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IoT-Based Continuity Analysis of Oil Pipeline Leakages

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Abstract

Oil pipeline leaks represent a complex and critical issue due to their potential to cause significant economic losses and severe environmental damage. This incident not only disrupts industrial operations but also poses risks to surrounding ecosystems and communities. Therefore, early detection and real-time monitoring are essential to minimize these adverse effects and enable a faster and more effective response to leakage events. This research aims to develop an Internet of Things (IoT)--based oil pipeline leak monitoring system by utilizing actual data obtained by integrating multiple sensors. Using actual data collected from field-simulated scenarios provides a realistic basis for evaluating system performance under real operating conditions. The proposed system employs an ultrasonic sensor (HC-SR04) to measure fluid levels within pipelines, a temperature sensor (DS18B20) to detect temperature fluctuations, and a pressure sensor to identify changes in internal pipeline conditions. All sensor data are wirelessly transmitted to a web-based application using a NodeMCU ESP32 microcontroller, enabling continuous remote monitoring. Additionally, sensor readings are displayed locally on an LCD screen to support immediate on-site observation. System evaluation was conducted through a series of controlled experiments simulation variations in pressure, temperature, and leak scenarios.), to evaluate the system's accuracy, precision, and consistency in leak detection. These metrics were used to measure the accuracy, precision, and consistency of the system's ability to detect leaks. This demonstrates a high level of reliability and effectiveness in monitoring real-time changes in pipeline conditions. Overall, the developed system proved effective in enhancing reliability in oil pipeline leak monitoring, facilitating faster responses and significantly reducing potential negative impacts caused by leaks.

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1. Introduction

Pipeline leaks are a critical issue that must be addressed by every industry operating a distribution system. Along with the advancement of pipeline networks, the number of leak incidents has increased, many of which go unaddressed by the industries concerned. This has drawn significant attention, particularly regarding efforts to prevent pipeline leaks from occurring[1], [2]. Pipeline leaks can lead to a significant drop in pressure within the pipeline. These leaks occur when fluid escapes from the piping system due to damages such as holes or cracks, allowing the fluid to exit in the form of liquid, gas, or solid[3].

Water flow sensors and the Internet of Things (IoT) streamline the process of monitoring pipeline networks. Water flow sensors are used to track the flow rate and measure the volume of water passing through the pipes. This data is critical for detecting anomalies that might indicate leaks. Meanwhile, IoT technology is employed to transmit data from sensors to the cloud in real time, enabling further processing, such as analyzing water consumption volume and changes in flow rate along the pipeline[4].

How to cite:

Understanding fluid behavior within pipelines is essential in analyzing and preventing leaks, as the physical and dynamic properties of the fluid-such as viscosity, flow velocity, and pressure greatly influence the stability of flow within the pipe. When a leak occurs, changes in inflow patterns and pressure can be used as indicators to detect the location and severity of the leak[5]. However, in practice, leak detection is often still performed manually by conducting direct field inspections. This method is not only time-consuming but also inefficient, potentially delaying the response to leaks, especially in large and hard-to-reach pipeline networks. Such conditions pose a serious challenge for industries that rely heavily on pipelines as their primary distribution system[6].

Therefore, early detection systems are crucial to prevent the widespread consequences of such leaks. The advancement of big data technology and predictive analytics also offers a more sophisticated approach to leak detection. By combining historical sensor data with statistical pattern analysis, systems can predict the likelihood of leaks before they occur. This technology works by identifying anomalies through learning from past data, enabling more strategic preventive action[7]. Compared to conventional methods, IoT-based systems often require routine field inspections by personnel, which are time-consuming, resource-intensive, and prone to human error. In contrast, IoT systems can automatically send alerts, log data continuously, and detect anomalies with high accuracy, making them highly suitable for large-scale pipeline infrastructure[8]. In developing countries like Indonesia, leak detection remains a major challenge due to technological and infrastructural limitations. Many oil pipelines built decades ago lack modern monitoring of IoT-based detection systems, which is considered an appropriate solution as it is relatively low-cost easily integrated with existing infrastructure, and can be monitored remotely via an internet connection [9]. The selection of sensors and microcontrollers in this system is based on the characteristics of the monitored pipelines and fluids. Ultrasonic sensors are chosen for their ability to measure fluid levels without direct contact, while pressure sensors are used to detect sudden pressure drops indicative of leaks. The ESP32 microcontroller is selected for its Wi-Fi connectivity and high processing performance, enabling real-time data transmission to a web-based server. This combination has proven effective in various previous pipeline monitoring studies[10], [11].

To analyze the accuracy and precision of miniaturized pipelines in representing fluid flow and detecting leaks, it's crucial to assess how well these models mimic the dynamics of full-scale pipelines. Miniaturized systems must replicate physical properties like viscosity, flow velocity, and pressure, though challenges arise due to scaling effects such as surface friction and turbulence. Precision depends on design factors, including material selection, sensor placement, and flow control. For leak detection, miniaturized models must simulate both steady and transient flow conditions to detect pressure or flow changes caused by leaks. Sensor calibration and the ability to detect minor deviations are key to identifying early leakage signs. Integrating IoT-based sensors allows for real-time data comparison with historical data and predictive models, improving accuracy over time. High-precision sensors and microcontrollers like the ESP32 enhance detection precision, making miniaturized systems more accurate in mimicking full-scale behavior. Studies show that miniaturized systems with IoT sensors can achieve over 95% accuracy in laboratory settings, with advanced data analytics and machine learning improving leak detection by identifying hidden patterns[12].

Through this research, an Internet of Things (IoT)-based leak detection system is developed and enabled. Real-time monitoring through a web-based application. With this system, workers no longer need to conduct manual field inspections to identify leak points. This innovation was expected to improve the effectiveness of pipeline maintenance and reduce the environmental and economic risks associated with delayed leak responses[13]. In this context, the Internet of Things (IoT) today represents an effective way to monitor the intended environment. Its purpose is to ensure that physical devices equipped with embedded electronics, software, sensors, actuators, and network connectivity can identify, collect, and exchange data with one another[14]. The environmental impact of oil leaks extends beyond water pollution, affecting biodiversity and human health. Spilled crude oil can contaminate marine and river ecosystems causing mass mortality of fish, water flow, and other aquatic life. Additionally, oil contamination can degrade groundwater quality, potentially leading to a clean water crisis in communities near the incident site[15].

2. Methods

The implementation of this research begins with conducting a literature review on feasibility studies and planning in order to gain insights from previous studies in the relevant field. The following is an outline of the method applied:Provide sufficient detailed methods to allow the work to be reproduced. Methods already published should be indicated by a reference: only relevant modifications should be described:

2.1. System Desain Pipe

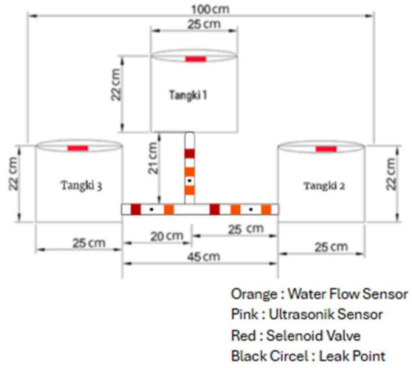

Figure 1. Two-Dimensional Oil Pipeline Design

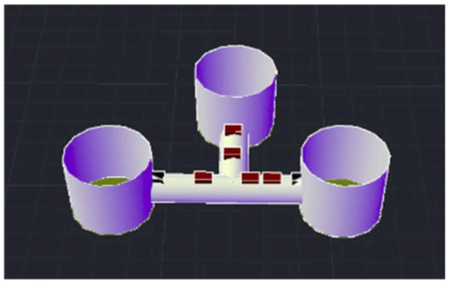

Figure 2. Three-Dimensional Oil Pipeline Design

Figure 1. Figure 1 presents the two dimensional layout of the T shaped pipeline: three tanks (Tangki 1–3) are connected by a 45 cm main header and two 25 cm branches; orange blocks denote five YF S201 flow sensors, pink blocks mark three HC SR04 ultrasonic sensors, red blocks indicate three solenoid valves, and black circles show the intentional leak points. Figure 2 translates this schematic into a three dimensional CAD model, clarifying the relative elevations and component placements.

During the instrumentation and design phase, each flow sensor and ultrasonic level sensor is installed, tested, and calibrated to generate two key data streams: (1) quantitative measurements—real time flow rates in each pipe segment and liquid heights in the three tanks, and (2) diagnostic insights—any discrepancy between the volume conveyed by the pipelines and the corresponding rise in tank levels. These data underpin validation of the solenoid valves' automatic cut off logic, enable early leak detection at the three critical points (left branch, right branch, and centre pipe), and provide an empirical basis for refining control algorithms, alarm thresholds, and loss mitigation strategies under realistic operating scenarios.

The practical implementation of this research therefore begins with a comprehensive literature review, which maps existing sensor technologies, leak detection methods, and pipeline control schemes;the insights gained from that review guide the subsequent hardware selection, system architecture, and experimental protocols employed throughout the instrumentation and design stage.

Instrumentation and design phase for the T-shaped pipeline system is essential to guarantee safe, efficient oil distribution before the plant enters full operation. During this stage, every flow sensor and ultrasonic level sensor is installed, tested, and calibrated to generate two key data streams: (1) quantitative measurements—real-time flow rates in each pipe segment and liquid heights in the three tanks, and (2) diagnostic insights—any discrepancy between the volume conveyed by the pipelines and the corresponding rise in tank levels. These data underpin validation of the solenoid valves' automatic cutoff logic, enable early leak detection at the three critical points (left branch, right branch, and central pipe), and provide an empirical basis for refining control algorithms, alarm thresholds, and loss-mitigation strategies under realistic operating scenarios. The practical implementation of this research therefore begins with a comprehensive literature review, which maps existing sensor technologies, leak-detection methods, and pipeline-control schemes; the insights gained from that review guide the subsequent hardware selection, system architecture, and experimental protocols used throughout the instrumentation and design phase

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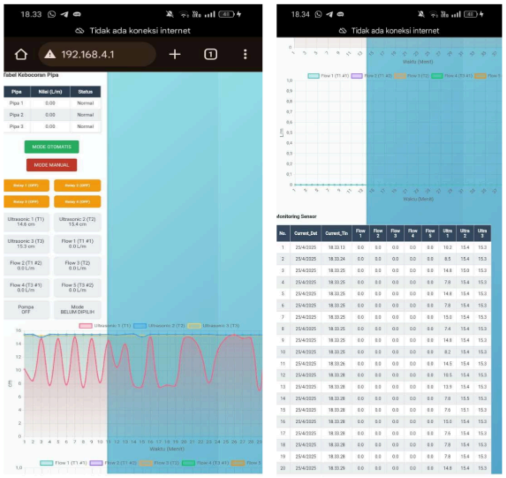


Tabel Kebocoran Pipa

Pipa	Nilai (L/m)	Status
Pipa 1	0.00	Normal
Pipa 2	0.00	Normal
Pipa 3	0.00	Normal

Ultrasonic 1 (T1) 14.6 cm
Ultrasonic 2 (T2) 15.4 cm
Ultrasonic 3 (T3) 15.3 cm
Flow 1 (T1 #1) 0.0 L/m
Flow 2 (T1 #2) 0.0 L/m
Flow 3 (T2) 0.0 L/m
Flow 4 (T3 #1) 0.0 L/m
Flow 5 (T3 #2) 0.0 L/m
Pompa OFF
Mode BELUM DIPILIH

Monitoring Sensor

No.	Current_Dat	Current_Tin	Flow 1	Flow 2	Flow 3	Flow 4	Flow 5	Ultra 1	Ultra 2	Ultra 3
1	25/4/2025	18.33.13	0.0	0.0	0.0	0.0	0.0	10.2	15.4	15.3
2	25/4/2025	18.33.24	0.0	0.0	0.0	0.0	0.0	8.5	15.4	15.3
3	25/4/2025	18.33.25	0.0	0.0	0.0	0.0	0.0	14.8	15.0	15.3
4	25/4/2025	18.33.25	0.0	0.0	0.0	0.0	0.0	7.8	15.4	15.3
5	25/4/2025	18.33.25	0.0	0.0	0.0	0.0	0.0	14.8	15.4	15.3
6	25/4/2025	18.33.25	0.0	0.0	0.0	0.0	0.0	7.8	15.4	15.3
7	25/4/2025	18.33.25	0.0	0.0	0.0	0.0	0.0	15.0	15.4	15.3
8	25/4/2025	18.33.25	0.0	0.0	0.0	0.0	0.0	7.4	15.4	15.3
9	25/4/2025	18.33.25	0.0	0.0	0.0	0.0	0.0	14.8	15.4	15.3
10	25/4/2025	18.33.25	0.0	0.0	0.0	0.0	0.0	8.2	15.4	15.3
11	25/4/2025	18.33.26	0.0	0.0	0.0	0.0	0.0	14.5	15.4	15.3
12	25/4/2025	18.33.28	0.0	0.0	0.0	0.0	0.0	10.5	15.4	15.3
13	25/4/2025	18.33.28	0.0	0.0	0.0	0.0	0.0	13.9	15.4	15.3
14	25/4/2025	18.33.28	0.0	0.0	0.0	0.0	0.0	7.8	15.5	15.3
15	25/4/2025	18.33.28	0.0	0.0	0.0	0.0	0.0	7.6	15.1	15.3
16	25/4/2025	18.33.28	0.0	0.0	0.0	0.0	0.0	15.0	15.4	15.3
17	25/4/2025	18.33.28	0.0	0.0	0.0	0.0	0.0	7.6	15.4	15.3
18	25/4/2025	18.33.28	0.0	0.0	0.0	0.0	0.0	7.8	15.4	15.3
19	25/4/2025	18.33.28	0.0	0.0	0.0	0.0	0.0	7.8	15.4	15.3
20	25/4/2025	18.33.29	0.0	0.0	0.0	0.0	0.0	14.8	15.4	15.3

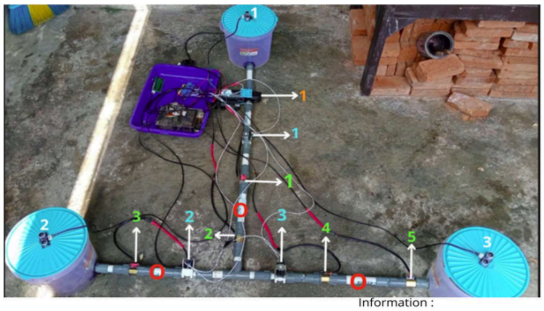
(a) (b)

Figure 3. Two-Dimensional Oil Pipeline Design

Figure 3 presents the web-based pipeline leak-monitoring system, which integrates real-time sensor acquisition with device control. The pipeline leakage monitoring system depicted in the images utilizes real-time data measurements from ultrasonic and flow sensors installed at various points within the pipeline system. The first image (a) presents the main user interface, displaying the status of sensors on pipes 1, 2, and 3, with the ultrasonic sensor readings shown in centimeters and a "normal" status. Users have the option to choose between Automatic Mode or Manual Mode, affecting the overall operation of the system. Additionally, the interface displays graphs that visualize fluctuations in data from the ultrasonic and flow sensors, with colors distinguishing each sensor for easy monitoring. The second image (b) provides more detailed information, where the graphs show the flow data and ultrasonic sensor readings for each pipe, along with a table that records the date, time, and measured sensor values. Which controls the pump to circulate water through the pipeline. When activated, Relay 1 turns on the pump to transfer water into the system. Relays 2, 3, and 4 each control a solenoid valve, used to regulate the flow of water at specific points in the pipeline. These solenoid valves operate by opening or closing depending on the commands received, allowing for precise control of water flow. Additionally, the graphs displayed show readings from five flow sensor points (Water Flow 1 to 5), which monitor the flow rate of water through the pipeline to detect significant changes in flow that may indicate a leakage.

The graphs also display data from three ultrasonic sensors (Ultrasonic 1, 2, and 3), which measure the water level within the pipeline and detect any changes in water levels that could signal potential leaks or other issues in the system. Overall, the system integrates device control and sensor monitoring, combining them into graphical visualizations to effectively and efficiently detect and address problems within the pipeline system.

2.3. Design and Function of Components in the Oil Flow Testing System



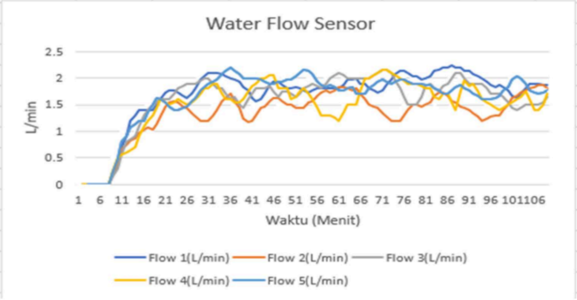
Information :
1 Orange = Pump12v
1-3 white = Ultrasonik Sensor
1-5 Green = Water Flow Sensor
1-3 Cyan = Selenoid Valve
3 Red Circel leak point

Figure 4. Design and Function of Components

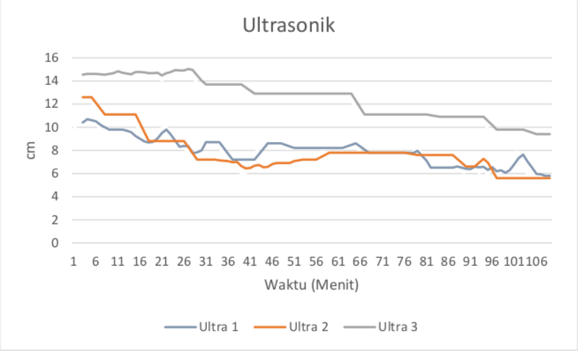
Figure 4 depicts an oil-flow testing system driven by a 12 V gear pump (orange label 1; 12 L min^{-1}, 2 m max head, 1.8 A). Under the supervision of an ESP32 micro-controller, the pump draws oil from Tank 1 and, via solenoid valves (cyan labels 1–3), divides the discharge into two branches that route the fluid toward Tank 2 and Tank 3. Each branch is instrumented with a YF-S201 flow sensor (green labels 1–5; 1–30 L min^{-1}) to record real-time volumetric flow, while an HC-SR04 ultrasonic sensor (white labels 1–3; 2–400 cm range, 3 mm resolution) tracks the corresponding rise in oil level in each tank when the lids are open. Three red-circled points on the piping serve as intentional leak sites for validation tests. At the start of a run, the ESP32 energises the pump, opens the solenoid valves in sequence to establish the flow path, and continuously acquires pulse counts and echo times from all sensors. Thus, the pump supplies motive force, the solenoid valves regulate flow direction, the flow sensors provide instantaneous rate data, and the ultrasonic sensors monitor stored volume, while the ESP32 orchestrates the entire procedure and logs each measurement. The assembly is powered by a regulated 12 V / 5 A supply and mounted in a protective ABS enclosure to ensure stable, safe operation.

3. Results and Discussion

3.1. Sensor Analysis of Oil Flow Rate in a Leaking Pipeline



(a) Graph of Oil Flow Rate Variations (Flow 1 - Flow 5) Showing Leakage

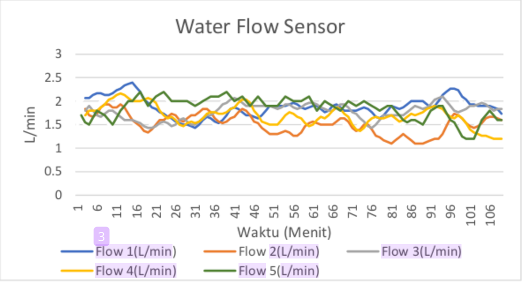


(b) Ultrasonic Sensors Showing Leakage

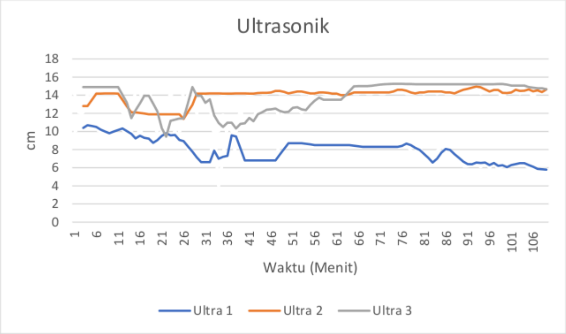
Figure 5. Design and Function of Components

According to the continuity principle, the measured pipe flow must balance the volume change in each tank; any unexplained mismatch indicates a leak. In Figure 5a all five flow curves initially rise uniformly to about 2 L min^{-1} before diverging: Flow 3 (grey) spikes and then drops near minute 25, while Ultra 2 (red) in Figure 5b simultaneously falls by ~4 cm—evidence of a leak on the left branch; Flow 4 (yellow) peaks at ≈ 2.4 L min^{-1} around minute 45, concurrent with a downward step in Ultra 3 (green), signalling a leak on the right branch; and between minutes 50–80 Flow 2 (orange) steadily declines from ~1.9 to 1.6 L min^{-1} as Ultra 1 (blue) drops by ~4 cm, indicating a central-line leak. The test fluid is Tawon cooking oil ($\rho \approx 0.92$ g cm^{-3}, $\mu \approx 50$ cP), chosen for its industrial-like viscosity and safe handling. Five YF-S201 flow sensors (1–30 L min) and three HC-SR04 ultrasonic sensors (2–400 cm range, 3 mm resolution) are sampled once per second by an ESP32 microcontroller, which streams data to a live web dashboard. Leaks are simulated by opening needle valves at three points (left, centre, right) in ~30-min intervals, each scenario repeated three times. The ESP32 algorithm compares cumulative flow with the drop in tank level and flags a leak when the discrepancy exceeds a ±3 % threshold, triggering a visual alarm. Thus, the characteristic surges or dips in flow without a proportional rise in tank level—captured in Figure 5—conclusively confirm oil leakage in the left branch, right branch, and central pipeline.

3.2. Oil Flow Rate Sensor Analysis on Non-Leaking Pipes



(a) Graph of Oil Flow Rate Variations (Flow 1 - Flow 5) Showing No Leakage



(b) Ultrasonic Sensors Showing No Leakage

Figure 6. The simulation graph of oil fluid pipe Non-leakage consists of two main parts (a) Water Flow Sensor, (b) Ultrasonic Sensors

Figure 6 clearly satisfies industry-accepted criteria for a leak-free pipeline: all five flow traces (Flow 1–Flow 5) fluctuate only modestly between roughly 1.5 and 2.1 L min^{-1}, while the three ultrasonic level curves remain essentially flat—Ultra 1 drifts downward by barely a centimetre, Ultra 2 maintains a constant head near 14 cm, and Ultra 3 oscillates gently around 13–14 cm without any step changes. Such coherence between steady flow rates and unchanging tank levels reflects perfect mass conservation, exactly as predicted for a tight pipeline in steady state where inlet flow equals outlet flow and the residual balance approaches zero. Comparable baseline tests reported in the literature employ high-precision ultrasonic flowmeters and level gauges, conduct pressure-hold trials following standards such as ASTM F2164, and accept only variations within the combined instrumental uncertainty; any imbalance beyond that threshold would flag a leak. Because the flows and levels in Figure 6 remain well inside those limits, the data confirm that the system retains pressure, conserves volume, and therefore operates under true non-leak conditions—providing a robust benchmark against which subsequent leak-induced experiments can be evaluated.

4. Conclusions

The experimental findings confirm that the IoT-driven monitoring scheme can clearly differentiate leak- and non-leak states in the pipeline. Under induced-leak conditions (Figure 5), three distinct intervals reveal mismatches between the cumulative inflow recorded by YF-S201 flow sensors and the volume rise measured by HC-SR04 ultrasonic gauges, unequivocally signalling leaks in the left, right, and central lines. By contrast, the non-leak scenario (Figure 6) exhibits steady flow traces within 1.5 – 2.1 L min^{-1} and virtually flat tank levels, validating strong mass balance and leak-free operation. Using Tawon cooking oil ($\rho \approx 0.92$ g cm^{-3}; $\mu \approx 50$ cP) as a realistic test fluid, all sensors were sampled at 1 Hz by an ESP32 micro-controller; the continuity-based algorithm flags a leak whenever the flow-versus-volume discrepancy exceeds ±3 %. Collectively, these results demonstrate that the instrumented pipeline meets industry benchmarks for leak detection: it remains stable when tight and raises immediate alerts when continuity is violated, thereby proving the reliability and real-time effectiveness of the proposed IoT leak-detection system.

Beyond confirming basic functionality, the study highlights several practical advantages. First, the dual-sensor approach—cross-checking flow and level data—provides redundancy that minimises false positives caused by individual sensor drift. Second, the 1 Hz sampling and on-device processing mean that leak events can be identified in under a minute, well within typical response windows for industrial safety protocols. Third, because the ESP32 publishes data to a cloud dashboard, maintenance staff can view live diagnostics on any web-enabled device, facilitating rapid decision-making and remote supervision. Future work will extend the system to longer pipe runs and integrate pressure sensing, enabling localisation algorithms that not only detect but also pinpoint leak positions. Additionally, machine-learning techniques could be trained on the high-resolution dataset to auto-classify leak severity, further enhancing the autonomy and robustness of the monitoring platform.

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References

[1] Bajakarya@next, “Pipa Galvanis dan Peranannya dalam Pencegahan Kebocoran,” PT.BAJAKARYA PERKASA. Accessed: Apr. 17, 2025. [Online]. Available: https://bajakaryaperkasa.co.id/pipa-galvanis-dan-peranannya-dalam-pencegahan-kebocoran/

[2] F. W. W. Dhany, “Enam Warga Terdampak Kebocoran dan Ledakan Pipa Industri di Cilegon,” 24/02/2022. Accessed: Apr. 18, 2025. [Online]. Available: https://www.kompas.id/baca/metro/2022/02/24/enam-warga-terdampak-kebocoran-dan-ledakan-pipa-industri-di-cilegon

[3] “Memperbaiki Pipa Industri Dengan Cepat,” 5/03/2024. Accessed: Apr. 18, 2025. [Online]. Available: https://libratama.com/memperbaiki-pipa-industri-dengan-cepat/

[4] M. Maheshkumar, S. C. Reddy, K. S. Prasad, B. Jagadeesh, S. Shahid, and B. Riyaz, “International Journal of Research Publication and Reviews IoT Based Automatic Fire Detection and Precautionary System,” vol. 4, no. 4, pp. 3505–3509, 2023.

[5] A. Phady, F. R. Rahim, I. M. Suci, and T. Rachman, “Kajian Teknologi Penanganan Kebocoran Pipa Pada Bangunan Lepas Pantai Di Laut Utara Karawang,” *Ris. Sains dan Teknol. Kelaut.*, vol. 2, no. 1, pp. 54–59, 2019, doi: 10.62012/sensistek.v2i1.13218.

[6] E. Comission, “Perancangan Aplikasi PEN+ Berbasis Mobile Untuk Memudahkan Kinerja Dosen Pada Perguruan Tinggi,” vol. 4, no. 1, pp. 1–23, 2016.

[7] M. Hussain, T. Zhang, and M. Seema, “Adoption of big data analytics for energy pipeline condition assessment - A systematic review,”

Int. J. Press. Vessel. Pip., vol. 206, no. July, p. 105061, 2023, doi: 10.1016/j.ijpvp.2023.105061.

[8] S. S. Aljameel *et al.*, "Oil and Gas Pipelines Leakage Detection Approaches: A Systematic Review of Literature," *Int. J. Saf. Secur. Eng.*, vol. 14, no. 3, pp. 773–786, 2024, doi: 10.18280/ijsse.140310.

[9] S. Ali, S. Bin Qaisar, H. Saeed, M. F. Khan, M. Naeem, and A. Anpalagan, *Network challenges for cyber physical systems with tiny wireless devices: A case study on reliable pipeline condition monitoring*, vol. 15, no. 4. 2015. doi: 10.3390/s150407172.

[10] T. Pipit Muliyah, Dyah Aminatun, Sukma Septian Nasution, Tommy Hastomo, Setiana Sri Wahyuni Sitepu, "Network Challenges for Cyber Physical Systems with Tiny Wireless Devices: A Case Study on Reliable Pipeline Condition Monitoring," *J. GEEJ*, vol. 7, no. 2, 2020.

[11] M. A. Adegboye, W. K. Fung, and A. Karnik, "Recent advances in pipeline monitoring and oil leakage detection technologies: Principles and approaches," *Sensors (Switzerland)*, vol. 19, no. 11, 2019, doi: 10.3390/s19112548.

[12] E. For, T. H. E. Metaverse, and M. M. Tukur, "Hamad bin khalifa university college of science and engineering ai-based creation of panoramic indoor environments for the metaverse," no. March, 2024.

[13] K. K. Patel, S. M. Patel, and P. G. Scholar, "Internet of Things-IOT: Definition, Characteristics, Architecture, Enabling Technologies, Application & Future Challenges," *Int. J. Eng. Sci. Comput.*, vol. 6, no. 5, pp. 1–10, 2016, doi: 10.4010/2016.1482.

[14] M. A. Elkoushy, A. H. Metwally, and Y. A. Noureldin, "Implications of different nephrolithometry scoring systems on clinical practice of endourologists: An international web-based survey," *Arab J. Urol.*, vol. 14, no. 3, pp. 216–222, 2016, doi: 10.1016/j.aju.2016.04.005.

[15] P. F. Kingston, "Long-term environmental impact of oil spills," *Spill Sci. Technol. Bull.*, vol. 7, no. 3–4, pp. 53–61, 2002, doi: 10.1016/S1353-2561(02)00051-8.

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