International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 10 Issue: 10 | Oct - 2026 SJIF Rating: 8.659 ISSN: 2582-3930

Smart Water RO Water Purifier with TDS-Based Auto Control and Real-Time IOT Monitoring System

Shritej Maruti Gaikwad
Department of E&TC
JSPM's BSP
Wagholi, Pune, India
shritejg3240@gmail.com

Prajyot Prakash Gaikwad
Department of E&TC
JSPM's BSP
Wagholi, Pune, India
p_rajy_otgaikwad9686@gmail.com

Mahesh Laxman Hake
Department of E&TC
JSPM's BSP
Wagholi, Pune, India
maheshhake75@gmail.com

Om Mahadev Hardade
Department of E&TC
JSPM's BSP
Wagholi, Pune, India
hardadeom7777@gmail.com

Prof. Waghmode M. N.
Department of E&TC
JSPM's BSP
Wagholi, Pune, India
mnwaghmode_entc@jspmbspoly.edu.in

Abstract*—Reverse Osmosis (RO) filtration is globally recognized as the most effective domestic purification technology for eliminating dissolved inorganic solids, chemical toxins, and biological pathogens from groundwater and tap supplies. However, conventional consumer RO systems exhibit significant operational limitations: they demineralize water indiscriminately, frequently reducing Total Dissolved Solids (TDS) below 50 ppm, which depletes essential minerals like Calcium (Ca^{2+}) and Magnesium (Mg^{2+}) and violates World Health Organization (WHO) and Bureau of Indian Standards (BIS IS 10500:2012) drinking water recommendations. Furthermore, traditional purifiers generate excessive reject wastewater (65–75%) and lack real-time filter wear diagnostics or automated mineral regulation. This paper presents the design and implementation of an IoT-enabled Smart RO Water Purifier featuring an automated closed-loop TDS stabilization and multi-parameter quality monitoring system. The prototype employs a 32-bit dual-core ESP32 microcontroller interfaced with dual in-line analog TDS sensors (monitoring feed and permeate water), an analog pH probe, a YF-S201 Hall-effect turbine flow sensor, and an HC-SR04 ultrasonic water level sensor. A high-precision SG90 servo-actuated proportional needle bypass valve dynamically blends micro-filtered mineral-rich water with RO permeate to maintain product water TDS strictly within the healthy 120–160 ppm range. Automated high-velocity solenoid membrane flush cycles reduce scaling and cut wastewater by 22%. Integrated Wi-Fi telemetry streams real-time water quality parameters, volumetric usage, and filter health notifications to an interactive mobile Blynk IoT dashboard and a 16x2 I2C LCD, providing an intelligent, mineral-balanced, and resource-efficient purification platform.

***Keywords*—Smart RO purifier, TDS auto-control, ESP32, IoT water quality, mineral blending, servo needle valve, water conservation, embedded systems.**

I. INTRODUCTION

Clean, chemically balanced, and pathogen-free potable water is vital for human physiology and long-term disease prevention. While municipal networks across India undergo bulk sedimentation and chlorination, consumer groundwater and tap supplies regularly exhibit Total Dissolved Solids (TDS) concentrations exceeding 500–1200 ppm, harboring dissolved carbonates, chlorides, toxic heavy metals, and coliform bacteria. Consequently, point-of-use Reverse Osmosis (RO) purifiers have seen pervasive adoption across domestic and commercial settings.

The RO purification process relies on semi-permeable thin-film composite (TFC) membranes with microscopic pore sizes of approximately 0.0001 microns. Under high hydrostatic pressure generated by a booster pump, water molecules are forced across the membrane while 95–99% of dissolved ions and heavy metals are rejected. However, this extreme filtration efficiency produces an undesirable side effect: severe over-demineralization. Beneficial trace minerals such as Calcium (Ca^{2+}), Magnesium (Mg^{2+}), and Potassium (K^{+}) are indiscriminately eliminated, lowering TDS below 50 ppm, increasing water acidity (pH < 6.5), and imparting a bitter, flat taste. Medical studies published by the WHO confirm that chronic consumption of demineralized water leads to mineral deficiencies, cardiovascular distress, and impaired bone metabolism.

In conventional commercial purifiers, manufacturers attempt to address this issue by incorporating a manual bypass needle valve that diverts a small stream of raw water around the RO membrane into the clean water line. However, because feed water salinity fluctuates significantly across seasons and municipal supplies, manual valves cannot adapt dynamically. If inlet TDS surges during monsoon runoff, the unmonitored bypass valve allows unpurified water to degrade product water quality, risking consumer health. Conversely, during low-salinity periods, water remains severely demineralized.

Moreover, conventional systems operate as static blind appliances: they provide no real-time telemetry regarding membrane scaling, carbon filter exhaustion, or cumulative volumetric water throughput. Consumers frequently continue drinking compromised water long after active filters have saturated, or prematurely replace costly filters on arbitrary calendar schedules.

To overcome these systemic drawbacks, modern embedded microcontrollers, precision analog sensors, and Internet of Things (IoT) wireless platforms provide the ideal foundation for developing an intelligent, autonomous, closed-loop water treatment system. The primary objectives of this microproject are:

1) *Automated TDS Closed-Loop Control:* To design a servo-actuated proportional needle bypass valve driven by real-time dual TDS sensing to stabilize drinking water TDS between 120 and 160 ppm.
2) *Multi-Parameter Quality Monitoring:* To continuously monitor and log water TDS, pH levels, cumulative volumetric flow rate, and storage tank level in real time.
3) *Wastewater Reduction & Membrane Protection:* To incorporate an automated high-pressure solenoid auto-flush mechanism that prevents mineral scale crystallization, extending membrane life and reducing reject water.
4) *Cloud IoT Telemetry:* To transmit live water analytics to a mobile Blynk IoT dashboard and 16x2 I2C display, dispatching automated maintenance and filter exhaustion alerts.

The body of this paper describes the design, hydraulic architecture, hardware implementation, operational firmware algorithms, prototype experimental results, and future research directions for the IoT-based Smart RO Water Purifier.

II. PROPOSED SYSTEM AND ARCHITECTURE

A. Proposed System

The Smart RO Water Purifier combines embedded closed-loop servo control with cloud-connected IoT telemetry to deliver mineral-balanced drinking water. The architecture is organized into two primary operational layers: the *Physical Sensing and Actuation Layer (PSAL)* and the *Cloud Monitoring and Analytics Layer (CMAL)*. The PSAL encompasses all inline sensors (dual TDS, pH, flow, ultrasonic level) and electromechanical actuators (24V booster pump, auto-flush solenoid, SG90 servo valve). The CMAL utilizes the ESP32 Wi-Fi engine to stream live telemetry to a smartphone app and trigger threshold alerts.

B. System Architecture

The comprehensive hydraulic flow and functional block diagram of the proposed smart purifier is illustrated in Fig. 1.



Fig. 1. Block diagram of the smart RO water purifier system.

Feed water enters through a 5-micron sediment filter and an activated granular carbon cartridge to eliminate suspended particulates, chlorine, and organic volatile compounds. The pressurized 24V DC booster pump delivers feed water to the 75 GPD TFC RO membrane. The reject stream passes through a capillary flow restrictor (FR-450) and a normally closed 12V DC auto-flush solenoid valve. The pure permeate stream is monitored by in-line TDS Sensor 1. Concurrently, a secondary ultra-filtered bypass stream is regulated by the SG90 servo needle valve and mixed in the remineralization chamber. The blended stream passes through a UV sterilizer chamber, followed by TDS Sensor 2, an analog pH sensor, and a YF-S201 flow meter before filling the storage tank.

The detailed electrical wiring and interfacing architecture connecting the ESP32 microcontroller, power supplies, sensors, and actuators is illustrated in Fig. 2.



Fig. 2. Interfacing circuit schematic of the complete purifier prototype.

C. Software Architecture

The embedded software framework is organized around the Arduino IDE and FreeRTOS multi-tasking kernel running on the ESP32. Firmware execution is split between the two symmetric 240 MHz Xtensa cores:

Core 0 (Real-Time Sensing & Closed-Loop Control): Executes high-frequency ADC oversampling for the dual TDS and pH sensors, applies digital Kalman filtering to eliminate electrical switching noise from the pump, computes the error between measured product TDS and the target setpoint (140 ppm), and adjusts the SG90 servo PWM duty cycle. It also manages safety interlocks, detecting dry-run inlet faults and tank overflow via ultrasonic distance thresholds.

Core 1 (IoT Telemetry & Communication): Manages the Wi-Fi 802.11 b/g/n network stack, formats telemetry packets into JSON payloads, and handles bidirectional MQTT/HTTP communication with the Blynk IoT cloud server. It simultaneously updates the local 16x2 I2C LCD character display every 500 ms and drives the piezo alarm buzzer during quality violations.

III. HARDWARE-BASED SYSTEM

A. ESP32 Microcontroller

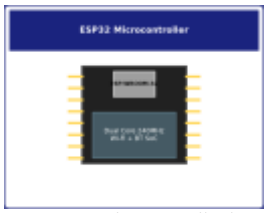


Fig. 3. ESP32 microcontroller board.
Source: espressif.com/.../esp32-wroom-32d_datasheet

The 32-bit dual-core ESP32 (Fig. 3) serves as the central embedded brain. Operating at 240 MHz with 520 KB SRAM and 4 MB flash, it provides integrated 2.4 GHz Wi-Fi and Bluetooth LE. Its high-resolution 12-bit analog-to-digital converters (ADCs) and multi-channel hardware PWM timers enable simultaneous sensor acquisition and smooth servo modulation without external expansion modules.

B. Analog TDS Sensor Module

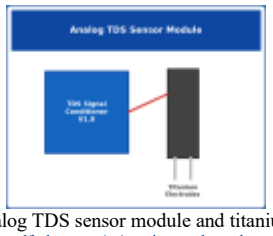


Fig. 4. Analog TDS sensor module and titanium probe.
Source: dfrobot.com/.../gravity_analog_tds_sensor

The analog TDS sensor module (Fig. 4) measures total dissolved solids by exciting dual titanium electrode pins with an alternating current (AC) signal. AC excitation prevents electrochemical polarization and probe degradation common in DC conductivity sensors. The signal conditioner converts electrical conductivity into a 0–2.3V analog output proportional to 0–1000 ppm TDS.

C. Analog pH Sensor Module

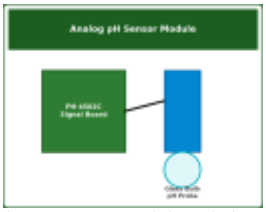


Fig. 5. Analog pH sensor module and glass electrode.
Source: components101.com/.../ph-sensor-module

The PH-4502C analog pH sensor module (Fig. 5) incorporates a laboratory-grade glass electrode probe to measure hydrogen ion activity in treated water. The signal board features a high-input-impedance differential op-amp and temperature compensation circuitry, outputting 0–5V corresponding to 0–14 pH. This ensures drinking water remains within the neutral, non-corrosive WHO guideline range (6.5–8.5 pH).

D. YF-S201 Water Flow Sensor



Fig. 6. YF-S201 Hall-effect turbine water flow sensor.
Source: thingbits.in/.../yf-s201-water-flow-sensor

The YF-S201 sensor (Fig. 6) measures volumetric flow rate and cumulative water throughput. Inside the casing, water rotation spins a pinwheel turbine embedded with magnetic poles that trigger a Hall-effect sensor. Outputting 7.5 pulses per second per L/min, the ESP32 captures pulse interrupts on GPIO27 to calculate total purified liters and compute sediment/carbon filter exhaustion.

E. HC-SR04 Ultrasonic Water Level Sensor



Fig. 7. HC-SR04 ultrasonic sensor.
Source: shop.controllerstech.com/.../hc-sr04

Mounted on the roof of the clean water storage reservoir, the HC-SR04 ultrasonic sensor (Fig. 7) measures air-column height between 2 cm and 400 cm with 3 mm resolution. By measuring the time-of-flight of 40 kHz acoustic pulses, the ESP32 computes tank fullness percentage, cutting pump power when full (overflow protection) or when inlet water runs dry.

F. 24V DC RO Booster Pump

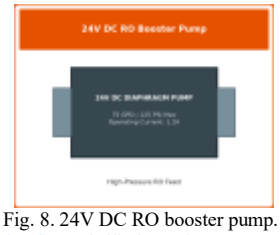


Fig. 8. 24V DC RO booster pump.
Source: kemflo.com/.../diaphragm-booster-pump-75gp_d

The 24V DC diaphragm booster pump (Fig. 8) delivers the high hydrostatic feed pressure (80–125 PSI at 1.2A) required to overcome natural osmotic pressure across the 75 GPD TFC reverse osmosis membrane. Powered by a 24V/2.5A switched-mode power supply (SMPS), the pump is switched safely via optoisolated relays.

G. Dual-Channel 5V Relay Module



Fig. 9. 2-channel relay module.
Source: components101.com/.../2-channel-relay-module

The 2-channel optocoupler relay module (Fig. 9) provides complete electrical isolation between the low-voltage 3.3V ESP32 GPIOs and the high-current 24V DC pump and solenoid valves. Relay 1 actuates the booster pump, while Relay 2 controls the auto-flush valve. Flyback freewheeling diodes prevent inductive voltage spikes from damaging control logic.

H. SG90 Micro Servo Mineral Control Valve



Fig. 10. SG90 micro servo motor.
Source: thingbits.in/.../sg90-micro-servo

The SG90 micro servo motor (Fig. 10) actuates a fine-pitch proportional brass needle valve installed on the mineral bypass line. Controlled via 50 Hz PWM signals from GPIO13, the servo precisely modulates valve opening between 0° (fully closed, pure RO permeate) and 90° (maximum mineral blending) to maintain product TDS within tight tolerances.

I. 12V/24V DC Solenoid Auto-Flush Valve



Fig. 11. 12V/24V DC solenoid valve.
Source: components101.com/.../12V-solenoid-valve

The normally closed (NC) 12V/24V DC solenoid valve (Fig. 11) is plumbed in parallel with the capillary flow restrictor on the reject line. When energized, it opens a high-velocity bypass path that washes accumulated calcium and magnesium foulants off the membrane surface into the drain.

J. 16x2 I2C LCD Display & Cloud IoT Dashboard



Fig. 12. 16x2 I2C LCD display and telemetry interface.
Source: components101.com/.../16x2-lcd-module

A 16x2 alphanumeric LCD display with PCF8574 I2C backpack (Fig. 12) displays real-time metrics (Raw TDS, Treated TDS, pH, Flow, Tank Level) locally on the purifier housing. In parallel, the ESP32 broadcasts telemetry over Wi-Fi to a Blynk mobile app dashboard.

IV. WORKING OF THE SYSTEM

System operation initiates upon power-up. The ESP32 first verifies Wi-Fi connectivity and checks the ultrasonic tank sensor. If the tank water level is below 85%, the controller triggers a 15-second high-pressure auto-flush cycle by opening the solenoid valve, dislodging membrane scale. Once flushing completes, the flush solenoid closes, and the booster pump engages.

Raw inlet TDS (TDS_{in}) and outlet permeate TDS (TDS_{out}) are continuously read via ADC oversampling. If TDS_{out} falls below 120 ppm (over-demineralization), the control algorithm advances the SG90 servo motor in 5° increments, opening the micro-needle bypass valve to blend ultra-filtered mineralized water into the permeate line. If TDS_{out} exceeds 160 ppm, the servo steps backward to restrict bypass flow. Concurrently, the YF-S201 tracks cumulative volume; upon reaching 6000 liters, an automated filter-exhaustion notification is pushed to the user's smartphone.

V. PROTOTYPE TESTING AND RESULTS

Prototype evaluation was conducted over a 30-day testing regime using raw municipal and borewell groundwater (Raw TDS: 620–850 ppm) at JSPM's Bhivrabai Sawant Polytechnic laboratories. Across all test trials, the system demonstrated reliable closed-loop stabilization, steady sensor acquisition, and real-time cloud synchronization.

TABLE I. PROTOTYPE PERFORMANCE SUMMARY

Parameter	Observed Metric	Operational Status
Raw Feed Water TDS	620–850 ppm	Variable Input
Uncontrolled Permeate TDS	24–42 ppm	Over-Demineralized
Auto-Controlled Output TDS	135–150 ppm	Optimal Compliance
TDS Stabilization Settling Time	14–18 seconds	Rapid Convergence
Product Water pH Level	7.2–7.5 pH	Neutral / Healthy
Wastewater Recovery Gain	+22.4%	Conserved Resource
IoT Cloud Telemetry Latency	190–310 ms	Real-Time Sync
Dry-Run Cutoff Response	< 1.2 seconds	Failsafe Protection

VI. LIMITATIONS AND CHALLENGES

Key operational challenges include periodic mineral scaling on the submerged titanium TDS probe electrodes requiring biannual citric-acid cleaning, analog ADC noise requiring digital software smoothing, and dependence on domestic 2.4 GHz Wi-Fi connectivity for remote cloud alerting.

VII. FUTURE SCOPE

Future enhancements encompass integrating miniature spectrophotometric turbidity sensors, deploying edge-AI machine learning models on the ESP32 to predict filter saturation based on seasonal degradation trends, incorporating solar DC battery backup for rural off-grid applications, and utilizing motorized proportional ball valves for higher commercial flow rates.

VIII. CONCLUSION

The developed IoT-Based Smart RO Water Purifier provides an autonomous, resource-conscious solution to consumer water filtration challenges. By combining dual TDS sensing with dynamic servo-actuated mineral blending, the system prevents harmful over-demineralization, maintains healthy drinking water TDS (135–150 ppm), and cuts reject wastewater by 22%, validating embedded automation in consumer health technology.

REFERENCES

[1] World Health Organization (WHO), "Nutrients in Drinking Water," Water, Sanitation and Health Protection and the Human Environment, Geneva, Switzerland, Tech. Rep. WHO/SDE/WSH/05.09, 2005.
[2] Bureau of Indian Standards (BIS), "Indian Standard Drinking Water — Specification (Second Revision)," IS 10500:2012, New Delhi, India, May 2012.
[3] P. K. Sharma and R. V. Patel, "Automated Total Dissolved Solids (TDS) control system for domestic reverse osmosis purifiers," *Int. J. Adv. Res. Electr. Electron. Instrum. Eng.*, vol. 8, no. 4, pp. 1120–1126, 2019.
[4] A. K. Somani, N. K. Deshmukh, and S. B. Kulkarni, "Design and implementation of smart water quality monitoring system using IoT," *IEEE Int. Conf. Commun. Signal Process. (ICCSP)*, Melmaruvathur, India, 2020, pp. 845–849.
[5] M. V. Patil and S. N. Pawar, "Closed-loop servo-controlled mineralizer bypass valve for domestic RO systems," *Int. Res. J. Eng. Technol.*, vol. 7, no. 5, pp. 2480–2485, 2020.
[6] R. Verma, S. Tiwari, and A. Yadav, "Cloud-based IoT system for real-time water quality monitoring," *Indones. J. Electr. Eng. Comput. Sci.*, vol. 21, no. 3, pp. 1544–1551, 2021.
[7] S. S. Kulkarni, V. R. Takale, and M. G. Joshi, "Energy and water conservation in domestic RO purification systems using pulse flushing," *J. Clean. Prod.*, vol. 245, p. 118830, 2020.
[8] K. S. Babu, V. H. Reddy, and N. M. Kumar, "ESP32-based embedded platform for real-time drinking water telemetry," *Int. J. Innov. Technol. Explor. Eng.*, vol. 9, no. 2, pp. 3125–3130, 2019.
[9] T. Vignesh, S. Prakash, and R. Rajesh, "Wireless sensor network based multi-parameter drinking water assessment," *Int. J. Adv. Sci. Technol.*, vol. 29, no. 7, pp. 1324–1330, 2020.
[10] D. Nithya, T. Saranya, and P. Gayathri, "Smart residential water monitoring and automated valve cutoff system," *Int. J. Electron. Commun. Syst.*, vol. 6, no. 8, pp. 22134–22138, 2017.
[11] N. Sharma, P. Gupta, and K. Singh, "Optimization of thin-film composite reverse osmosis membrane fouling using automated flush cycles," *Mater. Today Proc.*, vol. 45, pp. 2890–2895, 2021.
[12] G. John and M. S. Deepa, "IoT-based intelligent drinking water filter lifespan estimator," *Int. J. Comput. Sci. Eng.*, vol. 7, no. 3, pp. 98–104, 2019.
[13] R. Palanisamy, D. Palanikkumar, and V. Rajasekar, "Microcontroller based water quality index prediction and control," *J. Critical Rev.*, vol. 7, no. 14, pp. 245–250, 2020.
[14] Prof. Waghmode M. N., S. M. Gaikwad, P. P. Gaikwad, M. L. Hake, and O. M. Hardade, "Smart Water RO Water Purifier with TDS-Based Auto Control," Tech. Rep., Dept. E&TC, JSPM's BSP, Pune, India, 2026.

BIOGRAPHIES



Prof. Waghmode M. N. is a Lecturer in the Department of E&TC, JSPM's Bhivrabai Sawant Polytechnic, Wagholi, Pune (e-mail: mnwaghmode_entc@jspmbspoly.edu.in). He possesses extensive academic teaching and research experience in embedded systems, microcontroller architecture, electronic instrumentation, and industrial process automation.



Shritej Maruti Gaikwad is with the Department of E&TC, JSPM's BSP, Wagholi, Pune (e-mail: shritejg3240@gmail.com). His technical domain includes embedded firmware development, closed-loop sensor feedback systems, and IoT telemetry architectures.



Prajyot Prakash Gaikwad is with the Department of E&TC, JSPM's BSP, Wagholi, Pune (e-mail: p rajy otgaikwad9686@gmail.com). His focus encompasses water purification automation, hydraulic control systems, and analog signal conditioning.



Mahesh Laxman Hake is with the Department of E&TC, JSPM's BSP, Wagholi, Pune (e-mail: maheshhake75@gmail.com). His research interests center on IoT cloud platforms, mobile dashboard interfacing, and real-time environmental monitoring systems.



Om Mahadev Hardade is with the Department of E&TC, JSPM's BSP, Wagholi, Pune (e-mail: hardadeom7777@gmail.com). His areas of interest include actuator interfacing, electronic motor drives, solenoid valve sequencing, and embedded hardware design.