Embedded Closed-Loop Water Quality Control System for Domestic RO Units Using pH and TDS Monitoring

INTRODUCTION

Domestic Reverse Osmosis (RO) systems are widely used in households to improve the quality of drinking water. However, filtration efficiency can decrease over time due to filter wear, membrane fouling, and changes in the composition of source water. When this happens, the water produced may contain undesirable Total Dissolved Solids (TDS) levels or improper pH values.

Traditional domestic RO units rely on passive filtration, where water passes through filters regardless of its condition. Monitoring is typically done using handheld meters, which require manual checking and may allow unsafe water conditions to go unnoticed.

This project presents a closed-loop embedded water quality control system that continuously monitors water quality using pH and TDS sensors. When measured values fall outside predefined safe thresholds, the system automatically activates appropriate filtration processes such as reverse osmosis or alkaline filtration. The treated water is then recirculated back to the monitoring chamber for reevaluation until acceptable levels are achieved.

This approach enables automated monitoring, intelligent filtration control, and real-time feedback, improving the reliability of household water purification systems.

1.1. Background of the Study

Water quality plays an essential role in ensuring safe drinking water. Two common indicators used to evaluate water condition are Total Dissolved Solids (TDS) and pH level. TDS represents the concentration of dissolved minerals and salts, while pH indicates whether water is acidic or alkaline.

Domestic RO systems are designed to reduce dissolved solids and improve water quality. However, the efficiency of filtration components gradually decreases during long-term use. Without continuous monitoring, users may not realize that the system is no longer operating effectively.

Manual water testing methods provide accurate measurements but require human intervention and are not designed for continuous monitoring. Advances in embedded systems and sensor technology now allow the development of automated monitoring systems capable of detecting water quality changes in real time.

Integrating sensors with a microcontroller allows the system to automatically activate filtration processes when unsafe water conditions are detected. Such feedback-based systems improve the reliability and efficiency of domestic water purification.

1.2. Significance of the Study

This study aims to contribute to the development of intelligent water purification systems that improve household water safety through continuous monitoring and automated control.

1.2.1 Household Users

The proposed system helps ensure that drinking water consistently meets acceptable quality levels by automatically monitoring and correcting water conditions. This reduces the risk of consuming poorly treated water and minimizes the need for manual testing.

1.2.2 Researchers and Students.

The project demonstrates the integration of sensors, microcontrollers, and feedback control systems in a practical application. It can serve as a reference for future research involving embedded monitoring systems and smart environmental sensing technologies.

1.2.3 Water Treatment Technology Development.

The study highlights the potential of low-cost embedded solutions to improve the functionality of conventional filtration systems. The concept may contribute to the development of more intelligent domestic water purification technologies.

1.3. Objectives

1.3.1 General Objectives

To design and implement a closed-loop embedded water quality control system that continuously monitors TDS and pH levels and automatically activates appropriate filtration processes to maintain safe drinking water conditions.

1.3.2 Specific Objectives

1. To continuously measure total dissolved solids (TDS) levels in water using a TDS sensor.
2. To continuously measure the acidity or alkalinity of water using a pH sensor.
3. To process and average sensor readings using a microcontroller for stable real-time monitoring.
4. To compare measured values with predefined safe thresholds for drinking water quality.
5. To automatically activate appropriate filtration processes when unsafe conditions are detected.
6. To implement a recirculation mechanism that repeatedly filters water until acceptable quality levels are achieved.
7. To provide real-time system feedback through visual indicators and display modules**.**

1.4. Scope and Delimitations

This project focuses on designing and developing a prototype closed-loop water-quality monitoring and filtration system using embedded sensors and a microcontroller-based control system.

The system monitors two main water quality parameters: Total Dissolved Solids (TDS) and pH level. When these parameters fall outside predefined safe ranges, the system automatically activates filtration stages such as reverse osmosis or alkaline filtration.

The system includes sensor modules, a microcontroller platform, relay-controlled pumps, and visual feedback devices, including LED indicators and an LCD. A recirculation mechanism returns treated water to the monitoring chamber for continuous evaluation.

This project is limited to monitoring TDS and pH only. Other water quality parameters such as microbial contamination, turbidity, heavy metals, and chemical pollutant,s are not included.

The system is implemented as a laboratory-scale prototype intended for demonstration purposes rather than full household deployment.

1.5 Materials

- Arduino Uno
- pH Sensor Module with Probe
- TDS Sensor Module with Probe
- 16×2 LCD with I2C
- 2-Channel Relay Module (2 pcs)
- 12V Water Pump (2 pcs)
- 12V RO Booster Pump
- RO Membrane 1812 with Housing
- Alkaline Mineral Filter
- 1/4 inch RO water tubing
- 7mm water tube connectors
- 1/4 quick fit Connector (3pcs)
- LED Indicators (Green, Yellow, Red)
- 220Ω Resistors (3 pcs)
- 12V Battery
- Jumper Wires
- Sintra Board
- Zero PCB

1.6 Block Diagram

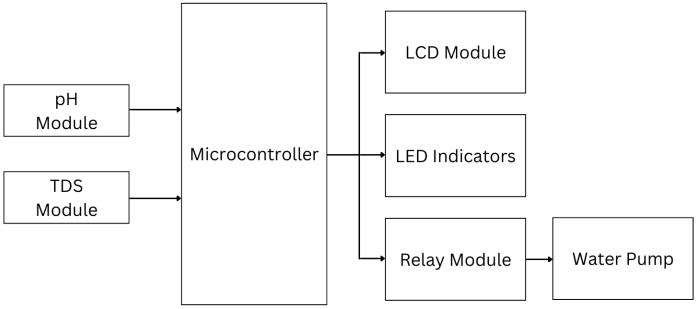


Figure 1. Block Diagram

1.7 Circuit Diagram

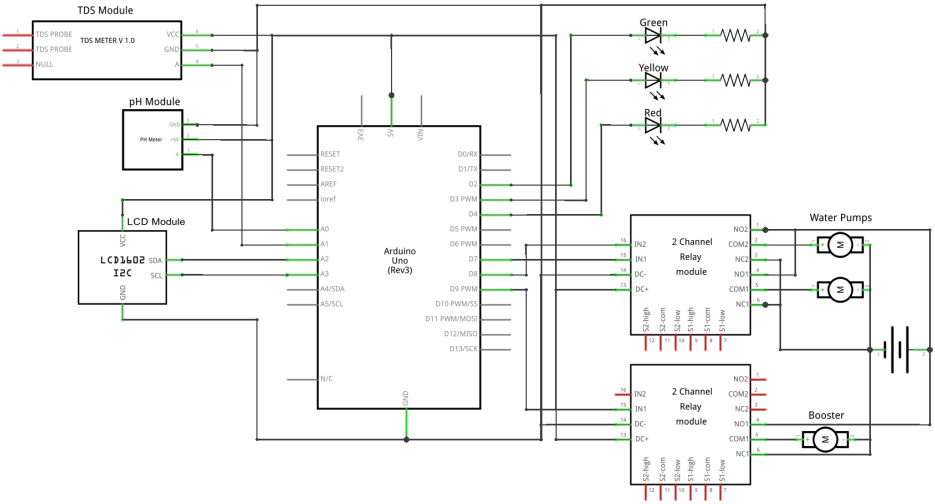


Figure 2. Schematic Diagram

1.8 System Flowchart

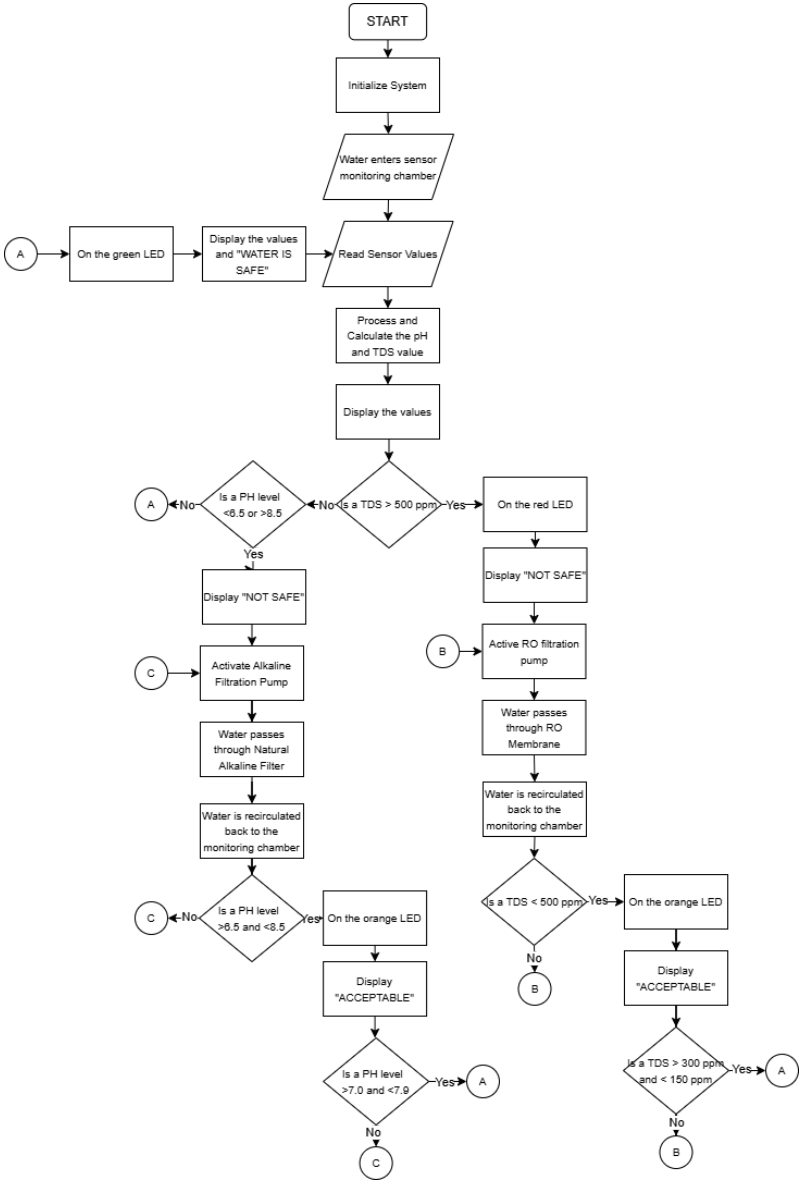


Figure 3. System Flowchart

The system flowchart describes the operational process of the proposed closed-loop water purification system designed for continuous monitoring and automatic regulation of water quality. The process begins when water enters the monitoring chamber, where the TDS sensor and pH sensor measure the dissolved solids concentration (ppm) and acidity level of the water. These readings are transmitted to the microcontroller, which evaluates whether the values fall within the safe drinking water range.

If the TDS level is within 150–300 ppm, the dissolved solids are considered acceptable. However, if the pH value drops below 6.5, the system classifies the water as unsafe and activates the alkaline pump to increase the pH level until it stabilizes within the safe range of 6.5–8.5. Conversely, if the TDS value exceeds 500 ppm while the pH remains within the safe range, the RO pump is activated to reduce the dissolved solid content.

If both parameters fall outside the safe limits, the system simultaneously activates the RO pump and alkaline pump to correct the water condition. The filtration process continues while the system repeatedly checks the sensor readings until the values return to the recommended levels.

The system also uses LED indicators to provide visual feedback. The green LED indicates good water quality, the orange LED signals acceptable but slightly elevated levels, and the red LED warns that the water is outside safe limits and requires filtration.

Once both pH and TDS values stabilize within safe thresholds, the pumps automatically stop, and the system returns to monitoring mode. This closed-loop process ensures continuous, reliable, and automated water purification without requiring manual intervention.

1.9 Hardware Specifications

Component	Model / Type	Key Parameters	Operating Range	Physical Size / Notes
Arduino Uno	ATmega328 CH340G	Microcontroller with soldered processor; Operating Voltage: 5V; Recommended Input Voltage: 7–9V; Digital I/O Pins: 14 (6 PWM); Analog Input Pins: 6; DC Current per I/O Pin: 40 mA	5V DC operation; Recommended Input: 7–9V	Standard Arduino Uno R3 form factor
TDS Sensor Module	Industrial grade	Input Voltage: DC 5V; Output Voltage: DC 1–24V; Working Current: 30mA; Output Power:	Temp: -20℃ ~ 85℃; Humidity: 0–95% RH	Size: 70 × 26 × 22 mm

		3W (Max); Conversion Efficiency: 94%		
pH Sensor Probe	Industrial grade	Measures pH 0–14; Accuracy ±0.1 pH	Temp: 0–60℃; Probe length ~120mm	Glass electrode, standard BNC connector
RO Membrane Cartridge	75 GPD Household RO	Filtration: 0.0001 µm; Flow: 189 L/d	Temp: 0–45℃	Length: 25.8 cm; Blue color; 1 pc
RO Membrane Housing	For 1812 & 2012 Membranes	Compatible with 1821 & 2012 RO membranes; Includes 3× Quick Fit 1/4” connectors	Standard	Holds RO membrane securely; Quick-fit connectors for easy plumbing
Alkaline Mineral Filter	Mineral Filter Cartridge	Remineralization: Adsorbs metals, releases minerals	Life: 10–12 months	Diameter: 50 mm; Inlet/Outlet: 1/4" Female NPT; Mesh: PP
RO Booster Pump	75–100 GPD	Voltage: 24V DC; Current ≤1–1.2A; Flow: 0.85–1.1 L/min; Pressure: 70 Psi working	Water Temp: 5–60℃; Inlet Pressure: 30 Psi; Bypass: 120–150 Psi	Dimension: L18 × H11 × W10 cm
Submersible Water Pump	Mini brushless	Voltage: DC 5–12V; Power: 2W; Current: 0.1A; Water Output: 3 L/min	Temp: -20–50℃; Lift: 0.5 m	Size: 43 × 23 mm
2-Channel Relay Module	5V 10A with Optocoupler	250VAC/10A, 28VDC/10A; Indicator LEDs; 5V control	Standard	Controls pumps safely
16×2 LCD with I2C	Standard	I2C Interface; Displays real-time pH/TDS & status	5V DC	Compatible with Arduino
LED Indicators	Standard	Colors: Green, Yellow, Red	5V DC	With 220Ω current-limiting resistors

Sintra Board	FR-4 / Protoboard	Double-sided, 1.6mm thick	–	Sizes: 4×6, 5×7, 6×8, 7×9, 8×12cm; Hole pitch 2.54 mm

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Project Cost

Material / Component	Quantity	Cost per Unit (₱)	Total Cost (₱)
Arduino Uno	1	209	209
TDS Sensor Module with Probe	1	249	249

pH Sensor Module with Probe	1	638	638
RO Membrane Cartridge (75 GPD)	1	900	900
RO Membrane Housing (for 1812 & 2012 membranes)	1	299	299
Alkaline Mineral Filter Cartridge	1	247	247
RO Booster Pump (75–100 GPD)	1	1399	1399
DC 5–12V Submersible Water Pump (Mini brushless)	2	85	170
2-Channel Relay Module (5V 10A)	2	79	158
16×2 LCD with I2C	1	150	150
LED Indicators (Green, Yellow, Red)	3	25	25
220Ω Resistors (3 pcs)	1 set	10	10
Sintra Board / Protoboard	3 A3 sized	30	90
1/4 inch Water Tubing	5 meters	40	200
Tubing Connectors (Quick-connect)	3	0 (free with RO)	0
Stranded 22 AWG wires	5 meters	4	20
5V Battery	1	220	220
Estimated Total Cost:	**4983.00 Php** (3584 Php without RO Booster)		

Project Documentation

