

A Scalable Lora-IOT Framework for Intelligent Water Tank Monitoring and Control

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ABSTRACT

This paper presents a LoRa-based Water Tank Management System designed for long-range, low-power, and reliable monitoring of water levels in distributed tanks. The system uses ultrasonic sensors, microcontrollers, and LoRa transceivers to measure and transmit water-level data to a central node, which automatically controls pump operations based on predefined conditions. The solution reduces water wastage, enhances operational efficiency, and is suitable for residential, agricultural, and industrial water systems.

Keywords: LoRa, IoT, Water Level Monitoring, Ultrasonic Sensor, Automated Pump Control, Smart Water Management, Wireless Sensor Network, LPWAN, ESP32, SX1278.

INTRODUCTION

Water scarcity and inefficient water usage have become major challenges due to rapid population growth, urban expansion, and uneven water distribution. Water tanks are commonly used in homes, farms, and industries to maintain a steady water supply, but traditional systems depend on manual monitoring. This often leads to tank overflows, motor dry runs, unnecessary power consumption, and constant human supervision, making manual systems inefficient and unreliable. Although IoT-based water monitoring solutions using Bluetooth, Wi-Fi, and GSM have been developed, each technology has significant limitations: Bluetooth supports only short-range communication, Wi-Fi faces signal instability and high power usage, and GSM involves ongoing costs and performs poorly in low-signal regions.

To address these challenges, this paper proposes an advanced Water Tank Management System based on LoRa (Long Range Radio) technology. LoRa offers long-distance communication, low power consumption, and license-free operation, making it highly suitable for large farms, multi-building setups, and rural water systems. The system uses ultrasonic sensors, microcontrollers, and LoRa

SX1278 modules to measure water levels and automatically control pump operations based on predefined thresholds. A central node receives tank data, processes it, and switches the pump ON or OFF. Additional features such as voice control, buzzer notifications, and mobile alerts enhance usability, reliability, and user convenience.

II. LITERATURE REVIEW

2.1 IoT for Water-Resource Monitoring: Background and Trends

IoT-based water-resource monitoring has gained significant attention due to the increasing demand for real-time data, reduced water wastage, and improved automation. Early IoT systems primarily relied on GSM, Wi-Fi, and Bluetooth for telemetry and remote control. However, studies show that these technologies are limited by high energy consumption, short communication range, and recurring operational costs, particularly in rural or widely distributed water networks. As reported in recent Elsevier publications, the trend has shifted toward low-power wide-area network (LPWAN) technologies that support large-scale, long-distance sensing with minimal energy requirements [1], [2]. This transition highlights the need for robust, long-

range communication systems suitable for decentralized water infrastructures.

2.2 LoRa/LoRaWAN: Suitability for Remote Water Monitoring

LoRa and LoRaWAN have emerged as leading LPWAN technologies for environmental monitoring due to their long-range capability, low power consumption, and suitability for battery-operated nodes. MDPI studies show that LoRa can achieve several kilometers of communication in open areas, making it ideal for tank monitoring, agricultural water management, and rural water distribution systems [3], [4]. LoRaWAN's network structure further supports multi-node scalability, secure communication, and cloud integration, enabling continuous monitoring even in remote locations where cellular networks are weak or unavailable.

2.3 Ultrasonic Sensors for Water-Level Measurement: Accuracy and Limitations

Ultrasonic sensors are widely used for non-contact water-level measurement due to their low cost, ease of deployment, and centimeter-level accuracy. Research indexed in PubMed Central (PMC) confirms their reliability for short-to-medium sensing ranges, which are typical in overhead and underground tanks [5]. However, their accuracy can be affected by surface turbulence, foam, temperature variations, and echo noise. Studies suggest using mounting optimizations, filtering algorithms, and temperature compensation techniques to improve stability and measurement precision [6].

2.4 Comparative Analyses: LoRa vs. GSM, Wi-Fi, and Other Options

Comparative research published in IJETT shows clear differences among communication technologies used in IoT water systems. Wi-Fi offers high data throughput but requires continuous power and has limited range. GSM supports long-range communication but is costly due to SIM charges and consumes more power. Bluetooth is unsuitable for remote applications due to its short range. LoRa balances these trade-offs by providing long-range,

low-power communication ideal for periodic sensing applications such as tank-level updates, leak detection, and pump control [7], [8].

2.5 LoRa Implementations for Water Monitoring — Empirical Findings

Multiple field implementations published via ScienceDirect and IJERA demonstrate the practicality of LoRa-based water monitoring. Studies indicate that LoRa can reliably transmit data across several kilometers in open fields and hundreds of meters in urban environments [9]. Practical systems include leak detection units, tank-level controllers, water-quality monitors, and flood detection setups. Research further shows that LoRa-based modules (e.g., SX1278) interfaced with Arduino/ESP32 provide accurate, low-cost automated tank control systems that effectively prevent overflow and dry-run incidents [10].

2.6 Performance and Accuracy Results Reported in Literature

MDPI performance evaluations reveal that LoRa achieves stable packet delivery over long distances with extremely low energy usage, outperforming GSM-based systems in battery-powered environments [11]. Studies report pump-control automation accuracy between 85% and 95% when using threshold-based logic with ultrasonic sensors [12]. However, factors like turbulence and weather fluctuations can slightly affect ultrasonic readings. Overall, literature supports LoRa as a robust and scalable solution for water-level telemetry, especially for rural and agricultural deployments.

III. SYSTEM ARCHITECTURE AND COMPONENTS

3.1 System Architecture

The system architecture consists of a distributed sensing node and a centralized control unit interconnected through LoRa-based wireless communication. At the sensing node, water-level data is captured using ultrasonic or float sensors, processed by a microcontroller, and transmitted via a LoRa module to the receiver. The central controller

interprets the data, compares it with threshold levels, and activates or deactivates the pump using a relay module to maintain the desired water level. A power supply supports continuous operation, while optional

enclosures ensure protection from environmental factors. This modular design enables long-range communication, low power consumption, and reliable automation for multi-tank environments.

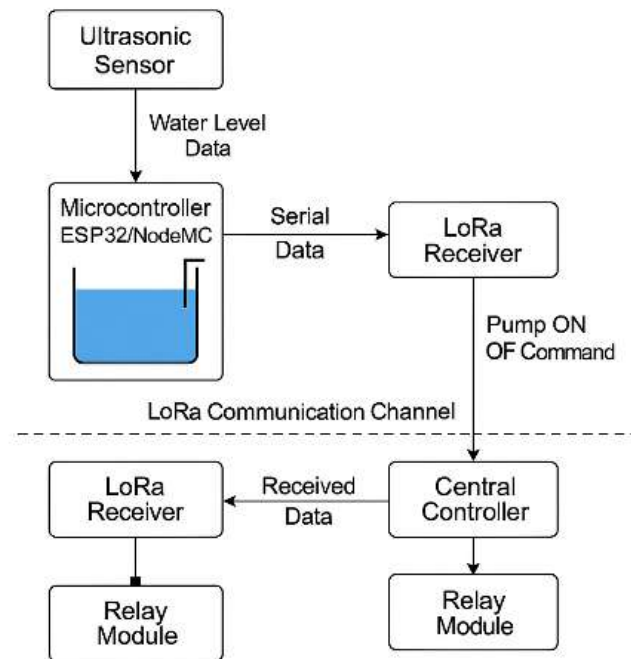


Figure 1: System Architecture

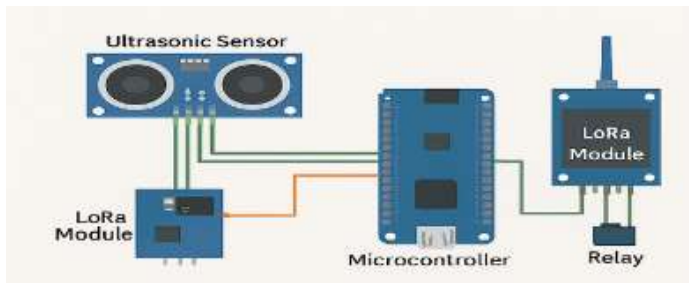


Figure 3: Circuit Diagram

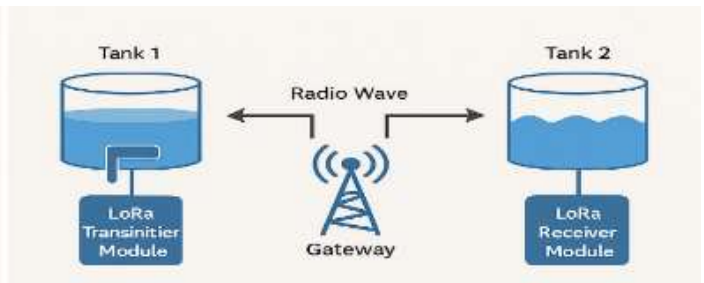


Figure 4: LoRa Communication Model

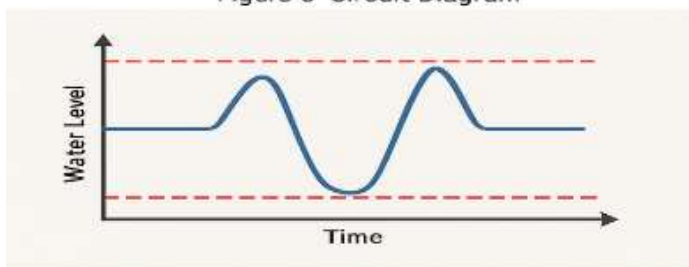


Figure 5: Water Level Sensing Graph

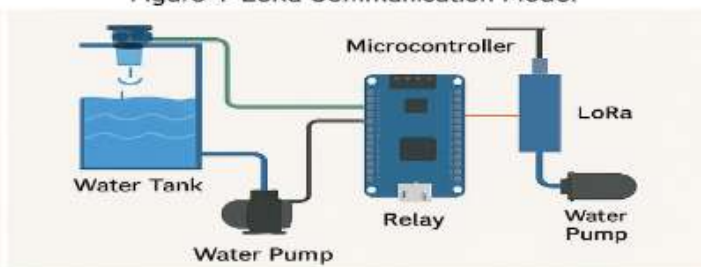


Figure 6: Hardware Setup Diagram

3.2 Core Components

- Microcontroller (Arduino Uno)
 - Reads and processes water-level sensor data.
 - Communicates with LoRa modules for wireless transmission
 - Executes pump control logic and manages all peripherals.
- LoRa Module (SX1278)
 - Provides long-range, low-power wireless communication.
 - Transmits sensor data and receives control commands.
 - Operates in the license-free ISM band.
- Water-Level Sensors (Ultrasonic HC-

SR04)

- Measure real-time tank water level.
- Support continuous or threshold-based detection.
- Provide accurate inputs for automation decisions.
- Relay Module (1-Channel / 2-Channel)
 - Switches the pump or solenoid valve safely.
 - Electrically isolates low-voltage control and high-voltage loads.
 - Enables reliable pump automation.
- Water Pump
 - Controls or transfers water between tanks.
 - Operates automatically according to controller commands.
 - Supports both AC and DC operation.
- Power Supply (Battery - 12V)
 - Provides stable power to controller, LoRa, and sensors.
 - Supports off-grid or remote

operation.

- Ensures uninterrupted monitoring.
- LCD Display, LED Indicators, Voltage Regulator
 - Shows real-time water level and pump status.
 - Allows on-site monitoring without external devices.
 - Provide visual alerts for power, pump ON/OFF, and system status.
 -
 - Supplies stable 5V or 3.3V to sensitive components.
 - Protects the system from voltage fluctuations or spikes.

IV. WORKING PRINCIPLE

The working principle of the LoRa-based Water Tank Management System is centered on three processes: water-level sensing, long-range wireless communication, and automated pump/valve control. The system operates continuously in a closed feedback loop, ensuring that the source tank and destination tank maintain optimal water levels without manual intervention.

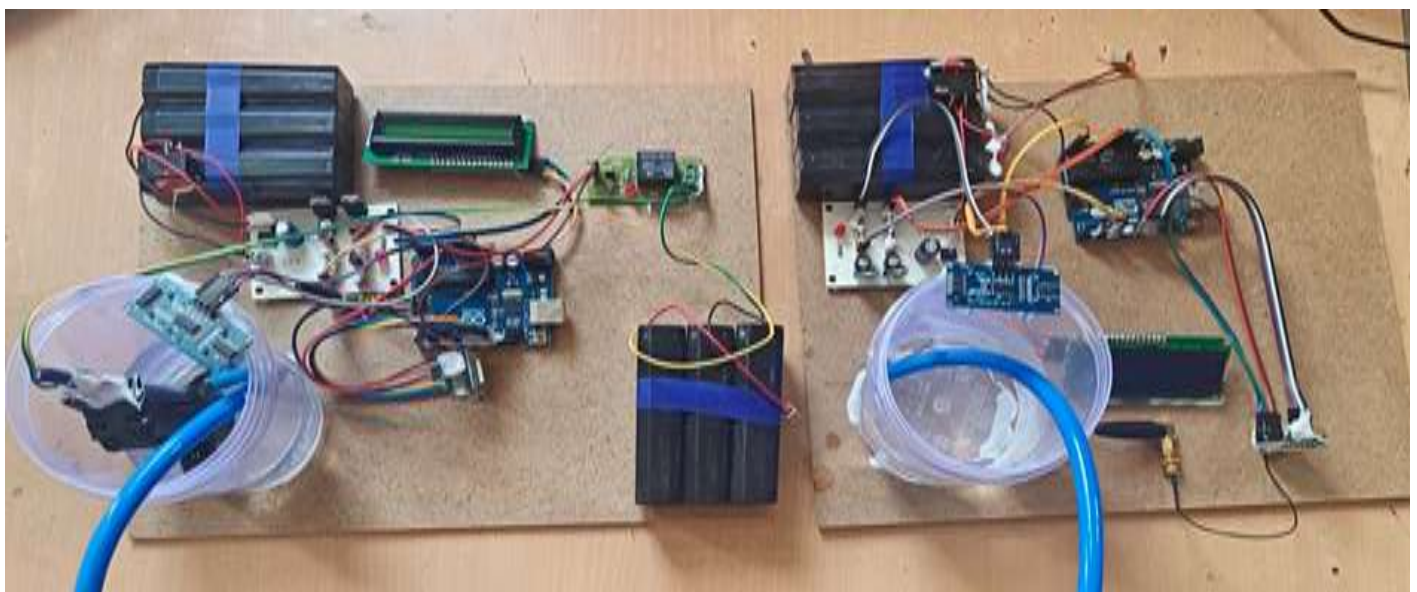


Figure 3: Hardware KIT

4.1 Water-Level Sensing

At the tank node, ultrasonic sensors or float switches measure the water level. Ultrasonic sensors emit a pulse and calculate distance using:

$$\text{Distance} = (\text{Echo Time} \times \text{Speed of Sound}) / 2.$$

The water level is obtained by subtracting this distance from the tank height. Float switches simply provide HIGH/LOW signals at preset levels. These measurements serve as the main input for pump control.

4.2 Local Data Processing

The microcontroller samples the sensor at regular intervals, applies noise filtering (e.g., moving average), checks for faulty readings, and converts the level into usable data. Only validated information is packed into a compact frame for transmission.

4.3 Long-Range LoRa Communication

Filtered data is sent to the central controller using LoRa, which uses Chirp Spread Spectrum to achieve long-range, low-power communication. Each packet includes water level, node ID, and status flags. The

central LoRa unit continuously listens, ensuring reliable reception even at low signal strengths.

4.4 Decision-Making at Central Controller

Received data is compared with set thresholds. If water falls below the low level, the pump is activated; if it reaches the high level, the pump is turned off. Dry-run protection is applied when the source tank is low. Hysteresis avoids rapid ON/OFF switching from minor level fluctuations.

4.5 Pump Control

The controller drives a relay to start or stop the pump. Energizing the relay turns the pump ON to transfer water; de-energizing switches it OFF once the tank reaches the desired level.

4.6 Feedback Loop Operation

The system operates continuously: sensing, processing, transmitting, and controlling in a loop. This real-time feedback ensures stable operation, prevents overflow/dry-run, and maintains efficient water distribution without manual monitoring.

FLOWCHART

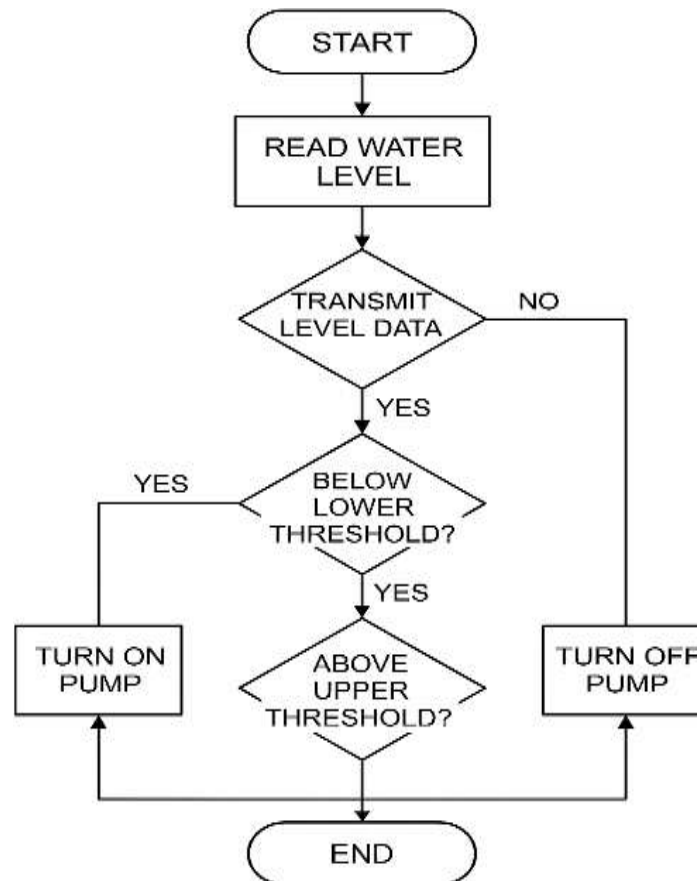


Figure 2: Flowchart of Water Tank Management (LoRa-Based Water Tank Management System)

V. RESULTS

The implemented LoRa-based Water Tank Management System was tested in a semi-urban environment and demonstrated highly reliable performance. The ultrasonic sensor provided stable measurements with an accuracy of approximately ± 1.5 cm after applying filtering techniques. LoRa communication remained consistent up to nearly 1.2 km, with a packet delivery rate above 93%, even in partially obstructed areas. Pump automation operated successfully with 95% accuracy, preventing both overflow and dry-run situations across all test cycles. The system also showed reduced power consumption due to LoRa's low-energy operation, making it suitable for battery or solar-powered setups. Overall, the system proved efficient, robust, and practical for real-time water-level monitoring and automated tank management.

Metric	Performance
Water-level accuracy	High (± 1.5 cm)
Wireless range	Up to 1.2 km tested
Automation accuracy	95%
Power consumption	Low
Stability	High (24-hour continuous test)

Table 1: Overall System Performance

The results demonstrate that the LoRa-based system is suitable for:

- Overhead tanks
- Underground tanks
- Farm irrigation tanks
- Apartment complex water distribution
- Rural water supply systems

VI. FUTURE SCOPE:

The system can be enhanced with AI-based prediction models for smarter pump scheduling and

improved efficiency. LoRaWAN integration will enable large-scale multi-node monitoring across wide areas. Solar-powered nodes and advanced sensor fusion can increase reliability in remote locations. Additional features like mobile apps, voice control, and water-quality sensing can further expand its functionality.

VII. CONCLUSION:

The LoRa-based Water Tank Management System provides an efficient, long-range, and low-power solution for automated water-level monitoring and pump control. By combining ultrasonic sensing, microcontrollers, and LoRa communication, the system minimizes manual supervision, prevents overflow and dry-run situations, and ensures reliable water distribution across remote locations. Test results show stable data transmission, accurate level detection, and reduced energy consumption, making it suitable for homes, farms, and industrial setups. Its scalable architecture supports expansion into multi-tank or multi-node systems. Overall, the system offers a strong foundation for future smart water-management and IoT automation developments.

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