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ORIGINAL CONTRIBUTION

DESIGN AND PROTOTYPE IMPLEMENTATION OF AN IoT ENABLED SMART POTABLE WATER MONITORING SYSTEM

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ABSTRACT

Water quality monitoring is essential for drinking-water safety and environmental sustainability. Conventional grab sampling followed by laboratory analysis is accurate but time-consuming, costly, and unable to provide immediate alerts. This paper presents the design, implementation, and validation of a low cost Internet of Things (IoT)-enabled smart potable water monitoring system based on the ESP32 microcontroller. The prototype integrates pH, Total Dissolved Solids (TDS), turbidity, and DS18B20 temperature sensing. Analog signals are sampled repeatedly, averaged, converted into engineering units through calibration models, and processed locally using threshold-based decision logic. An I2C SSD1306 OLED and RGB LED provide local feedback, while Wi-Fi and Blynk support remote monitoring. Reference-condition calibration produced reported errors of 0.4% for temperature, 1.4% for pH, 1.7% for TDS, and 4.0% for turbidity. Tests on diverse water samples demonstrated useful real-time screening capability. Analysis of the supplied firmware also identified a safety gap: the original NEUTRAL branch did not constrain pH, allowing some strongly acidic or alkaline samples to be classified as neutral. A corrected multi-parameter decision rule is therefore proposed. The prototype demonstrates the feasibility of low-cost edge-based water-quality screening while highlighting the need for improved ADC accuracy, periodic sensor calibration, and rugged field deployment.

KEYWORDS: IoT, ESP32, water quality monitoring, pH, TDS, turbidity, DS18B20, Blynk, edge computing, sensor calibration.

1. INTRODUCTION

Potable water resources are increasingly affected by population growth, urbanization, agricultural runoff, untreated wastewater, and industrial discharge. The supplied project report emphasizes continuous monitoring because transient contamination events can be missed by manual grab-sampling. The principal parameters considered are pH, TDS, and turbidity, supported by temperature measurement for compensation and validation. The report identifies three major engineering challenges for low-cost monitoring nodes: high-impedance analog signals are vulnerable to interference, the ESP32 internal ADC exhibits non-linearity, and pH/EC related measurements are temperature dependent. The project therefore combines regulated power, decoupling, repeated sampling, calibration, compensation, local indication, and wireless telemetry. The main objectives are to develop a

multi-sensor acquisition system; stabilize analog inputs using an LM7805 regulator and decoupling; implement calibration and temperature-related processing; provide OLED/RGB status indication; and support Wi-Fi/cloud telemetry.

2. THEORY AND DESIGN BASIS

The proposed architecture follows the conventional IoT chain of sensing, embedded processing, local visualization, and remote telemetry. The project adopts a nominal pH potability range of 6.50–8.50, while its broader report discusses TDS and turbidity as complementary indicators. The report's introductory standards table lists TDS below 300 ppm as an excellent level and below 500 ppm as a secondary limit, with turbidity below 1 NTU as strict and below 5 NTU as acceptable. The pH electrode produces an electrochemical potential related to hydrogen-ion activity. The report

describes a linear calibration model, $pH = \text{Slope} \times V_{pH} + \text{Offset}$, with temperature-dependent Nernstian sensitivity. TDS is derived from electrical conductivity, where dissolved ions increase conductivity. Turbidity is obtained optically from light scattering/attenuation caused by suspended particles.

3. COMPONENTS USED

3.1. ESP32 Microcontroller

The ESP32 is the central processing unit. The project uses its ADC inputs for pH, TDS and turbidity, its 1-Wire interface for the DS18B20, I2C for the OLED, PWM-capable GPIOs for the RGB LED, and built-in Wi-Fi for telemetry. The architecture therefore minimizes external processing hardware and allows calibration and classification to occur at the edge.

3.2. pH Sensor

The pH sensing assembly uses a glass-electrode interface and conditioning board. Standard buffer solutions at pH 4.0, 7.0, and 10.0 are used for calibration. The supplied implementation reports a fitted slope of -5.70 and offset of 21.34 .

3.3. TDS Sensor

The TDS sensor operates using the electrical-conductivity principle. Dissolved salts and minerals provide ions that increase conductivity. The sensor output is mapped to TDS in ppm using a conversion factor; the implementation uses an approximate 500 ppm/V scaling.

3.4. Turbidity Sensor

The TS-300/380 turbidity sensor contains an infrared LED and phototransistor. Clear water transmits more light, whereas suspended particles scatter or absorb light and reduce the detected intensity. The resulting electrical signal is converted to NTU.

3.5. DS18B20 Temperature Sensor

The DS18B20 provides digital temperature through a 1-Wire connection. In the supplied project, the device is validated against a reference thermometer and is also used as a useful variable for temperature-dependent processing.

3.6. SSD1306 OLED and RGB LED

The SSD1306 OLED provides local numerical display. A common-cathode RGB LED indicates SAFE, NEUTRAL, and UNSAFE states using

green, blue, and red, respectively. The report specifies GPIO25, GPIO26 and GPIO27 for the three LED channels.

3.7. Power Regulation and Supporting Hardware

An LM7805 linear regulator establishes a regulated +5 V rail. A $1.00 \mu F$ decoupling capacitor is connected at the regulator output to suppress line oscillations. The ESP32 VIN receives the regulated rail, while its +3.3 V output supplies low-draw digital modules.

Table 1: Hardware Connection

COMPONENT	ESP32 CONNECTION	SIGNAL / PURPOSE
LM7805 OUT	VIN	+5V regulated supply
pH sensor	GPIO34	Analog input
TDS sensor board	GPIO33	Analog input
Turbidity sensor board	GPIO32	Analog input
DS18B20	GPIO4	1-Wire; 4.7 k Ω pull-up
SSD1306 OLED	GPIO21/22	I2C SDA/SCL
RGB LED	GPIO25/26/27	PWM status outputs

The complete pin-connection table in the supplied report gives the same GPIO allocation and identifies the signal type of each connection.

4. SYSTEM IMPLEMENTATION

4.1. Hardware Architecture

The physical implementation connects the water sensors to the ESP32, with the analog sensors routed to GPIO32–34 and the DS18B20 connected to GPIO4. The OLED uses I2C, and the RGB LED provides local status. The report specifies common grounding and isolation of analog connections, with the OLED selected for its low GPIO requirement.

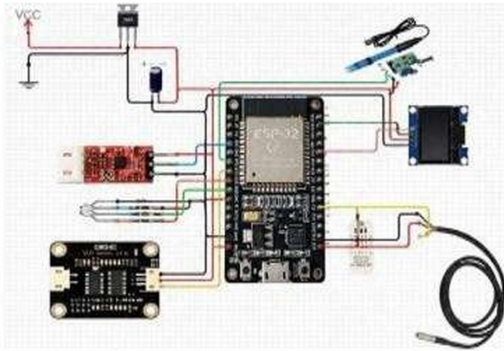


Figure 1: Circuit diagram and physical interconnections of the prototype.

4.2. Data Acquisition

Each firmware loop executes approximately every three seconds. The DS18B20 is requested first, followed by repeated analog sampling. The implementation takes 40 samples for turbidity, 30 for TDS, and 15 for pH. The average ADC reading is converted to voltage using a 3.3 V reference and 12-bit resolution.

For averaged ADC code A, the report uses $V = A(3.3/4095)$. The implementation then calculates turbidity as $NTU = (3.3 - V_{turb}) \times 1000$ with a 0–3000 NTU clamp, TDS as $TDS(ppm) = VTDS \times 500$, and pH using the calibrated linear slope and offset.

4.3. Calibration Procedure

Temperature was validated at 0 °C, 25 °C and 50 °C, with an offset below 0.5 °C. The pH sensor was calibrated with pH 4.0, 7.0 and 10.0 buffers. TDS was calibrated using KCl solutions, while turbidity used reference solutions including 0 NTU distilled water and a 200 NTU suspension.

Table 2: CALIBRATION RESULT

PARAMETER	REFERENCE	SYSTEM	ERROR
Temperature	25.0 °C	25.1 °C	0.4%
pH	7.00	7.10	1.4%
TDS	300 ppm	305 ppm	1.7%
Turbidity	5.0 NTU	5.2 NTU	4.0%

The supplied report notes that periodic recalibration is recommended to compensate for sensor drift.

4.4. Remote Monitoring

Blynk IoT Cloud is used to visualize water-quality parameters remotely. The dashboard displays TDS, temperature, pH and turbidity

through gauges/value widgets, enabling the operator to observe the prototype through an internet connection.

5. FIRMWARE AND DECISION LOGIC

The firmware processes the sensor signals, displays the numerical results on the OLED, sets the RGB status, and can transmit values wirelessly. The OLED screen presents temperature, pH, TDS, turbidity and the overall status, followed by a three-second delay before the next acquisition cycle.

The original classification logic is: SAFE when pH is 6.5–8.5, TDS <300 ppm and turbidity <50 NTU; otherwise NEUTRAL when TDS <600 ppm and turbidity <200 NTU; otherwise UNSAFE.

5.1. Identified Safety Gap

The supplied report performs a critical analysis of this logic. The NEUTRAL branch checks only TDS and turbidity and does not check pH. Consequently, a sample with extreme acidity or alkalinity can fail the SAFE condition because of pH, but still satisfy the relaxed TDS/turbidity limits and be labelled NEUTRAL. The report demonstrates this with acidic rainwater and alkaline algal-bloom water.

5.2. Corrected Multi-Tier Decision Architecture

The report proposes explicitly constraining pH in the NEUTRAL state: SAFE = $[(6.5 \leq pH \leq 8.5) \text{ AND } (TDS < 300) \text{ AND } (NTU < 50)]$; NEUTRAL = $[(6.0 \leq pH \leq 9.0) \text{ AND } (TDS < 600) \text{ AND } (NTU < 200)]$; otherwise UNSAFE.

This ensures that pH below 6.0 or above 9.0 is immediately flagged UNSAFE regardless of TDS and turbidity.

5.3. Processing Flow

The complete embedded processing sequence can therefore be represented as: initialize sensors and communications → acquire temperature and repeated ADC samples → average ADC values → convert voltages to pH/TDS/NTU → apply decision thresholds → update OLED and RGB LED → publish data to Blynk → repeat after approximately three seconds.

5.4. Prototype Integration

The finished prototype places the ESP32, regulator, display, sensor boards and wiring

inside a compact enclosure. The report concludes that regulated power and decoupling improve stability during active Wi-Fi operation, while calibration and software processing mitigate measurement drift and ADC effects.

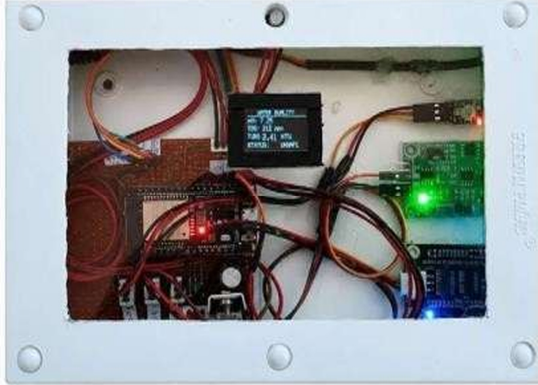


Figure 2: Finished prototype assembled inside the enclosure.

6. RESULTS AND DISCUSSION

The fully assembled prototype was tested using a range of water samples. The edge-processing layer analysed each sample, categorized the safety status, and updated the visual indicators. The expanded dataset in the supplied report is summarized below.

Table 3: Water Quality Test Results

SAMPLE	TEMP (°C)	pH	TDS	NTU	STATUS
Distilled	24.2	6.95	4	0.0	SAFE
Municipal tap	24.8	7.32	152	0.8	SAFE
RO purified	24.5	6.65	18	0.1	SAFE
Bottled mineral	22.5	7.20	210	0.3	SAFE
Chlorinated pool	26.1	7.40	280	1.5	SAFE
High-mineral well	18.2	6.42	420	8.5	NEUTRAL
Brackish estuary	20.8	7.85	550	45.0	NEUTRAL
Natural rainwater	16.5	6.20	25	1.2	NEUTRAL
Acid rainwater	15.4	4.50	85	5.0	NEUTRAL
Algal bloom lake	23.4	8.70	180	75.0	NEUTRAL
Agricultural runoff	21.5	5.65	618	38.4	UNSAFE
Industrial discharge	27.9	9.42	1115	124.0	UNSAFE
Sea-water intrusion	19.5	8.10	1000	12.0	UNSAFE
Domestic sewage	19.5	6.80	750	320.0	UNSAFE

The largest reported reference-condition error is 4.0% for turbidity. The pH and TDS errors are 1.4% and 1.7%, respectively, while temperature error is 0.4%. These values indicate useful prototype-level screening performance but do not constitute certified laboratory measurement.

6.1. Safe and Neutral Samples

Distilled and RO water show very low dissolved solids and negligible turbidity and are classified SAFE. Municipal tap, bottled mineral and chlorinated pool water also remain inside the

project's safe ranges. High-mineral well and brackish estuary water exceed the ideal 300 ppm TDS level but remain below the original neutral thresholds and are therefore classified NEUTRAL.

6.2. Firmware Vulnerability Demonstration

Natural rainwater and acid rainwater have low particulate loading but acidic pH values. Because the original NEUTRAL branch ignores pH, both can be labelled NEUTRAL rather than UNSAFE. Algal bloom lake water at pH 8.70 is similarly

reported NEUTRAL because its TDS and turbidity remain below the relaxed neutral limits.

6.3. Highly Contaminated Water

Agricultural runoff, industrial discharge, sea-water intrusion and domestic sewage fail the relevant thresholds and are classified UNSAFE. The report notes that seawater intrusion reaches the low-cost TDS board's 1000 ppm scaling limit, while domestic sewage exhibits very high turbidity.

6.4. Calibration Accuracy and Discussion

The results demonstrate the value of combining several independent indicators rather than relying on a single sensor. At the same time, the safety logic must treat extreme chemical conditions as dominant faults. The report's corrected logic is therefore a significant improvement over the original implementation because it prevents the blue/neutral state from masking extreme pH conditions.

7. CONCLUSION AND FUTURE WORK

This research demonstrates the design, physical implementation, and validation of an IoT-based edge-computing platform for real-time water-quality screening. By integrating pH, TDS, turbidity and temperature sensors with an ESP32, the prototype acquires, filters, calibrates, classifies, displays and transmits water-quality information. The LM7805 regulator and decoupling support stable sensor power, while repeated ADC sampling and calibration improve practical measurement stability.

The prototype successfully differentiates several water conditions and provides both local and remote feedback. However, the supplied report identifies important limitations: internal ESP32 ADC non-linearity, firmware classification gaps, and electrochemical drift/fouling of submerged pH and TDS probes.

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The most important implementation improvement is the corrected decision logic, which requires pH to remain within a defined range even for the NEUTRAL state. This prevents highly acidic or alkaline samples from being hidden by acceptable TDS and turbidity values.

Future work proposed in the source report includes replacing the ESP32 internal ADC with a 16-bit ADS1115 external ADC, correcting the nested decision logic in production firmware, migrating telemetry to LoRaWAN or NB-IoT for remote low-power operation, and using an IP68-rated enclosure for field deployment.

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