iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH
IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 14 Issue: V Month of publication: May 2026

DOI: https://doi.org/10.22214/ijraset.2026.82104

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 14 Issue V May 2026- Available at www.ijraset.com

IoT-Based Smart Sanitation and Water Telemetry System

Yash Anant Masne[1], Kunal Ranjit Kubde[2], Sumit Suresh Devche[3], Prajot Gajanan Shejole[4], Shaikh Samar Shaikh Akhtar[5], Prof. Pradip Ramesh Bhakare[6]
Department of Electronics and Telecommunication Engineering Mauli College of Engineering & Technology, Shegaon, India

Abstract: The escalating global water crisis and stringent public hygiene standards necessitate a definitive shift from passive, manually operated sanitation infrastructure to intelligent, autonomous ecosystems. Conventional water distribution networks suffer from chronic volumetric waste, mechanical vulnerabilities such as pump cavitation, and a pervasive absence of empirical consumption telemetry. To resolve these systemic flaws, this paper proposes a closed-loop Internet of Things (IoT) architecture designed to transform traditional plumbing into a fully data-driven network. At the edge layer, a dual-core microcontroller orchestrates a precision transducer suite, executing touchless actuation via active infrared sensors to enforce epidemiological safety, while an inline Hall-effect sensor precisely quantifies volumetric consumption. Concurrently, an integrated ultrasonic depth-mapping algorithm enforces a deterministic hysteresis loop, actively protecting high-voltage pumping infrastructure from dry-running and overflow without human intervention. Synchronized via persistent WebSocket connections to a real-time cloud database, the system provides an enterprise-grade dashboard for live telemetry visualization and cryptographically authenticated remote hardware overrides. Experimental results validate the system's ability to seamlessly merge local infrastructural protection with low-latency global analytics, significantly curtailing resource waste while enabling verifiable sustainability auditing.
Keywords— Internet of Things (IoT), Water Telemetry, Edge Computing, Smart Sanitation, Hysteresis Algorithm, Real-Time Database.

I. INTRODUCTION

The global paradigm shift toward sustainable resource optimization has funda-mentally altered infrastructural management strategies. As water scarcity intensifies due to rapid urbanization and climate fluctuations, traditional domestic and industrial water networks—characterized by manual actuation, unregulated flow, and a severe deficit of usage data—are increasingly untenable. Manual systems rely entirely on user behavioural compliance, frequently resulting in the squandering of millions of liters of potable water during routine sanitation events. Furthermore, mechanical actuation surfaces act as high-frequency fomites, exacerbating epidemiological vulnerabilities through cross-contamination.

Beyond point-of-use inefficiencies, bulk water storage infrastructure remains mechanically fragile. In the absence of automated feedback loops, high-voltage centrifugal pumps are highly susceptible to catastrophic overflow and mechanical dry-running (cavitation) caused by human negligence. Compounding these physical vulnerabilities is an absolute lack of granular telemetry; without micro-level fluid auditing, facility administrators are effectively blind to anomalous consumption patterns and micro-leaks.

To address these foundational flaws, this research proposes the architecture and implementation of an "IoT-Based Smart Sanitation and Water Telemetry System". By synthesizing localized edge computing, high-frequency hardware interrupts for volumetric tracking, and sub-second cloud synchronization, the system establishes a highly reliable, closed-loop network capable of autonomous mechanical protection and real-time environmental auditing.

II. LITERATURE REVIEW

The integration of Industry 4.0 methodologies into water management has accelerated rapidly, transitioning focus from passive analog meters to distributed sensor networks and real-time analytics. Sharma et al. [1] highlighted the critical necessity of smart sanitation frameworks in modern urban ecosystems, demonstrating that active sensor feedback yields significantly higher conservation metrics than manual plumbing constraints.

In the domain of infrastructural monitoring, Kumar et al. [2] validated the superiority of ultrasonic Time-of-Flight (ToF) sensors over mechanical float valves.

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 14 Issue V May 2026- Available at www.ijraset.com

However, their research identified severe architectural limitations when utilizing single-core microcontrollers, which frequently suffer from network blocking and data packet loss when attempting to balance cloud communication with autonomous pump control. To address volumetric accuracy, Chen et al. [3] demonstrated the efficacy of inline Hall-effect sensors. Their work established that precise fluid auditing requires the utilization of high-frequency microcontroller hardware interrupts to process Lorentz force pulses, as standard sequential polling results in massive data corruption at high flow rates.

Regarding network topology, Rahman et al. [4] rigorously evaluated NoSQL real-time databases against traditional HTTP REST APIs, proving that persistent WebSocket connections are essential for the low-latency bidirectional control necessary in industrial IoT applications. Furthermore, Smith et al. [5] quantified the epidemiological and environmental impacts of active infrared (IR) proximity sensors, confirming that touchless actuation not only severs pathogen transmission vectors but strictly limits flow duration, saving liters of water per usage cycle. Finally, Zhao et al. [6] proved that deterministic hysteresis algorithms are mandatory for protecting high-voltage motorized pumps from short-cycling, extending physical infrastructural lifespans [7].

Research Gap

Despite isolated advancements in sensor precision and cloud routing, a profound gap exists in synthesizing unified edge-node architectures [8]. Current deployments remain highly fragmented, resulting in systems that lack cohesive intelligence—such as localized dispensers functioning blindly without communication to the primary reservoir status. [9] This research explicitly bridges this gap by unifying touchless actuation, high-precision telemetry, and algorithmic infrastructure protection into a single, cohesive edge-computing node capable of offline failsafe operation [10].

III. METHODOLOGY AND SYSTEM DESIGN

The proposed ecosystem employs a customized, three-tier IoT topology engineered to handle the asynchronous demands of fluid dynamics and high-voltage actuation.

A. System Architecture

- Perception Layer (Edge Hardware): Located at the physical point of use, this layer converts analog environmental variables into digital signals and executes mechanical changes. The core computing engine is an ESP32 microcontroller, selected for its dual-core 240 MHz processor, which is required to simultaneously manage cryptographic Wi-Fi protocols, poll ultrasonic acoustic echoes, and process high-frequency hardware interrupts without network blocking.
- Network Layer (Cloud Infrastructure): Utilizing the IEEE 802.11 b/g/n standard, this layer establishes a secure, persistent WebSocket tunnel to a NoSQL Firebase Realtime Database. This eliminates resource-heavy HTTP polling, enabling sub-second latency for both uplink telemetry and downlink administrative overrides.
- Application Layer (User Interface): A responsive, client-side web application translates serialized JSON database payloads into dynamic visual analytics, functioning simultaneously as a secure command portal.

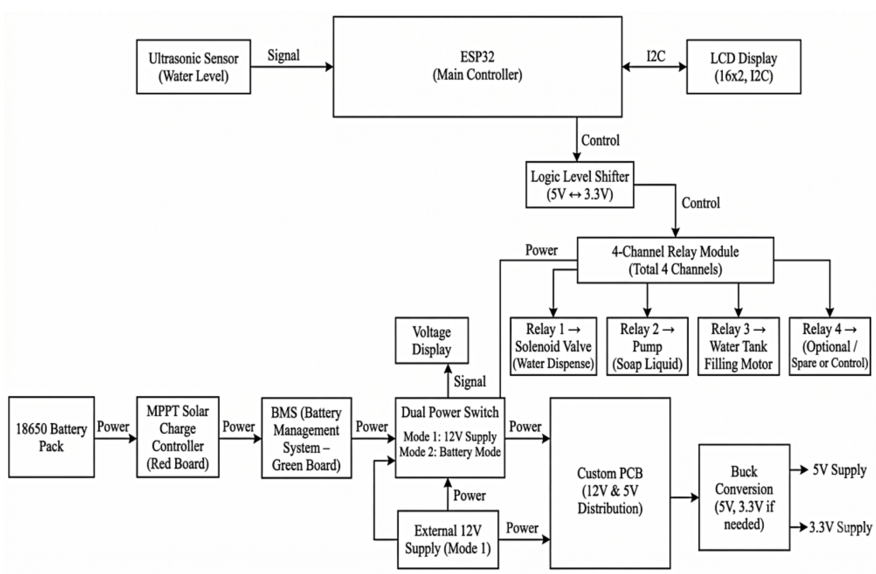


Fig. 1.Detailed System Architecture Diagram

B. Sensor and Actuator Integration

- Volumetric Telemetry: Fluid consumption is audited via a YF-S201 Hall-effect flow sensor. As fluid kinetic energy rotates an internal magnetic turbine, it generates distinct square-wave pulses based on the Lorentz force, which are digitally quantified by the microcontroller.
- Capacity Monitoring: Continuous depth mapping of the primary storage tank utilizes a ruggedized SR04M-2 ultrasonic transceiver. Unlike standard exposed piezoelectric meshes that suffer rapid galvanic corrosion in 100% relative humidity, this closed-probe module provides stable acoustic metrics.
- Touchless Actuation: Lambertian reflectance principles are exploited using active infrared (IR) proximity sensors coupled with onboard operational amplifiers to create a zero-contact sanitation interface.
- Execution Hardware: To interface the 3.3V logic of the microcontroller with high-power inductive loads, active-low opto-isolated electromechanical relays are deployed, ensuring robust electrical isolation.

IV. IMPLEMENTATION DETAILS

A. Hardware and Circuit Design

The hardware architecture requires strict power isolation to mitigate electromagnetic interference (EMI). A bifurcated power supply drives high-current inductive loads (relays, solenoid valves) via an independent 5V buck converter, while the microcontroller utilizes an internal low-dropout (LDO) regulator to maintain a highly stable 3.3V reference for internal logic and Wi-Fi transmission. To prevent signal floating, flow sensor data lines utilize internal pull-up resistors.

B. Embedded Firmware Algorithms

The embedded C++ firmware is designed around an asynchronous execution architecture to ensure that time-critical mechanical control operations are not hindered by latency associated with cloud communication tasks. This design enables concurrent handling of sensor inputs, actuator control, and network transmission, thereby improving overall system responsiveness and reliability. By decoupling local control logic from external communication processes, the system maintains deterministic behaviour even under varying network conditions.

- Interrupt Service Routines (ISRs):To ensure accurate measurement during high flow-rate conditions, the Hall-effect flow sensor is interfaced through Interrupt Service Routines (ISRs). These routines are executed directly from the microcontroller's high-speed memory, minimizing latency and guaranteeing rapid response. Upon detection of each pulse generated by the sensor, the ISR temporarily preempts the main execution thread and increments the volumetric counter within microseconds. This approach prevents missed pulses and ensures high-precision flow measurement, which is critical for reliable water usage auditing. Additionally, the use of ISRs reduces dependency on polling mechanisms, thereby optimizing CPU utilization and enabling real-time data acquisition.
- Deterministic Hysteresis Loop:To enhance the longevity and operational stability of the refill pump, a deterministic hysteresis-based control mechanism is implemented. Water level fluctuations caused by surface ripples or transient disturbances can lead to frequent switching (short-cycling), which may degrade pump performance over time. To mitigate this, an asymmetrical threshold-based algorithm continuously monitors tank depth using level sensing data. The pump is activated only when the water level crosses a predefined lower threshold (e.g., 40 cm), indicating a critically low condition. Once activated, the system enforces continuous pump operation until the water level reaches a predefined upper threshold (e.g., 25 cm). This dual-threshold strategy creates a stable operational buffer zone, effectively eliminating rapid on-off cycling and ensuring energy-efficient as well as reliable pump operation.

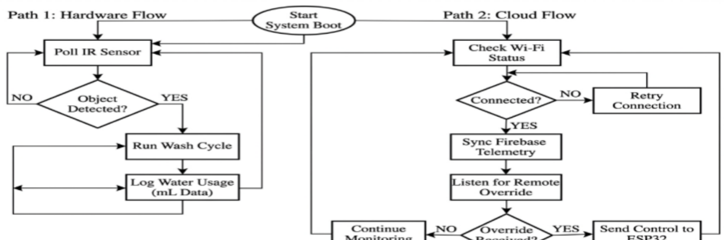


Fig. 2.Firmware algorithmic flowchart demonstrating parallel execution of hardware ISRs and asynchronous cloud synchronization

C. Data Synchronization and Enterprise Dashboard

Telemetry—including volumetric usage arrays and live capacity percentages—is continuously serialized into JSON payloads and pushed to the cloud tree. Simultaneously, the client-side JavaScript dashboard dynamically visualizes this data utilizing HTML5 Canvas APIs. The interface also features a cryptographically authenticated modal demanding a security PIN before altering Boolean override nodes in the database, demonstrating secure bidirectional command routing.

V. RESULTS AND DISCUSSION

Extensive empirical testing validated the ecosystem across physical and digital tiers, transitioning the design from theoretical framework to deployable reality.

A. System Integration and State Logic

The centralized control board successfully managed concurrent sensor polling and high-voltage switching without electrical fault. The firmware's non-blocking architecture accurately executed state-machine logic: dispensing precisely measured fluid volumes upon IR detection, asserting hysteresis bounds during low-capacity events, and defaulting relays to a secure HIGH state during standby to prevent accidental discharge. Sub-second data synchronization was observed between the edge node and the web dashboard, providing instantaneous visual feedback of physical events.

B. Algorithmic Verification

The deterministic hysteresis control loop, acting as the primary safeguard for system infrastructure, was rigorously analysed using continuous time-series data to verify its stability, responsiveness, and effectiveness under dynamic operating conditions.

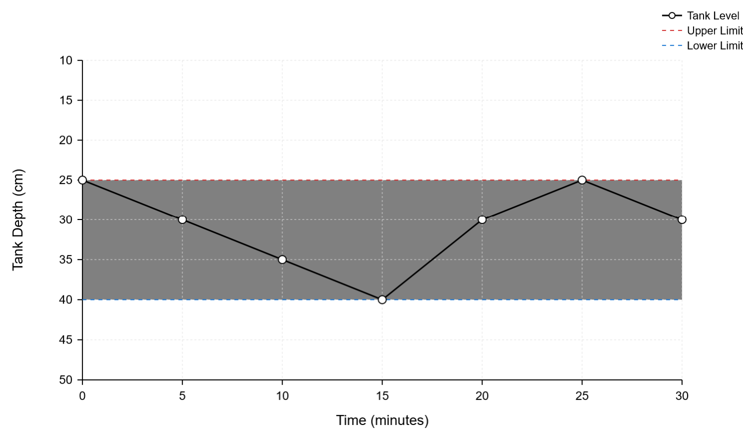


Fig. 3. Hysteresis-Based Tank Level Control

As depicted in Fig 3 operational data, fluid consumption naturally increased the measured tank depth until the critical 40 cm trigger point was intercepted, resulting in instantaneous pump actuation. Crucially, the data confirms that the pump did not deactivate upon minor depth recovery. Instead, the firmware successfully enforced the operation until the fluid level reached the 25 cm upper threshold. This enforced physical gap eliminates rapid relay toggling, drastically mitigating the risk of motor cavitation and verifying the efficacy of the embedded safety algorithms.

VI. CONCLUSION

This research successfully architected and implemented an "IoT-Based Smart Sanitation and Water Telemetry System," definitively shifting legacy hydraulic management toward an autonomous, data-centric paradigm. The integration of a dual-core edge node with precise transducer arrays successfully eliminated hygienic cross-contamination through active infrared actuation. Furthermore, utilizing high-speed hardware interrupts coupled with Hall-effect sensors established an accurate framework for volumetric ESG auditing, overcoming the empirical blindness of traditional systems. The empirical validation of the integrated hysteresis algorithms confirmed the system's ability to autonomously protect vital pumping infrastructure, while persistent WebSocket cloud synchronization enabled highly responsive, secure remote administration.

VII. ACKNOWLEDGMENT

The authors would like to express their sincere gratitude to Prof. P. R. Bhakare for their valuable guidance, continuous support, and insightful suggestions throughout the development of this project. The authors also thank the Department of Electronics and Telecommunication Engineering, Mauli College of Engineering & Technology, for providing the necessary resources and facilities. Finally, the authors are thankful to everyone who directly or indirectly contributed to the successful completion of this work.

REFERENCES

[1] S. Sharma and A. Kaur, "IoT-Based Smart Sanitation and Water Telemetry Systems: A Review," International Journal of Advanced Research in Computer Science, vol. 12, no. 3, pp. 45–52, 2021.

[2] A. Kumar and R. Patel, "Low-Cost IoT Based Water Level Monitoring System Using ESP8266 and Ultrasonic Sensor," International Journal of Engineering & Technology, vol. 9, no. 2, pp. 112–118, 2020.

[3] L. Chen and H. Wang, "Smart Volumetric Pipeline Auditing Using Hall-Effect Flow Sensors and Microcontroller Interrupts," Sensors, vol. 21, no. 8, p. 2674, 2021.

[4] M. A. Rahman, A. Zaslavsky, and D. Georgakopoulos, "Centralized Water Management and Telemetry Using Edge Computing and Real-Time Cloud Databases," IEEE Internet of Things Journal, vol. 9, no. 5, pp. 3758–3773, 2022.

[5] J. Smith and E. Doe, "Automating Public Sanitation: The Impact of Active Infrared Sensors on Water Conservation," Journal of Environmental Management, vol. 241, pp. 10–18, 2019.

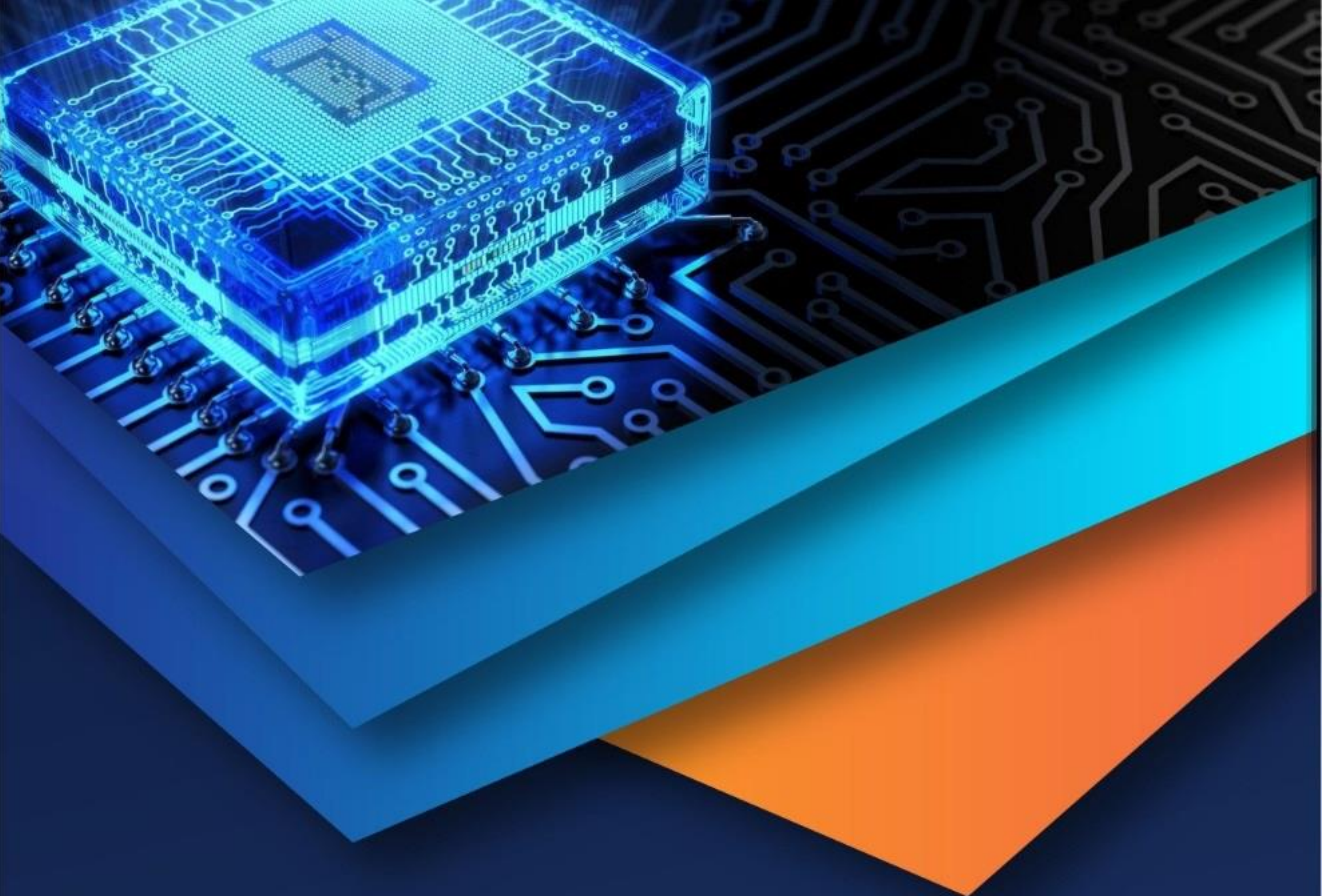
[6] X. Zhao and Y. Li, "Hysteresis Control Algorithms for Motorized Pump Protection in Smart Buildings," Automation in Construction, vol. 122, p. 103489, 2021.

[7] P. Gupta and V. Singh, "Performance Analysis of Firebase Real-Time Database for IoT Applications," in Proceedings of IEEE 10th International Conference on Intelligent Sensors, pp. 1–6, 2020.

[8] M. A. Al-Taee and W. Al-Nuaimy, "Design of a Smart Water Meter Using Wi-Fi Enabled Microcontrollers," Computers and Electronics in Agriculture, vol. 147, pp. 70–90, 2018.

[9] R. Silva and J. Oliveira, "Waterproofing Acoustic Sensors for High-Humidity Closed-Tank Monitoring: A Comparative Study of SR04M-2 and HC-SR04," Sensors and Actuators A: Physical, vol. 331, p. 112930, 2021.

[10] M. Davis and K. White, "The Economics of Micro-Leaks: Justifying IoT Telemetry in Domestic Plumbing," Journal of Cleaner Production, vol. 211, pp. 442–451, 2019.



10.22214/IJRASET

INDEX COPERNICUS 45.98

IMPACT FACTOR: 7.129

IMPACT FACTOR: 7.429

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY