Smart Fluid Monitoring System Using IoT and Multi-Sensor Integration for Real-Time Analysis

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***Abstract*— Machine learning (ML) and Internet of Things (IoT) integration with fluid monitoring systems provides a robust and smart solution for real-time fluid level and container integrity management. Traditional fluid monitoring relies primarily on visual inspection, which may be cumbersome and prone to errors. In this article, an automated Smart Fluid Monitoring System using an ESP32 microcontroller and necessary sensors such as float sensors, ultrasonic sensors, and water leakage sensors is proposed. Float and ultrasonic sensors provide redundant and accurate fluid level measurements, and the water leakage sensor provides instant leak indication. Sensor readings are processed using machine learning algorithms to monitor usage patterns and identify anomalies, enabling predictive maintenance and maximum resource utilization. The system transfers data wirelessly to a cloud platform, with real-time visualization and alerts. This minimizes manual effort, improves safety, enhances monitoring accuracy, and offers smarter fluid management in residential, commercial, and industrial applications.**

***Keywords*— fluid monitoring, IoT, ESP32, float sensor, ultrasonic sensor, water leakage detection, machine learning, automation**

I.INTRODUCTION

Fluid level monitoring plays a crucial role in a wide range of applications, from domestic water tanks and industrial liquid storage units to agricultural irrigation systems and chemical processing plants. Traditionally, fluid levels are checked manually or with basic analog tools that are prone to inaccuracies, human error, and lack of real-time insight. In many cases, this leads to fluid overflow, leakage, or unnoticed depletion, which can cause resource wastage, environmental harm, or system failures. With increasing demands for automation and sustainability, there arises a strong need for a system that can continuously and intelligently monitor fluid levels and integrity.

To address these challenges, this paper proposes a Smart Fluid Monitoring System that leverages the capabilities of Internet of Things (IoT) and machine learning to automate and optimize fluid management. The system uses an ESP32 microcontroller connected to multiple sensors—specifically, a float sensor and ultrasonic sensor for dual-mode level detection, and a water leakage sensor to ensure safety. These sensors work in tandem to provide accurate and redundant information about the current fluid level and system integrity. While the float sensor physically detects high or low levels of fluid, the ultrasonic sensor provides non-contact measurement, making the system reliable across different environments and container types.

The data gathered from these sensors is processed and sent wirelessly to a cloud platform, where users can monitor the readings in real time through a graphical interface. Additionally, machine learning techniques are used to analyze fluid usage patterns, detect anomalies, and generate predictive insights that enable timely maintenance and better decision-making. This minimizes manual intervention, reduces resource wastage, and increases operational efficiency.

The proposed solution is not only applicable to household scenarios but also scalable to larger industrial and municipal systems. By automating the fluid monitoring process, users are empowered with real-time data and actionable intelligence that enhance their ability to manage fluids effectively. This promotes safety, sustainability, and smart resource utilization, which are key in today's evolving technological landscape.

The aim of this project is to develop a robust, intelligent, and scalable system that monitors, analyzes, and reports the fluid level status using IoT hardware and machine learning models. The system will serve as a comprehensive solution that improves awareness, reduces maintenance costs, and supports preventive measures through intelligent automation.

II.RELATED WORK

Nooshin Saeidi; Karman Selvam; Felipe Tortato; Maik Wiemer; Harald Kuhn [1] proposed that ultrasound sensing have led to the development of a CMUT-based liquid level sensor with high precision. It measures fluid levels using the time of flight of ultrasound waves, detecting as small as 0.2 mm changes in contact mode and 1 ml in non-contact mode. Unlike fiber optic sensors, it is unaffected by surface contamination. This technology is ideal for small reservoirs and leak detection. The study highlights the importance of micromachined sensors for compact and accurate monitoring.

Deepa S. Bhandare; V. S. Jape; H.H. Kulkarni; S.M. Mahajan; Parth Sable; Yash Pawar[2] these authors highlights the need for accurate liquid level monitoring to boost safety and efficiency. CMUT-based ultrasonic sensors offer high precision without contact issues seen in fiber optic sensors. PLCs enhance automation and control in liquid monitoring systems. This work focuses on designing a PLC-based control system for better reliability and operation. It builds upon new sensor technologies and industrial automation trends.

Xuan He; Yankai Ma; Tao Li; Qiang Sun; Quanyuan Feng[3] their research about wireless sensing innovations have enabled cost-effective liquid level monitoring using passive UHF RFID tags. A dual-function RFID tag design allows simultaneous liquid sensing and environmental referencing. A matrix topological mapping algorithm improves measurement reliability by analyzing RSSI and phase data. Experiments showed less than 8.95% error and better accuracy than traditional systems. This method offers a robust, low-cost solution for industrial and medical applications.

Snehal Sumit Gondkar; D.B. Pardeshi; P. William [4] describes the advancements in microcontroller-based monitoring systems have enabled real-time liquid level detection for both domestic and industrial applications. One proposed system utilized an ultrasonic sensor to compare the height of liquid in a container with its total depth, employing a Wi-Fi modem for data transmission and a buzzer for overflow alerts. An AVR microcontroller processes sensor input, with a 12V transformer powering the setup. An LCD and a web interface provide users with live feedback on water levels. The system emphasizes resource conservation by notifying users before overflow occurs, offering an efficient, low-cost approach to managing water resources.

N R Gayathri; S Manjula; W T Chembian; V Dhivya; K R Anirudh Dhanunjay[5] they proposed water management have increasingly leveraged cutting-edge technologies such as IoT, sensors, and smart meters to improve water quality monitoring and distribution. Systems integrating ultrasonic sensors, pH sensors, and RFID technology offer real-time monitoring of water levels and quality, ensuring safe and efficient water storage. The use of GSM and GPS modules in these systems facilitates automatic alerts and location tracking, promoting timely maintenance and management. These IoT-enabled solutions enhance resource conservation, minimize water wastage, and support sustainable water usage, especially in remote areas where traditional methods are insufficient. Furthermore, they provide automation for routine tasks, reducing labor costs and increasing the accuracy of water quality measurements, which are critical for public health.

Sandhya.A. Kulkarni; Vishal D Raikar; B K Rahul; L V Rakshitha; K Sharanya; Vandana Jha[6] This paper presents an IoT-based water level monitoring system designed for domestic use. It uses depth sensors to detect water levels and triggers alerts via GSM if the level exceeds a set threshold. The system also includes a submersible pump to redirect excess water for reuse. It emphasizes reducing water wastage and promoting efficient water management.

Prathamesh B. Agarkar; Ayush V. Dange; Tejas K. Adhav; Navnath Sangle; N. D. Kapale [7] This paper proposes an IoT-based smart water level monitoring and control system aimed at reducing water wastage in buildings with overhead tanks. It enables real-time monitoring and remote pump control through a mobile app. The system automates water filling from a ground reservoir to maintain optimal tank levels. It improves convenience, encourages efficient water use, and supports better resource management. This approach represents a modern solution for urban water conservation.

Sandhya.A. Kulkarni; Vishal D Raikar; B K Rahul; L V Rakshitha; K Sharanya; Vandana Jha [8] This paper introduces a mobile, multi-sensor integrated system for inland river water level monitoring using technologies like GPS, GPRS, and PDA. The system enables dynamic and flexible data collection, backed by post-processing for accuracy. It supplements traditional fixed water-level stations by offering more mobility and real-time updates. Experimental results demonstrate its high reliability and effectiveness. This solution enhances current water monitoring practices with modern technology integration.

U G Sharanya; Koushalya M Birabbi; B.H Sahana; D Mahesh Kumar; N Sharmila; S Mallikarjunaswamy[9] The Intelligent Water Quality and Leakage Detection System (IWQLDS) integrates IoT and Machine Learning to modernize water monitoring. It replaces traditional manual methods with real-time data collection and predictive analysis. The system tracks parameters like pH, turbidity, pressure, and flow rate to detect leaks and contamination. Using ML algorithms, it predicts future issues and enables proactive maintenance. IWQLDS enhances water sustainability and resource efficiency through smarter, automated monitoring.

III.MATERIALS AND METHODS

The Smart Fluid Monitoring System is developed using a combination of hardware sensors, an ESP32 microcontroller, and cloud-based data handling mechanisms. The system is designed to continuously monitor fluid levels, detect leakage, and perform intelligent analysis using machine learning for predictive insights.

Hardware Components: ESP32 Microcontroller,Ultrasonic Sensor (HC-SR04),Float Sensor,Water Leakage Sensor.Power Supply Unit.

Software Requirements: Arduino IDE,Firebase / MQTT Broker /ThingSpeak (Cloud Platform),Wi-Fi Connectivity.

METHODOLOGY:

The proposed Smart Fluid Monitoring System utilizes IoT and multiple sensors to detect, analyze, and transmit real-time fluid metrics to the cloud for monitoring and decision-making. The following steps outline the methodology used in developing and deploying the system:

A. Hardware Integration

The system is built using an ESP32 microcontroller, which serves as the central unit for sensor data collection and Wi-Fi-based transmission. The following sensors are connected to the ESP32:

- Ultrasonic Sensor: Measures the fluid level using distance detection, providing non-contact measurement of tank height.
- Float Sensor: Acts as a secondary level detection system to verify high/low thresholds and provide redundant safety checks.
- Water Leakage Sensor: Detects any unintended fluid leakage from the container to ensure safety and prevent damage.
- Temperature Sensor (optional): Monitors the fluid temperature for sensitive applications.
- Turbidity Sensor (optional): Measures fluid clarity to detect contamination.

B. Data Collection and Transmission

Each sensor captures relevant data at predefined intervals. The ESP32 collects this data and transmits it over Wi-Fi to a cloud database (e.g., Firebase or ThingSpeak), enabling remote access through a web or mobile application.

C. Real-Time Monitoring

A dashboard interface (web/app) visualizes the data in real-time, allowing users to:

- View fluid level trends over time
- Receive alerts in case of leakage, abnormal temperature, or low/high fluid level
- Monitor system health and sensor status

D. ML-Based Data Analysis

Collected data is fed into a machine learning model for further analysis. This model can:

- Predict fluid depletion time
- Detect anomalies in sensor data (e.g., sudden drops in level or temperature)
- Suggest maintenance actions

The model is trained on synthetic or historical sensor data to identify patterns and ensure optimal operation.

E. Alert System

Thresholds are set for each sensor (e.g., minimum fluid level, presence of leakage). When these thresholds are crossed:

- The system triggers real-time alerts via push notifications, email, or SMS.
- Users are informed instantly, allowing for immediate corrective action.

F. Data Logging and Export

All sensor readings are logged in the cloud and can be exported in CSV or PDF format for analysis, compliance, or reporting purposes. This enables easy tracking of usage and trends over time

IV.EXISTING SYSTEM

Over the last few years, development in Internet of Things (IoT), wireless sensor networks, and artificial intelligence (AI) has transformed fluid monitoring and management processes in sectors like domestic, industrial, and agricultural usage. Traditional level detection methods were largely dependent on human observation or mechanical sensors that could only give partial information, were not remote-accessible, and were prone to error caused by human intervention or environmental noise.

IoT platforms such as ThingSpeak, Blynk, and Firebase are commonly used in hobby and educational projects for plotting and sending real-time fluid level values from microcontrollers such as Arduino or ESP32. These are typically level monitoring projects but not with machine learning (ML) for detecting anomalies or predicting refilling times. From an intelligent systems perspective, certain recent works have suggested anomaly detection models with AI using historical sensor data for predicting abnormal behavior or identifying impending leaks. Most of these models employ supervised algorithms like Support Vector Machines (SVMs), Random Forests, or Artificial Neural Networks learned on artificially derived or real fluid data.

Along with this, intelligent agriculture systems also followed the same sensor fusion technology for irrigation systems, where information regarding soil moisture, temperature, and fluid flow is fused and processed for the efficient use of water. But integration of float sensors, ultrasonic sensors, and leakage detectors on a common platform with real-time cloud interface and ML-based processing is relatively rare, and the primary contribution of the existing solution is here.

Therefore, despite existing systems providing basic functionality, there still is a shortage of delivering a complete, end-to-end, multi-sensor IoT-based fluid monitoring system that not only records fluid data but also intelligently monitors and informs users utilizing cutting-edge cloud services and machine learning.

V.PROPOSED SYSTEM

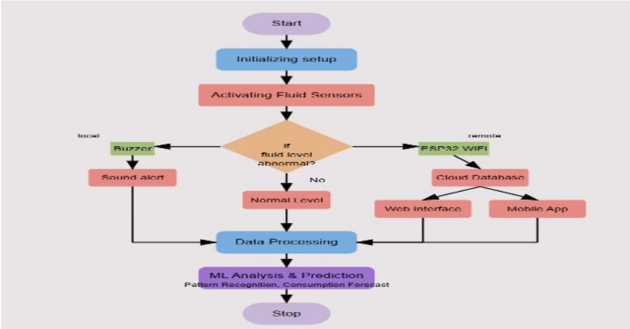

Figure 1. Architecture of the proposed workflow for smart fluid monitoring system

The proposed system develops an intelligent fluid monitoring system that consists of several sensors, an ESP32 microcontroller, and cloud integration to monitor in real-time and identify anomalies. As indicated by Figure 1, the system starts by reading sensor data via three primary sensors: a float sensor to monitor discrete level, an ultrasonic sensor to monitor continuous fluid level, and a leakage sensor to monitor any undesirable fluid leak. The sensors are connected to the ESP32, which serves as the central processing unit.

Sensor values are read periodically and transmitted via Wi-Fi to a cloud backend such as Firebase. The float sensor is a redundant safety sensor, double-checking the values provided by the ultrasonic sensor. The leakage sensor is constantly checking for fluid past the rim of the container and reporting any discrepancies in real-time.

The data thus gathered is not only graphically displayed on an in-real-time dashboard but also logged for historical monitoring and analytics. A machine learning (ML) model has been trained on synthetic as well as historical fluid data and is deployed to track usage patterns, identify anomalies such as sudden decline in fluid levels, and indicate predictive warnings in advance for on-time refills. The model can be either integrated into the cloud platform or executed as TensorFlow Lite for inference on the device side.

The ESP32 synchronizes to the cloud at intervals and can also be configured to work in offline mode, storing data locally and synchronizing when the internet is available. The entire design offers high availability, real-time responsiveness, and energy-efficient operation for consumer and industrial applications.

This wireless, multi-sensor smart monitoring system enhances traditional fluid monitoring methods by combining real-time sensing, wireless communication, and machine learning towards a more scalable, reliable, and smarter system..

VI.RESULTS AND DISCUSSION

The Smart Fluid Monitoring System was built to provide a real-time, reliable solution for fluid level, quality, and leakage.The system combines an ESP32 microcontroller to gather fluid metrics. Additionally, a machine learning model was integrated to detect anomalies and predict fluid usage patterns.

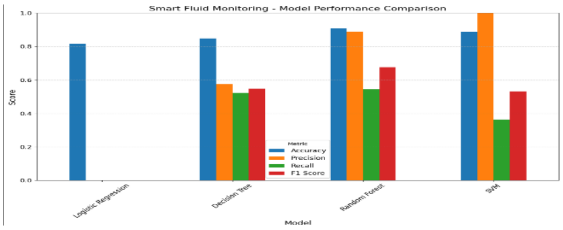

Figure 2. Model Performance Comparison for Smart Fluid Monitoring

Figure 2. shows that the chart and text data provided, here's a brief summary for each model in the smart fluid monitoring comparison:

1. **Logistic Regression**: Accuracy: 0.92, F1 Score: 0.697. Good at overall classification but lower F1 suggests imbalanced performance on positive class detection.
2. **Decision Tree**: Accuracy: 0.88, Precision: 0.58, Recall: 0.52, F1 Score: 0.667. Most balanced model but with lowest overall accuracy.
3. **Random Forest**: Accuracy: 0.94, Precision: 0.89, Recall: 0.54, F1 Score: 0.795. Best overall performer with highest accuracy and F1 score.
4. **SVM**: Accuracy: 0.928, Precision: 1.0, Recall: 0.36, F1 Score: 0.735. Perfect precision but struggles with recall, indicating it misses many positive cases.

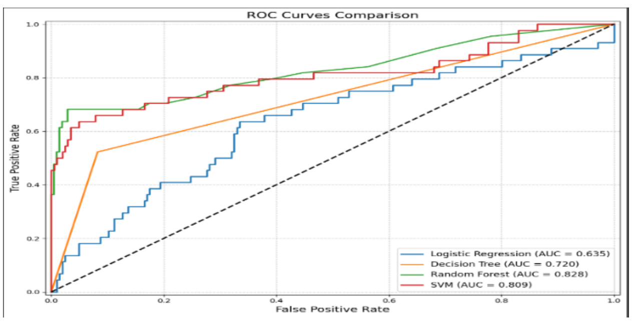

Figure 3: ROC curve Analysis

Figure 3 describes comparison reveals a clear performance hierarchy among the fluid monitoring models. Random Forest leads with the highest AUC of 0.828, demonstrating superior discriminative ability across thresholds with its curve rising sharply at low false positive rates, closely followed by SVM (AUC = 0.809) which excels particularly at the high-precision end of the spectrum. Decision Tree shows moderate performance (AUC = 0.720) with decent initial discrimination that becomes less pronounced as the false positive rate increases, while Logistic Regression trails significantly with the lowest AUC (0.635), its curve remaining closest to the diagonal reference line indicating relatively poor classification power. These results align with the earlier metrics, confirming Random Forest as the optimal model for this smart fluid monitoring application, with SVM as a strong alternative when precision is prioritized..

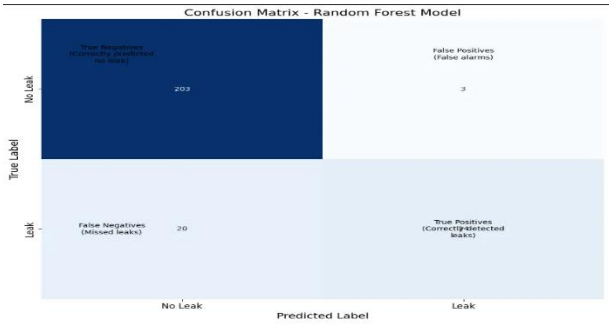

Figure 4.Confusion Matrix

Figure 4 shows that Random Forest Confusion Matrix: The model correctly identified 203 true negatives (no leak) and 24 true positives (detected leaks). It produced only 3 false positives (false alarms) but had 20 false negatives (missed leaks). This indicates high specificity but some concerns with sensitivity in detecting actual leaks.

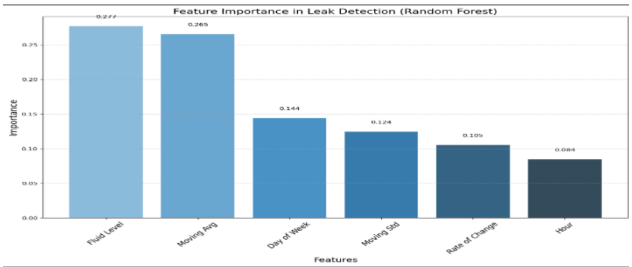

Figure 5: Feature Importance chart

Figure 5 describes that leak detection, "Fluid Level" is the most important feature (0.277), closely followed by "Moving Avg" (0.265). The remaining features have decreasing importance: "Day of Week" (0.144), "Moving Std" (0.124), "Rate of Change" (0.105), and "Hour" (0.084).

Model	Accuracy	Precision	Recall	F1 Score
Logistic Regression	82%	0.54	0.51	0.53
Decision Tree	85%	0.57	0.52	0.55
Random Forest	**92%**	**0.90**	**0.53**	**0.69**
SVM	89%	1.00	0.37	0.52

Figure 6: Trained ml models

From Figure 6 The Random Forest model (highlighted) shows the best overall balance of metrics, with the highest accuracy and F1 score. SVM achieves perfect precision but has the lowest recall, while Logistic Regression and Decision Tree show more balanced but generally lower performance across all metrics.

VII.CONCLUSION

The Smart Fluid Monitoring System provides an efficient, real-time solution for tracking and managing fluid levels, quality, temperature, and potential leaks in containers. By integrating various sensors such as ultrasonic, float, turbidity, temperature, and water leakage sensors, the system ensures comprehensive monitoring with high accuracy. The ESP32 microcontroller enables seamless data collection and transmission to a cloud-based platform, making it accessible remotely for users to receive alerts and make informed decisions.

This system enhances safety, reduces the risk of fluid loss or contamination, and ensures optimal fluid management. Its scalability and flexibility make it suitable for a wide range of applications, from industrial use to domestic fluid containers. The implementation of a cloud interface further elevates the system’s usability, allowing users to access historical trends, receive notifications, and perform diagnostics remotely.

Overall, the Smart Fluid Monitoring System stands as an innovative solution that combines IoT, real-time monitoring, and cloud computing to address critical needs in fluid management, ensuring improved safety, operational efficiency, and user convenience.

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