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Oil and Gas Pipeline Integrity Monitoring and Alert System

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Abstract

The oil and gas industry face significant risks of explosions, often due to factors like gas and oil leakage as well as external corrosion. These substances are highly flammable, and even minor leaks can create volatile environments where the smallest spark can lead to catastrophic explosions. While internal corrosion in pipelines receives attention, external corrosion is often overlooked. Over time, pipeline coatings deteriorate, leaving them susceptible to external corrosion, which can result in leaks, endangering workers and the environment. Detecting and addressing corrosion promptly is crucial for preventing accidents and environmental harm. To address these challenges, a pipeline monitoring system has been developed using a Raspberry Pi Model 3B+ and advanced sensors. This system continuously monitors temperature, pressure, and external corrosion along pipeline routes. It utilizes a K-type thermocouple and a 1.2MPa pressure transducer for real-time data collection. Additionally, a laptop camera integrated with YOLOv8 enables visual inspection for detecting corrosion. The Raspberry Pi processes sensor data and images, triggering alerts for anomalies like temperature or pressure drops indicating leaks, or corrosion spots identified by YOLOv8. The system interfaces with ThingSpeak for remote data visualization and analysis, empowering operators to make informed decisions and take prompt corrective actions.

Keywords: Oil and Gas Industry, Explosion, Corrosion, Pressure sensor, Temperature Sensor, YOLOv8, Raspberry Pi, ThingSpeak.

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1. Introduction

The oil and gas industry faces significant risks of spills, releases, and serious environmental issues, including explosions that can endanger employees, due to pipeline corrosion[1]. These leaks can occur at various stages, like during production, transportation, or refining, posing dangers such as the formation of flammable vapor clouds. External corrosion worsens these risks as metal surfaces degrade over time due to environmental factors. Corrosion weakens equipment integrity, leading to cracks or holes in pipelines, increasing the likelihood of leaks and explosions. Inadequate maintenance exacerbates these risks. Hence, effective corrosion management is crucial, including regular inspections, monitoring, and timely repairs. While internal corrosion protection in oil and gas pipelines is prioritized, external corrosion's impact is often underestimated. Pipeline coatings offer initial protection, but they degrade over time, leaving surfaces vulnerable to corrosion. Without proper protection and monitoring, external corrosion can cause leaks, ruptures, and operational disruptions. Therefore, comprehensive corrosion management is necessary, including inspections, monitoring, maintenance, and advanced coating technologies. Pressure and temperature are vital indicators of oil and gas leakage. Pressure drops indicate leaks, prompting immediate action. Temperature changes near leaks due to friction further confirm issues. Continuous monitoring of pressure and temperature detects leaks swiftly, reducing damage and environmental risks. To address these challenges, a safety system using Raspberry Pi, sensors, and cameras has been developed for proactive intervention.

1.1 Objective

The research focuses on proactively identifying and resolving external corrosion in oil and gas pipelines to ensure long-term integrity and minimize leakage risks. Real-time monitoring allows immediate responses to anomalies or corrosion signs, reducing incidents and associated risks. Efficient resource utilization targets maintenance efforts to corroded areas, optimizing costs while ensuring network integrity. Continuous improvement enhances detection accuracy and system performance, ensuring compliance with regulations and standards, and reducing penalties and liabilities. Operational resilience minimizes corrosion-related impacts, ensuring uninterrupted production and distribution. Data collection aids industry knowledge expansion, fostering safety and maintenance research. Ultimately, the approach enhances safety, reliability, and sustainability across pipeline infrastructure, benefiting stakeholders and communities.

2. Related Work

Ananya Chandran et. al proposed the creation of an Internet of Things (IoT)-enabled smart stove with built-in safety functionalities to mitigate potential mishaps. This innovative stove incorporates a two-way safety system, featuring a child lock and gas leak detection capabilities. It offers real-time video streaming for enhanced safety assurance and age verification. The stove's design prioritizes safety concerns, particularly regarding children's interaction with the appliance. Utilizing Raspberry Pi hardware and a gas detection module with an audible alarm, the system integrates deep learning and machine learning object detection techniques for seamless operation. In summary, the IoT-enabled stove provides both manual and remote safety features to effectively prevent unintended accidents.[2]

L. B. Coelho et.al conducted a comprehensive examination of the burgeoning research domain focused on applying machine learning (ML) to predict electrochemical corrosion. Their primary objective was to identify the ML models utilized and assess their performance across different corrosion topics. Through an exhaustive analysis of corrosion literature featuring comparable performance metrics, they compiled a 'Machine Learning for Corrosion Database,' serving as a resource for corrosion experts and model developers interested in ML applications. The study also addresses potential research gaps, offers recommendations, and outlines future research directions to foster advancements in this field.[3]

D. Ma et.al [developed a pavement crack detection system utilizing a Pavement Crack Generative Adversarial Network (PCGAN) and a crack detection/tracking network named YOLO-MF. PCGAN generates realistic crack images to overcome data scarcity, while YOLO-MF, an improved YOLO v3, detects and tracks cracks in videos using a median flow algorithm. Achieving 98.47% accuracy and a 0.958 F1 score, the system demonstrates superior performance. Integration with an intelligent device, including a calculation module and automated UAV, enhances its applicability [4]

The research by P. Jiang et.al provides a comprehensive overview of object detection techniques, focusing on the evolution of the You Only Look Once (YOLO) algorithm and its advanced versions. Through thorough analysis, the paper highlights key differences and similarities among YOLO versions and with Convolutional Neural Networks (CNNs), emphasizing ongoing improvements in the YOLO algorithm. Additionally, it outlines the development process, methods of target recognition, and feature selection, contributing valuable insights to YOLO and object detection literature, with potential applications in various fields including finance.[5]

M. Wasim et.al conducted an updated review focusing on the external corrosion and failure mechanisms observed in buried natural gas and oil pipelines. The review thoroughly examines various forms of external corrosion and failure mechanisms, including hydrogen-induced cracking (HIC), hydrogen embrittlement (HE), corrosion fatigue (CF), stress corrosion cracking (SCC), and microbiologically influenced corrosion (MIC), as they relate to oil and gas pipelines. Additionally, the study delves into the factors influencing external corrosion and explores potential forms of environment-assisted cracking (EAC) in pipeline steels within soil environments. Furthermore, the review analyzes existing monitoring tools for assessing external corrosion, as well as models for corrosion prevention and prediction, failure occurrence, and estimating the remaining life of oil and gas pipelines.[6]

Y. Zuo et.al introduced a blockchain-driven IoT framework designed for enhancing real-time monitoring and control to improve efficiency and safety in oil field operations and asset management. The framework encompasses essential components such as system architecture, operational workflows, algorithms, and smart contracts. To validate the concept, a smart contract was developed and tested on a blockchain platform. A comparative assessment highlights the benefits of leveraging blockchain technology and smart contracts to deliver reliable and automated monitoring and control for oil field operations.[7]

Md Toufikul Islam et.al have introduced a sensor network design employing pressure sensors to monitor water pressure at various points within pipelines. The system utilizes Arduino and XBee (Zigbee) technology for collecting pressure data. Additionally, an exponential curve fitting technique is applied to analyze the data, enabling accurate detection of leaks and their respective locations. The study validates the efficacy of the proposed method in real-world scenarios and offers insights into determining the optimal distance between pressure sensors along a pipeline.[8]

K. Lalitha et.al have devised a real-time monitoring system to measure the flow rate of liquids using flow sensors. Gas sensors placed at regular intervals detect leakages in the pipeline. Given the considerable length of crude oil pipelines, spanning thousands of kilometers, solenoid valves are strategically placed along the entire length to manage flow. The system utilizes the PIC16F1526 microcontroller to monitor sensors and make informed decisions during critical situations. Data transmission to remote stations is facilitated by a GSM module through IoT devices, allowing for control and monitoring from anywhere with internet connectivity. This approach is instrumental in preventing industrial accidents.[9]

Nhat-Duy Nguyen et.al conducted a thorough evaluation of current state-of-the-art deep learning models for object detection, including Fast RCNN, Faster RCNN, RetinaNet, and YOLOv3. Their study provides an in-depth assessment of the advantages and limitations of each model. By experimenting with different backbones on various datasets containing multiscale objects, the researchers aimed to determine which types of objects are best suited for each model and backbone combination. The empirical evaluation involved testing on two standard datasets: a small object dataset and a filtered dataset from PASCAL VOC 2007. Comparative results and detailed analyses of the findings are presented, offering valuable insights into the performance of different models for object detection tasks.[10]

Y. M. Baiji et.al conducted a validation and demonstration showcasing the benefits of implementing IoT solutions within the midstream sector. They achieved this by developing a leak detection monitoring system, aiming to reduce non-productive time and enhance revenue generation for Oil and Gas companies. Their innovative approach involved constructing a prototype from start to finish, utilizing a low-power communication protocol named LoRaWAN. Experimental procedures were performed on an operational pipe using water. The proposed methodology delivered a real-time leak detection accuracy of 90.83%.[11]

Kemahyanto Exaudi et.al have introduced an enhancement to the FSR sensor and conducted testing for detecting leaks in water pipes based on pressure variations within the pipe. The sensor is installed in a manner that does not harm or puncture the test pipe. Test outcomes demonstrate the successful detection of pressure fluctuations by the FSR sensor, effectively identifying water pipe leaks.[12]

Jamadagni et.al proposed a system utilizing an MQ-2 sensor for gas leakage detection under various atmospheric conditions and a fire sensor for fire protection. The Raspberry Pi serves as a crucial component, enabling the interfacing of all system elements. This setup allows users to monitor changes remotely from anywhere in the world. The primary function of the gas detection system is continuous environmental monitoring. Upon detecting gas or smoke, the system sends a Short Message Service (SMS) to the user, prompting them to take appropriate action.[13]

K. Exaudi et.al sought to detect pipe leakage resulting from illegal tapping, a method of theft involving the unauthorized piercing or tapping of pipelines. This illicit activity affects pressure values between upstream and downstream pipes. Any irregular mounting detected by sensors on upstream and downstream values in experimental pipes leads to pressure changes. The obtained data undergoes processing and analysis using continuous wavelet transformation to identify differences in time and frequency. Despite the experimental nature of the results, the detection of pipeline leaks is achievable through this method.[14]

P. Karkulali et.al conducted a simulation study focusing on leak location determination using an Incident Pressure Field, which generates waves in the frequency range of approximately 20-200Hz. Their findings were validated through experimental work involving the introduction of synthetic leak and disturbance signals. The Fast Fourier Transform (FFT) was employed as a mathematical tool to identify the dominant peak in the frequency spectrum during leak or disturbance events. The experimental results aligned with the simulated outcomes, demonstrating the accuracy of event detection with an error margin of less than 5%.[15]

3. Proposed Work

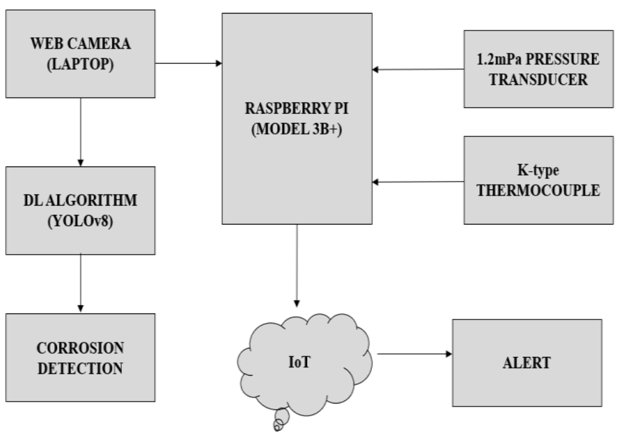

Figure 1. Block Diagram of the Proposed System

The proposed system is shown in Figure 1. It consists of hardware and software part. The hardware components are depicted in Table 1

Table 1. Hardware Components of the Proposed System

Hardware used	Function and model
Raspberry Pi	Acts as the main controlling system Model- Raspberry pi model 3B+
Web Camera	To capture the Real Time Images of Pipes
Pressure Sensor	To monitor the pressure, drop in the pipeline Model- 1.2 Mpa Pressure Transducer
Temperature Sensor	To monitor the temperature, drop in the pipeline Model- K- Type Thermocouple

The proposed monitoring system integrates various components to ensure comprehensive monitoring and preventive maintenance of gas and oil pipelines. The Block diagram of the proposed system is depicted in Figure 1. Firstly, the wiring configuration for the K-type thermocouple and the 1.2MPa pressure transducer is established, with the Raspberry Pi Model 3B+ serving as the central processing unit. The thermocouple and pressure transducer continuously measure temperature and pressure variations along the pipeline route, respectively. This data is crucial for detecting anomalies that could indicate potential gas or oil leakage.

Additionally, the Raspberry Pi interacts with ThingSpeak, an IoT platform, to transmit temperature and pressure data for real-time monitoring and analysis. Threshold values are set to trigger alerts when temperature drops below a specified level or when pressure falls below 100. Upon meeting these conditions, alerts are generated to notify operators of potential leakage, enhancing proactive monitoring and preventive measures.

Simultaneously, the system incorporates a laptop camera equipped with YOLOv8, an advanced object detection algorithm, to monitor the external surface of the pipeline for corrosion or damage. YOLOv8 continuously analyzes images captured by the camera, identifying and localizing corrosion spots with precision. This visual inspection data is correlated with sensor data to provide a comprehensive assessment of pipeline integrity.

Operators interact with the system through a user interface, accessing real-time monitoring dashboards on ThingSpeak. These dashboards provide detailed insights into temperature, pressure, corrosion detection results, and historical data trends, enabling informed decision-making and timely corrective actions.

In the event of detected corrosion or damage, the system facilitates proactive maintenance measures, allowing operators to prioritize inspection and repair activities to prevent further deterioration. By combining sensor data with visual inspection capabilities offered by YOLOv8, the system offers enhanced monitoring and predictive maintenance capabilities, ultimately reducing the risk of pipeline failures and ensuring the safe and reliable transportation of gas and oil resources.

3.1 Flow Chart

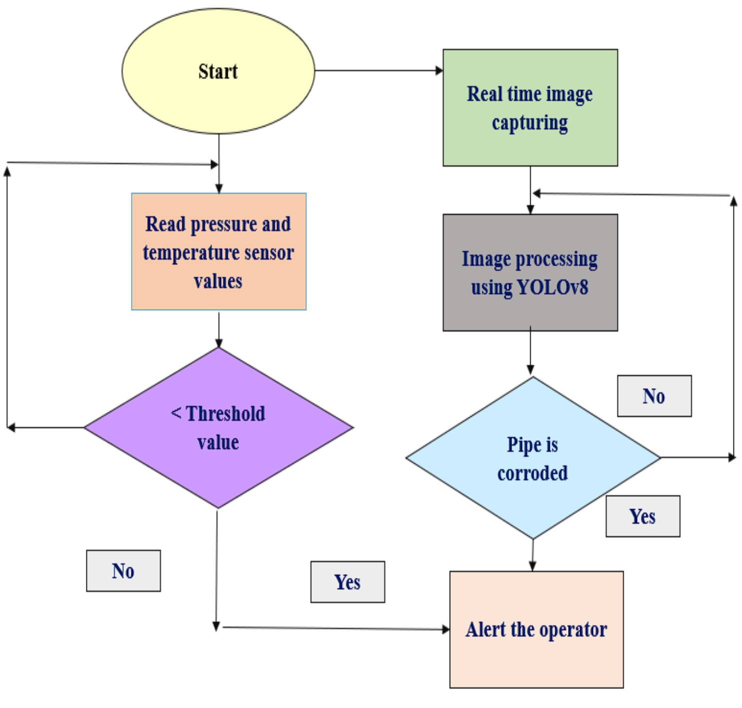

Figure 2. Flowchart of the Proposed System

The Figure 2. depicts the process of the proposed system flows as follows

a. Initialize System Set up Raspberry Pi, sensors (thermocouple and pressure transducer), laptop camera, and internet connection.

b. Read Sensor Data- Continuously read temperature and pressure data from the sensors.

c. Check Thresholds- Determine if temperature is below specified threshold. And determine if pressure is below 100.

d. Alert Triggered? - If both conditions are met, trigger an alert for potential gas or oil leakage.

e. Transmit Data to ThingSpeak-Send temperature and pressure data to ThingSpeak for real-time monitoring.

f. Capture Images- Continuously capture images using the laptop camera.

g. Process Images with YOLOv8- Use YOLOv8 to analyze images for corrosion or damage on the pipeline surface.

h. Corrosion Detected? - If corrosion or damage is detected, proceed to the next step.

i. Notify Operator- Send alerts or notifications to operators regarding detected corrosion or damage.

j. Data Visualization on ThingSpeak- Visualize temperature, pressure, and corrosion detection results on ThingSpeak's dashboard.

4. Results and Discussion

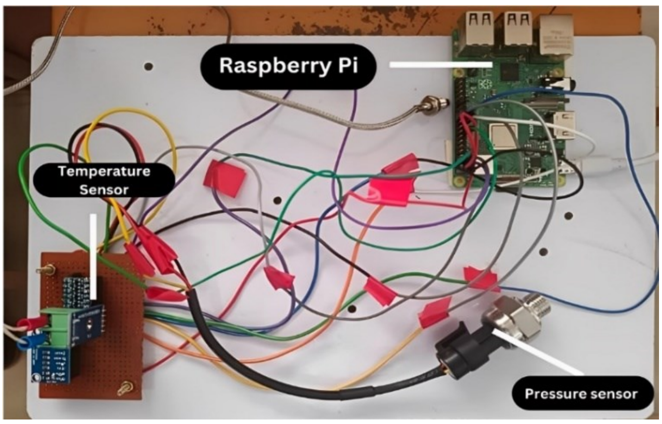

Figure 3. Hardware Setup of Proposed System

The Figure 3 depicts the hardware setup of the proposed system. The oil and pipeline integrity monitoring system developed in this research was tested successfully. The pressure values are read continuously from 1.2Mpa pressure transducer and the temperature value are read continuously from the K-type temperature transducer. The sensor data is transmitted to Thingspeak in real-time for analysis and visualization The system was able to effectively monitor based on the sensor values purifier when the pressure and temperature value of crude oil and natural gas met the desired threshold condition.

Figure 4 depicts the temperature data that is measured from the K type thermocouple. It proves the continuous monitoring and variation of temperature levels in pipelines if leakage is present.

Figure 5 depicts the pressure data that is measured from the K type thermocouple. It proves the continuous monitoring and variation of temperature levels in pipelines if there is any leakage.

As a result, YOLOv8 model was trained using 2575 image datasets (Source: Google and Roboflow). The training end result is shown in the Figure 6 clearly signifying the corroded areas of the pipelines in red box. The efficiency we attained can be improved by using more image sets. The model we designed has an maP accuracy of 93% and precision of 94.7%.

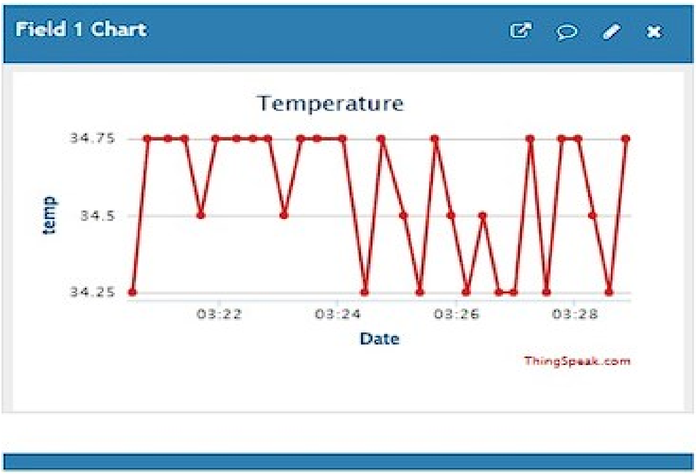

Figure 4. Variation in Temperature Levels in IoT Monitor (ThingSpeak)

Figure 5. Variation in Pressure Levels in IoT Monitor (ThingSpeak)

Figure 6. Results of YOLOv8

5. Conclusion

The proposed monitoring system, with Raspberry Pi, sensor technologies, YOLOv8, and ThingSpeak integration, offers a comprehensive solution for enhancing the safety and reliability of gas and oil pipelines. By continuously monitoring temperature, pressure, and external corrosion, the system enables operators to detect anomalies in real-time and take timely corrective actions, thus minimizing the risk of leaks and ensuring the integrity of the pipeline infrastructure. The combination of sensor data and visual inspection capabilities provided by YOLOv8 offers a holistic approach to pipeline monitoring, empowering operators with actionable insights to prevent potential failures and optimize maintenance strategies.

In the future, the proposed pipeline monitoring system could be enhanced by integrating advanced machine learning algorithms for anomaly detection and predictive maintenance, incorporating additional sensors for detecting mechanical disturbances, implementing remote control functionalities for proactive interventions, developing advanced visualization tools for deeper insights, integrating with IoT platforms for seamless data sharing, conducting extensive field testing for validation, and ensuring compliance with industry regulations and standards. These advancements would collectively contribute to a more sophisticated and comprehensive solution for ensuring the integrity and security of gas and oil pipelines, thereby enhancing operational efficiency and sustainability.

References

[1] Nagalakshmi, T. & A. Ph.D., Sivasakthi. (2019). Corrosion Control, Prevention and Mitigation in Oil & Gas Industry. International Journal of Innovative Technology and Exploring Engineering. 9. 1568-1572. 10.35940/ijitee.B7272.129219

[2] Chandran and S. Kavitha, "A Smart Gas Stove with Gas Leakage Detection and Multistage Prevention System Using IoT," International Journal of Mechanical and Design Engineering (IJMDES), vol. 1, no. 9, pp. 5–9, Sep. 2022.

[3] L. B. Coelho, D. Zhang, Y. Van Ingelgem, D. Steckelmacher, A. Nowé, and H. Terryn "Reviewing machine learning of corrosion prediction in a data-oriented perspective," npj Materials Degradation, vol. 6, pp. 1-16, 2022.

[4] D. Ma, H. Fang, N. Wang, C. Zhang, J. Dong and H. Hu, "Automatic Detection and Counting System for Pavement Cracks Based on PCGAN and YOLO-MF," in IEEE Transactions on Intelligent Transportation Systems, vol. 23, no. 11, pp. 22166-22178, Nov. 2022,

[5] P. Jiang, D. Ergu, F. Liu, Y. Cai, and B. Ma, "A Review of YOLO Algorithm Developments," Procedia Computer Science, vol. 199, pp. 1066-1073, ISSN: 1877-0509, 2022.

[6] M. Wasim and M. B. Djukic, "External corrosion of oil and gas pipelines: A review of failure mechanisms and predictive preventions," Journal of Natural Gas Science and Engineering, vol. 100, p. 104467, 2022.

[7] Y. Zuo and Z. Qi, "A blockchain-based IoT framework for oil field remote monitoring and control," IEEE Access, vol. 10, pp. 2497-2514, 2022.

[8] Islam, Md Toufikul, and Semih Aslan. "Leak detection and location pinpointing in water pipeline systems using a wireless sensor network." In 2021 IEEE International Symposium on Circuits and Systems (ISCAS), pp. 1-7. IEEE, 2021.

[9] K. Lalitha, V. Balakumar, S. Yogesh, K.M. Sriram, and V. Mithilesh, "IoT Enabled Pipeline Leakage Detection and Real-Time Alert System in Oil and Gas Industry," International Journal of Recent Technology and Engineering (IJRTE), vol. 8, no. 5, ISSN: 2277-3878, Jan. 2020.

[10] Nguyen, Nhat-Duy, Tien Do, Thanh Duc Ngo, and Duy-Dinh Le. "An evaluation of deep learning methods for small object detection." Journal of electrical and computer engineering 2020 (2020): 1-18.

[11] Y. Baiji and P. Sundaravadivel, "iLoLeak-Detect: An IoT-Based LoRAWAN-Enabled Oil Leak Detection System for Smart Cities," 2019 IEEE International Symposium on Smart Electronic Systems (iSES) (Formerly iNiS), Rourkela, India, pp. 262-267, 2019.

[12] K. Exaudi, R. Passarella, A. Rendyansyah, and A. Duri, "Leak Detection in Water Pipe using FSR (Force Sensitive Resistor) Sensor," in 2019 International Conference on Electronics, Control, Optimization and Computer Science (ICECOS), pp. 145-149, 2019.

[13] Jamadagni, Sourabh, Priya R Sankpal, Shwetali Patil, Nikita Chougule and Shailesh S. Gurav. “Gas Leakage and Fire Detection using Raspberry Pi.” 2019 3rd International Conference on Computing Methodologies and Communication (ICCMC), pp.495-497, 2019.

[14] K. Exaudi, R. Passarella, Rendyansyah and R. Zulfahmi, "Using Pressure Sensors towards Pipeline Leakage Detection," 2018 International Conference on Electrical Engineering and Computer Science (ICECOS), Pangkal, Indonesia, pp. 89-92, 2018.

[15] P. Karkulali, H. Mishra, A. Ukil and J. Dauwels, "Leak detection in gas distribution pipelines using acoustic impact monitoring," IECON 2016 - 42nd Annual Conference of the IEEE Industrial Electronics Society, Florence, Italy, pp. 412-416, 2016.

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