FUDMA Journal of Sciences (FJS)
ISSN online: 2616-1370
ISSN print: 2645 - 2944
Vol. 10 No. 7, April, 2026, pp 87 – 90
DOI: https://doi.org/10.33003/fjs-2026-1007-5189

MULTIFACTOR RESERVOIR LEAKAGE DETECTION, MONITORING, AND MANAGEMENT SYSTEM USING PATTERN RECOGNITION AND ULTRASONIC SENSORS

Adamu Abubakar

Department of Computer Science, Ibrahim Badamasi Babangida University, Lapai, Niger State, Nigeria.

*Corresponding authors' email: abubakaradamu2003@gmail.com
ORCID: https://orcid.org/0000-0002-8146-8857

ABSTRACT

Reservoir leakage constitutes a crucial challenge to water resource, monitoring, safety, management and environmental sustainability. Late detected or undetected leakage can lead to loss of water, structural degradation, and severe environmental consequences. This paper presents multifactor reservoir leakage detection, monitoring, and management system based on ultrasonic sensors and pattern recognition techniques. The proposed system integrates multiple ultrasonic signal features, including temporal variation, echo amplitude and signal attenuation, alongside environmental compensation factors such as pressure and temperature. A pattern recognition framework is employed to classify reservoir states into normal and severe leakage conditions. Experimental evaluation demonstrates that the proposed system achieves high detection accuracy, reduced false alarm rates, and robust performance under varying noise and operational conditions. The results confirm the feasibility of the system for real-time reservoir monitoring and intelligent leakage management.

Keywords: Ultrasonic Sensors, Reservoir Leakage Detection, Pattern Recognition, Water Infrastructure Management

INTRODUCTION

Water is one of the most significant resource on the planet used by human, animal and plants (Gati and Lias). Water is also considered as universal solvent which plays an essential role in daily life of human being, plants, animals and ecosystem (Pawar *et al.,* 2022). Water resources storage medium such as water reservoirs (tanks) are used to store water resources in hostel of an institutions, industries, farms and organizations. The daily routine of both human and animals begins with water. Water is one of the basic needs of life and means to survive. Hostels, hotel, companies and farms depend on water reservoir for their daily usage. Sustainability, monitoring and proper management of available water resources in many organizations, educational institution, residential homes, agricultural and industries are now facing dominant issues on water reservoir monitoring and management because of the traditional method being utilize. The significant of water to diverse life of living organism cannot be over emphasized (Kumawat et al, 2022). Management and conservation of water are crucial for survival of human and other living organism. Water reservoirs and storage tanks play a crucial role in ensuring reliable water supply for institutional, domestics and industrial and agricultural application (Pranita et al, 2020). In university campuses, efficient and effective water tank monitoring and management are vital to maintaining uninterrupted water supply, availability, reducing wastage, and preventing infrastructure damage. Many institutions solely rely on multiple reservoir or water storage tanks who's monitoring and control are largely based on conventional or semi-automated methods.

In many institutions, the management and distribution of water are monitored by using conventional method.

The conventional method involves the use of human to monitor and manage the distribution of water. The reservoir methods of leak detection have evolved from the conventional model to a machine learning algorithm (Shiddiqi et al, 2020). The conventional methods are often characterized by lack of real time reporting, delayed fault detection, high dependence on human intervention and inaccurate localization of leak event. Consequently, issues such as undetected leak, water overflow, faulty pump due to dry running, and proper maintenance planning may persist, which can lead to wastage of water. Hence, the need of an effective method is to monitor and manage the water resource.

Advances in sensor technology, artificial intelligence (AI), and pattern recognition provide an opportunity to address these challenges through intelligent, automated systems. By integrating ultrasonic sensing with AI-based decision-making, it is possible to develop a robust solution capable of continuous monitoring, leakage detection, water level management, automated pump control, and real-time reporting.

The ultrasonic sensor is broadly used in reservoir leak detection systems due it contactless capability in measuring abnormalities such as leakages (Li et al., 2019). The ultrasonic sensors operate by transmitting high-frequency ultrasonic waves toward the water surface and measuring the time-of-flight of the reflected signal to estimate the water level (Djalilov et al, 2023). Under normal operating conditions, water level variations occur gradually due to routine consumption. However, leakage events introduce abnormal and rapid water level reductions, which can be continuously monitored using ultrasonic sensors. Compared to traditional float or pressure-based sensors, ultrasonic sensors are less susceptible to corrosion, contamination, and mechanical wear, making them suitable for long-term deployment in water storage systems. Several studies have demonstrated that ultrasonic sensing provides reliable real-time water level monitoring and forms an effective foundation for intelligent leakage detection systems (Kumar and Singh, 2021).

Pattern recognition techniques when integrated with ultrasonic sensors significantly enhance water reservoir leak detection by employing AI based interpretation of water level data (Zhang et al., 2020). Pattern recognition algorithms analysis temporal features such as trend consistency, rate of change and statistical changes or variations in water level data to distinguish between leak state and no-leak state conditions.

Leak events are typically identified by continuous and rapid drops in water level that deviate from learned normal patterns. By applying rule-based or classification pattern recognition methods, the system can accurately detect leak events in real time. The integration of pattern recognition with ultrasonic sensing has been shown to improve detection accuracy, reduce false positives, and support early warning mechanisms in smart water management systems (Patel and Shah, 2022).

MATERIALS AND METHODS

The architecture of the Reservoir Leakage Detection Monitoring and Management System (RLDMS) consist of four layers. The perception (sensor acquisition layer), signal processing layer, pattern recognition layer and decision management layer as shown in Figure 1.

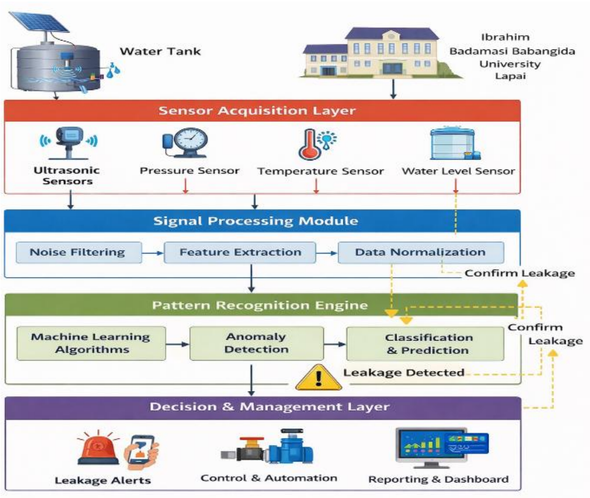

Figure 1: Architecture of the RLDMS

Figure 1 presents the architecture of the RLDMS; it consists of the four layers; the perception (sensor acquisition) layer, the signal processing layer, the pattern recognition layer and the decision management layer. The perception layer also known as the sensor acquisition layer is responsible for the detection and acquisition of signals. Ultrasonic sensors are placed in the reservoir measure water levels, detect leak events and flow rates precisely. They work by emitting high-frequency sound waves and measuring the time it takes for the echo to return analogue signals are detected by the sensors converted into digital signals and forward to the signal processing layer. Pressure, temperature and water flow sensors are used to provide multiple data analysis.

The signal processing layer receives the detected signals from the perception layer, denoise the signal, extract relevant features and normalize the data. At the pattern recognition layer, pattern recognition machine learning algorithm is applied for the modeling of the RLDMS for classification and detection of leak events. Monitoring and management of the overall RLDMs takes place at the decision and management layer. The layer consists of computer system, valve control and buzzer. When leak occurs, the sensor detects and transmit the signals to the decision and management layer via the signal and pattern layer. The leak events and other anomalies are displayed on the monitor. Figure 2 shows the sensors attached to the water reservoir.

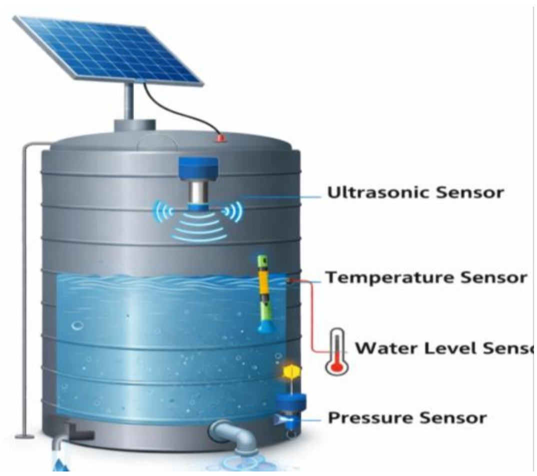

Figure 2: Water Reservoir and Sensor Configuration

The physical configuration of the reservoir equipped with temperature, ultrasonic, pressure and water level sensors all powered by an attached solar energy system. This configuration enables continuous and autonomous monitoring and management of the overall system. Machine learning based pattern recognition model is employed, consisting of pressure, temperature and flow rate. In training, the data were labeled with 0 representing normal state and 1 leak conditions. Figure 3 shows the developed prototype of the RLDMS

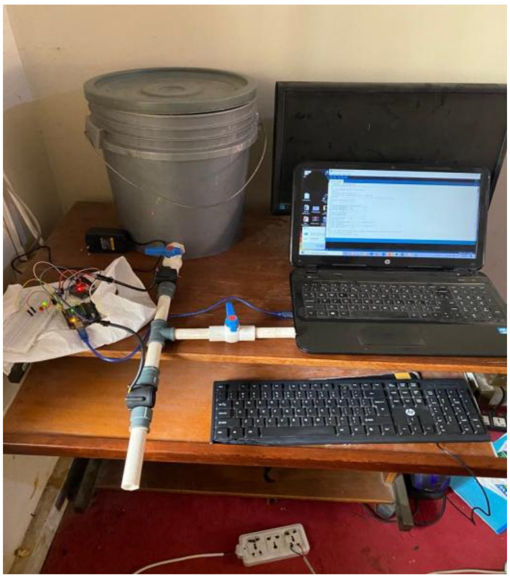

Figure 3: Prototype of the RLDMS

RESULTS AND DISCUSSION

The RLDMS integrates pattern recognition algorithms with ultrasonic sensing to identify abnormal conditions in real time. Experiments were conducted on a controlled reservoir testbed equipped with ultrasonic sensors. Artificial leakage scenarios were introduced by creating controlled seepage paths of varying sizes. Data were collected under different environmental conditions to evaluate system robustness. The datasets were divided into two subsets, 80% for training and 20% for testing the model.

Figure 4: Leak and No Leak Events

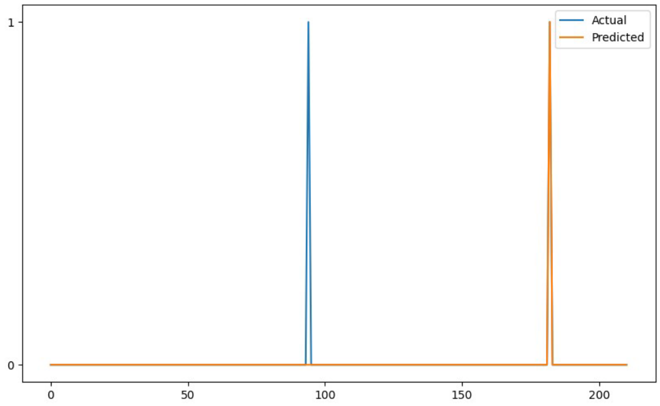

Figure 5: Actual Leak and Predicted Leak

Figure 5 shows the actual and predicted leak, with the blue curve depicting the truth label of the actual operational state of the model while the orange curve represents the classification output for each point of time metric, thus indicating the model can effectively efficiently detect reservoir leakage in real world scenario.

The system successfully identified leak events with high accuracy. Out of 50 scenarios, 48 leaks were correctly detected, resulting in an accuracy of 96%, with a sensitivity of 95% and specificity of 97%. False positives were minimal, occurring in only 2 cases, likely due to sudden water consumption fluctuations. Figure 6 summarizes these results.

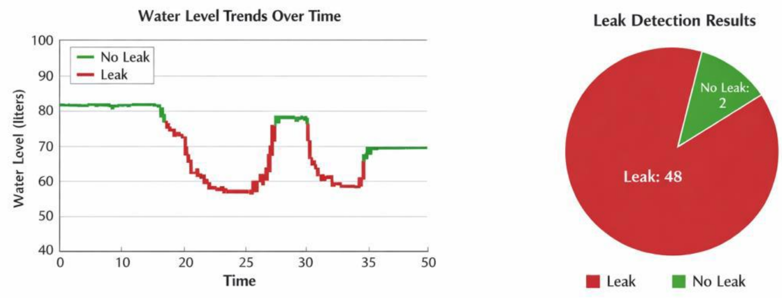

Figure 6: Water Level Trends and Leak Detection

Figure 6 illustrates the water level trends over time. Sudden drops in water level correspond to detected leak events (red), while stable periods represent no-leak states (green). The pattern recognition algorithm effectively distinguishes actual leak events from normal water usage variations, demonstrating robustness across different scenarios.

The experimental results demonstrate that the proposed multifactor approach significantly outperforms single-feature detection methods. The pattern recognition model achieved high classification accuracy across all leakage scenarios, with a notable reduction in false alarms. The system exhibited strong resilience to environmental noise and parameter variability, confirming the effectiveness of multifactor feature integration. Real-time detection capability was validated, making the system suitable for continuous reservoir monitoring.

CONCLUSION

The integration of ultrasonic sensing with pattern recognition provides reliable real-time leakage monitoring. The system's high detection accuracy and low false alarm rate indicate its suitability for practical deployment in water reservoir management. Limitations include potential environmental interferences, such as air bubbles or sensor misalignment, which could affect readings. The system accurately detects leaks in real time and provides clear visual feedback for operators. The dashboard-ready figures enable rapid interpretation of leak status and water levels, supporting timely interventions and minimizing water loss.

Future improvements may involve multi-sensor fusion and advanced machine learning models to enhance detection reliability.

REFERENCES

Djalilov, A., Sobiron, E., Nazarov, O., Urolou, S. and Gayipov, I. (2023). Study on Automatic Water Level Detection Process using Ultrasonic Sensor. *IOP Conference Series: Earth and Environmental Science*. Vol. 1142, doi: https://doi.org/10.1088/1755-1315/1142/1/012020.

Gati, M. A and Lias, J. (2022). Monitoring the Water Level System using Ultasonic Sensor. Evolution in Electrical and Electronic Engineering Vol. 3 No. 2 (2022) 642-649

Kumar, A., & Singh, R. (2021). Smart water tank monitoring and leakage detection using ultrasonic sensors. International Journal of Smart Infrastructure, 5(2), 45–53.

Kumawat, R., Tambe, T., Vishwakarma, V. and Ansari,R. (2022). Water Level Monitoring System using IOT. *International Journal of Research Publication and Reviews. 3(11), pp 1159-1161.*

Li, X., Zhang, Y., & Wang, J. (2019). Water leakage detection based on ultrasonic sensing and signal analysis. Sensors, 19(18), 4025

Patel, R., & Shah, M. (2022). Pattern recognition–based smart water tank monitoring using ultrasonic sensors. Measurement, 195, 111091.

Pawar, J., Deshpande, A., Kalikate, S., Ranade, N., Diwanji, A., & Kshirsagar, K. (2022). Water leakage detection system. International Journal of Engineering and Management Research, 12(6), 259–263. https://doi.org/10.31033/ijemr.12.6.35

Pranita, S. P., Poorwa D. K., Shambhavi B. R., Nitin P. M. and Rajendra G. K. (2020). Water Level Monitoring and Leakage Detection System using Long Range Module (LoRa), Volume 12, Special Issue 2, 2020

Shiddiqi, A., Cardell-Oliver, R. and Datta, A. (2020). An Advanced Sensor Placement Strategy for Small Leaks Quantification Using Lean Graphs, Journal of Water, vol. 12, p. 3439, 2020.

Zhang, H., Liu, Y., & Chen, X. (2020). Leakage detection in water storage systems using pattern recognition and ultrasonic sensing. IEEE Sensors Journal, 20(14), 7856–7864.