Journal on Technical and Vocational Education (JTVE), Vol 11 No 1 (April, 2026)
eISSN: 0128-0821 http://upikpolimas.edu.my/ojs/

Smart Pipe Leakage Detector

Jamilah binti Abbas[1], Nor Hazlin binti Md Gharip[1], Azizi Mursidy bin Zainol Abidin[2], Zarina binti Mat Sapri[2]
[1]Politeknik Sultan Azlan Shah, Department of Civil Engineering, 35950 Behrang, Perak
[2] Politeknik Sultan Salahuddin Abdul Aziz Shah, Department of Civil Engineering, 40150 Shah Alam, Selangor

Abstract: Water leakage in concealed or underground piping systems often causes significant water loss and increases maintenance costs. This project aims to design and develop a Smart Pipe Leakage Detection System that efficiently detects leaks using acoustic sensors and Internet of Things (IoT) technology. It supports Sustainable Development Goal (SDG) 6: Clean Water and Sanitation and SDG 9: Industry, Innovation and Infrastructure by promoting efficient water management and sustainable innovation. The system integrates a stethoscope-type acoustic sensor to detect abnormal pipe vibrations, an ESP32 microcontroller for data processing and wireless communication, and the Blynk IoT platform for real-time monitoring. When a leak is detected, the system alerts users through indicator lights, mobile notifications, and email alerts. Product testing involved simulating different leak conditions to analyze accuracy and response time. Results showed that the system reliably detects leaks and provides instant notifications. User evaluation confirmed the system's effectiveness, efficiency, and ease of maintenance. This smart system helps reduce water wastage, lower repair costs, and support sustainable water management practices. In conclusion, this project demonstrates a reliable and innovative leak detection solution for modern infrastructure.

Key words: *Pipe leakage, acoustic sensor, leak detection, water management*

1.0 Introduction

Water leakage in piping systems, especially in hidden or underground pipes, can cause significant water loss, property damage, and increased maintenance costs. Traditional leak detection methods are often manual, time-consuming, and reactive. The Smart Pipe Leakage Detector project aims to address these issues by developing an automated system that detects leaks in real-time using acoustic sensors, pressure monitoring, and IoT technology. By integrating the ESP32 microcontroller, Blynk IoT platform, and LED indicators, the system provides early alerts of pipe leaks, enabling faster maintenance and efficient water management. This project supports sustainable water usage and aligns with global initiatives such as SDG 6 (Clean Water and Sanitation) and SDG 9 (Industry, Innovation, and Infrastructure).

2.0 Literature Reviews

2.1 Traditional Methods of Leak Detection

Early leak detection techniques relied heavily on manual inspection and basic monitoring methods, which had limitations in efficiency and accuracy. Human inspection remains the most basic method. It uses signs such as stains, damp patches, peeling paint, or flowing water from visible outlets. The inspection visual method involves physically inspecting pipelines for visible signs of leakage, such as pooled liquid or soil discoloration. Although simple, it is labor-intensive and ineffective for underground or small leaks. Dángelo et al. (2018) note that visual inspection is widely used for roof and wall leaks due to simplicity and low cost. However, visual methods are subjective and fail in early hidden-pipe leaks (Kang & Siravara, 2019). Thus, the efficiency of these techniques depends on the inspector's experience

(Clifton et al., 2020). Mohd Yussof et al. (2020) show that pressure testing can detect leakage in mains and services using controlled pressure drops.

Leaks create sound as water escapes pressurized pipes. Therefore, acoustic methods detect sound waves generated by escaping fluid or gas. While useful, especially for gas pipelines, performance may be affected by environmental noise and may not reliably detect small or remote leaks. Flow meters identify discrepancies between expected and actual flow rates, while pressure testing detects pressure drops within the pipeline. Although more reliable than visual inspection, pressure testing often requires temporary shutdowns and is not suitable for continuous monitoring. Overall, traditional methods are time-consuming, labour-intensive, and less effective for detecting small or slow leaks.

2.2 Sensor Technologies for Leak Detection

To improve efficiency and accuracy, modern leak detection systems increasingly use advanced sensor technologies that enable continuous and real-time monitoring. Pressure Sensors continuously monitor pipeline pressure and can detect sudden pressure changes caused by leaks. However, they require regular calibration and may be less sensitive to very small leaks. Flow sensors measure the rate of fluid or gas movement and are often combined with pressure sensors to enhance detection accuracy. Acoustic Emission (AE) sensors detect high-frequency sound waves generated by cracks or escaping fluids. They are highly sensitive to small leaks but can be affected by environmental interference.

Temperature sensors and infrared thermography technologies detect temperature variations caused by leaks. They are effective for above-ground pipelines but less reliable for underground systems. Vibration sensors monitor changes in pipeline vibration patterns and are often integrated into multi-sensor systems for improved reliability. Modern sensor technologies significantly enhance early leak detection and overall system efficiency.

2.3 Machine Learning and Artificial Intelligence in Leak Detection

Machine learning (ML) and artificial intelligence (AI) improve leak detection by analyzing large volumes of sensor data to identify abnormal patterns. Anomaly Detection, such as Support Vector Machines (SVM), classifies operational data as normal or leak conditions. These systems improve over time through continuous training. Artificial Neural Networks (ANN) and deep learning models can detect complex and subtle changes in pressure, temperature, and flow data, enabling accurate real-time leak prediction.ML models analyze long-term data to predict potential pipeline failures, allowing preventive maintenance and reducing downtime and repair costs. Integrating ML with IoT enables decentralized data processing through edge computing. This reduces latency and allows faster decision-making in leak detection systems.

3.0 Methodology

3.1 Project Design

The Smart Pipe Leakage Detector was designed as a portable and IoT-enabled monitoring device capable of detecting water leaks using acoustic sensing technology. The system architecture consists of three primary subsystems: sensing, processing, and communication. The sensing subsystem includes an acoustic sensor integrated with a microphone amplifier to capture and enhance leak-generated sound signals. The processing subsystem is centered on the ESP32 microcontroller, which analyzes incoming signals and determines leakage conditions. The communication subsystem enables wireless transmission of data to a mobile application via Wi-Fi connectivity. The design prioritizes portability, ease of operation, low power consumption, and real-time responsiveness. The device is enclosed in a compact structure equipped with a handle to facilitate stable positioning during inspection.

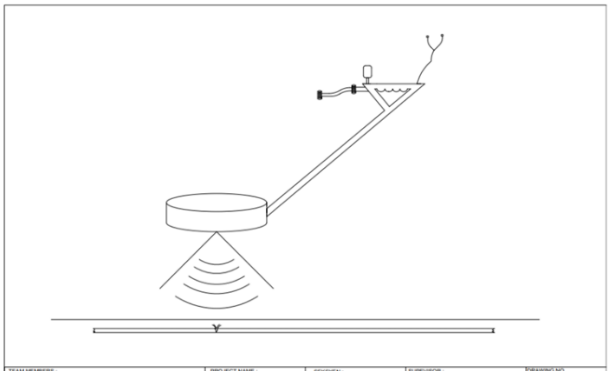

Figure 1.0: Schematic diagram of project design Smart Pipe Leakage Detector

3.2 Item Selection and Justification

The selection of components was based on performance requirements, reliability, energy efficiency, and cost considerations. Each component contributes to the overall effectiveness of the system.

3.2.1 Acoustic Sensor (Stethoscope Type)

The acoustic sensor serves as the primary detection element. It captures high-frequency sound waves generated by water escaping from cracks or joints. This non-invasive method enables early detection without dismantling pipeline structures.

Figure 2.0: Acoustic Sensor

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3.2.2 Battery

A rechargeable battery provides a portable and continuous power supply, enabling operation in remote or underground locations where direct electrical access is unavailable.

3.2.3 Handle

The handle enhances ergonomic stability and ensures consistent sensor contact with the pipeline surface, improving measurement accuracy during inspection.

3.2.4 Blynk IoT Application

The Blynk IoT platform enables real-time remote monitoring. Sensor data are transmitted wirelessly to a smartphone interface, where users can visualize readings, receive alerts, and monitor system status.

Figure 3.0: Implementation of Blynk- Based Iot Monitoring System

3.2.5 Smartphone (Display Interface)

The smartphone acts as the primary display and notification interface, eliminating the need for additional hardware display modules.

3.2.6 ESP32 Microcontroller

The ESP32 functions as the central processing unit. It processes acoustic data, executes detection algorithms, and manages wireless communication. Its built-in Wi-Fi capability and low power consumption make it suitable for IoT-based applications.

Figure 4.0: ESP32 Microcontroller

3.2.7 LED Indicator (Three-Color System)

The LED provides immediate visual feedback regarding system status, including normal operation, warning, and leak detection conditions.

3.2.8 Microphone Amplifier (MAX4466 / MAX9814)

The amplifier enhances low-amplitude acoustic signals, ensuring accurate detection of subtle leak-generated sounds while minimizing noise interference.

3.2.9 Voltage Regulator / Buck Converter

The voltage regulator ensures stable and consistent power delivery to all components, preventing damage from voltage fluctuations and improving overall system reliability.

3.2.10 Arduino IDE / Platform IO

The development environment was used for firmware programming, algorithm testing, and system debugging. It facilitated the efficient implementation of signal processing and IoT communication protocols.

3.3 Installation of the equipment

The methodology of this study consisted of four main phases: system design, hardware development, testing and calibration, and system evaluation. Initially, appropriate sensors were selected based on their suitability for water leak detection. A microphone was employed to detect high-frequency acoustic signals generated by leaks, a pressure gauge was used to monitor pressure fluctuations within the system, and ultrasonic sensors were integrated to identify structural irregularities in pipelines.

Following sensor selection, the hardware system was developed by integrating all sensors with a microcontroller. Proper wiring connections and a stable power supply were established. The microcontroller was programmed to collect, process, and analyze sensor data using predefined detection algorithms.

Subsequently, the system underwent controlled experimental testing to assess its functionality under various leak conditions, including different leak sizes and pipe materials. Each sensor was calibrated to optimize detection sensitivity and accuracy.

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Finally, system performance was evaluated using key metrics such as detection accuracy, response time, false positive rate, and power consumption. Based on the evaluation outcomes, improvements were implemented to enhance system reliability and overall performance.

4.0 Results and analysis

The Smart Pipe Leakage Detector successfully identified leaks in the tested pipe system. Sensor data from the acoustic and pressure sensors were accurately transmitted to the Blynk IoT platform, allowing real-time monitoring. The LED indicators provided immediate visual alerts whenever a leak was detected. Testing showed that the system could detect small and large leaks with high reliability. Analysis of the data confirmed that the combination of acoustic sensing and pressure monitoring improves detection accuracy, making the system effective for proactive water management and maintenance**.**

Figure 4.0: Smart Pipe Leakage Detector

The system uses visual indicators to show the current leak status. A green circle under "Normal" signifies that no leakage is currently detected. If the sensor readings exceed the predefined thresholds, the "Possible Leakage" indicator, shown in yellow, will illuminate, alerting users to a potential issue. Should the readings continue to rise beyond critical levels, the "Leakage" indicator, shown in red, will light up, signaling an active leak that requires immediate attention**.**

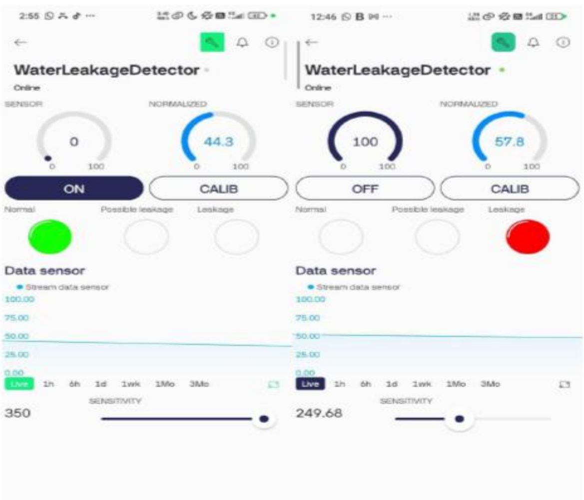

Figure 5.0 : Green Indicator (No Leakage) & Red Indicator (Leakage)

5.0 Discussion and Conclusions

The Smart Pipe Leakage Detector project successfully developed an automated system for detecting water leaks in pipes. By integrating acoustic sensors, pressure monitoring, ESP32 microcontroller, and Blynk IoT, the system can monitor pipes in real-time and provide immediate alerts through LED indicators. Testing showed that the system is reliable and capable of detecting leaks accurately, including small or hidden leaks. This project contributes to efficient water management, reduces maintenance costs, and supports sustainable practices aligned with SDG 6 (Clean Water and Sanitation) and SDG 9 (Industry, Innovation, and Infrastructure).

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