 values, are used for the training dataset, and the remaining 33%, which equals 330 values, are taken for the test dataset. In Fig. 2, the training set contains 670 values marked in orange; Fig. 3 represents the testing test marked in red. Each value is applied to a neural network model, which predicts the next value from the current value, the Markov process.

From the acquired dataset, a massive amount of “pH" values of water is updated repeatedly at regular intervals. The aim is to monitor whether the pH of the water is at a constant level or not. It is attained by applying the LSTM RNN model and the “Train Predict Plot" graph for the Entire dataset in blue and the training data in orange. Consider 1000 pH values, and the graph is represented and grounded on it. So, the training dataset contains 670 values, and the epoch is set for 5. epoch indicates the number of passes the entire training dataset has to complete. The predicted values are noted as red here, nearly equal to the corresponding dataset values, which are blue. A fundamental neural network concept is to repeat the process to forecast the following value, and the output rate will be within 0 – 1. To maintain and adapt the model to learn the given condition, 67 is considered. During training, the validation and training error of the model for every epoch is calculated. If the training error drops, the model will work impeccably and accurately.

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Conflict of interest

There is no conflict of interest among the authors.

Data Availability

All data generated or analyzed during this study are included in the manuscript.

Author’s contributions

V. Sowmiya and G. R. Kanagachidambaresan contributed to this study's design and methodology, assessing the outcomes and writing the manuscript.

References

[1] Nawandar, N. K., & Satpute, V. R. (2019). IoT based low cost and intelligent module for smart irrigation system. Computers and Electronics in Agriculture, 162, 979-990.

[2] Yanes, A. R., Martinez, P., & Ahmad, R. (2020). Towards automated aquaponics: A review on monitoring, IoT, and smart systems. Journal of Cleaner Production, 263, 121571.

[3] Sharma, B. B., & Kumar, N. (2021). IoT-based intelligent irrigation system for paddy crop using an internet-controlled water pump. International Journal of Agricultural and Environmental Information Systems (IJAEIS), 12(1), 21-36.

[4] Mahmud, H., Rahaman, M. A., Hazra, S., & Ahmed, S. (2023). IoT based integrated system to monitor the ideal environment for shrimp cultivation with Android mobile application. European Journal of Information Technologies and Computer Science, 3(1), 22-27.

[5] Poovendran, A. (2024), a systematic literature review of the elliptic curve cryptography (ECC) algorithm for encrypting data sharing in cloud computing, International Journal of Engineering & Science Research, IJESR/April. 2024/ Vol-14/Issue-2/1717-1736, ISSN 2277-2685.

[6] Sri, H.G. (2021). Integrating HMI display module into passive IoT optical fiber sensor network for water level monitoring and feature extraction. World Journal of Advanced Engineering Technology and Sciences, 02(01), 132–139.

[7] Maulana, F., Fakhrurroja, H., & Lubis, M. (2022, November). Smart dashboard design and water sensor integration architecture by applying Internet of Things (IoT) technology using data analysis and prediction methods. In 2022 International Conference Advancement in Data Science, E-learning and Information Systems (ICADEIS) (pp. 1-7). IEEE.

[8] Bersani, C., Ruggiero, C., Sacile, R., Soussi, A., & Zero, E. (2022). Internet of Things approaches for monitoring and control of smart greenhouses in Industry 4.0. Energies, 15(10), 3834.

[9] Ramakrishnam Raju, S. V. S., Dappuri, B., Ravi Kiran Varma, P., Yachamaneni, M., Verghese, D. M. G., & Mishra, M. K. (2022). Design and implementation of smart hydroponics farming using IoT-based AI controller with mobile application system. Journal of Nanomaterials, 2022, 1-12.

[10] Pejić Bach, M., Topalović, A., Krstić, Ž., & Ivec, A. (2023). Predictive maintenance in Industry 4.0 for the SMEs: A decision support system case study using open-source software. Designs, 7(4), 98.

[11] Khurshid, H., Mumtaz, R., Alvi, N., Haque, A., Mumtaz, S., Shafait, F., Ahmed, S., Malik, M. I., & Dengel, A. (2022). Bacterial prediction using Internet of Things (IoT) and machine learning. Environmental Monitoring and Assessment, 194(2), 133.

[12] Pejić Bach, M., Topalović, A., Krstić, Ž., & Ivec, A. (2023). Predictive maintenance in Industry 4.0 for the SMEs: A decision support system case study using open-source software. Designs, 7(4), 98.

[13] Mahmud, H., Rahaman, M. A., Hazra, S., & Ahmed, S. (2023). IoT based integrated system to monitor the ideal environment for shrimp cultivation with Android mobile application. European Journal of Information Technologies and Computer Science, 3(1), 22-27.

[14] Saravanan, S., Guntuku, N., Akshaya, C., Prakash, B., Kumar, D. G., & Goud, P. C. D. (2023, July). A novel sensor-based water quality monitoring system using Internet of Things (IoT). In 2023 4th International Conference on Electronics and Sustainable Communication Systems (ICESC) (pp. 355-360). IEEE.

[15] Butinyac, M. G., Montaño, V. A., Downes, J., Ruane, N. M., Ryder, E., Egan, F., Staessen, T., Paull, B., & Murray, E. (2023). Continuous nitrite and nitrate monitoring of recirculating aquaculture systems using a deployable ion chromatography-based analyzer. Aquaculture International, 1-14.

[16] Dipali, D., Subramanian, T., & Kumaran, G. S. A smart oyster mushroom cultivation using automatic fuzzy logic controller.

[17] Mantravadi, S., Srai, J. S., & Møller, C. (2023). Application of MES/MOM for Industry 4.0 supply chains: A cross-case analysis. Computers in Industry, 148, 103907.

[18] de Camargo, E. T., Spanhol, F. A., Slongo, J. S., da Silva, M. V. R., Pazinato, J., de Lima Lobo, A. V., Coutinho, F. R., Pfrimer, F. W. D., Lindino, C. A., Oyamada, M. S., & Martins, L. D. (2023). Low-cost water quality sensors for IoT: A systematic review. Sensors, 23(9), 4424.

[19] Hassoun, A., Cropotova, J., Trollman, H., Jagtap, S., Garcia-Garcia, G., Parra-López, C., Nirmal, N., Özogul, F., Bhat, Z., Aït-Kaddour, A., & Bono, G. (2023). Use of Industry 4.0 technologies to reduce and valorize seafood waste and by-products: A narrative review on current knowledge. Current Research in Food Science, 100505.

[20] Fulton, S. G., Stegen, J. C., Kaufman, M. H., Dowd, J., & Thompson, A. (2023). Laboratory evaluation of open source and commercial electrical conductivity sensor precision and accuracy: How do they compare? PLOS ONE, 18(5), e0285092.

[21] Cafuta, D., Dodig, I., Cesar, I., & Kramberger, T. (2021). Developing a modern greenhouse scientific research facility—a case study. Sensors, 21(8), 2575.

[22] Murillo, L. F. R., & Wenzel, T. (2017). Welcome to the journal of open hardware. Journal of Open Hardware, 1(1).