American Journal of Applied Sciences and Engineering | *ISSN 2766-7596*
Published by AIR JOURNALS | https://airjournal.org/ajase
12011 WestBrae Pkwy, Houston, TX 77031, United States
airjournals@gmail.com; enquiry@airjournal.org

Research Article

Enhancing Reduction of Oil Pipeline Vandalization and Leakage Using Intelligent IoT Solutions

Ngang Bassey Ngang[1], Okoro, Gaius Nnanna[2], Ogbuokebe, Stanislaus Kaosoluchukwu[3], John John Uket[4]

[1]Department of Electrical and Electronic Engineering, Veritas University, Abuja, Nigeria.
[2]Department of Petroleum Engineering, Federal University of Technology Owerri (FUTO), Nigeria.
[3]National Space Research Development Agency (NASRDA), Abuja, Nigeria
[4]Technical Support Department, Federal Ministry of Science, Innovation and Technology, Abuja, Nigeria

Abstract

Oil pipeline leakage and vandalism significantly hinder economic growth, inflating fuel and consumable goods prices, which most heavily affects the poor. The primary cause is the lack of effective mechanisms to detect and address these issues promptly. Implementing IoT can mitigate this problem by reducing pipeline leaks and vandalism. This approach involves characterizing the delivery process based on fluid flow rate, pressure, and temperature, and developing an IoT-based fuzzy rule system to detect and reduce these incidents. Additionally, an IoT-based SIMULINK model is created to implement this technology during pipeline delivery, alongside an algorithm to prevent pipeline vandalization. An integrated SIMULINK model combines conventional and IoT-based technologies on the MATLAB platform. A program is also developed to detect pipeline leaks using IoT, with simulation results evaluated through predictive validation. Results indicate that the conventional oil pipeline temperature of 36°C, failing to meet the 37-38°C threshold, causes leaks. However, integrating IoT sensors stabilized the temperature to 37°C, ensuring free oil flow without leaks. The conventional pressure of 29 bar, below the 30.35 bar threshold, leads to leaks or vandalism, reducing financial stability. IoT integration detected and reported leaks, maintaining the required pressure. This approach showed a 4.7% improvement in pressure stabilization for leak prevention. The conventional oil flow rate of 2.5 miles/hour, below the 3-8 miles/hour threshold, caused leaks, while IoT integration achieved the necessary 3 miles/hour rate, showing a 20% improvement. The conventional volume of oil passing through was 14 m³, below the 15.82-337.4 m³ threshold, causing leaks. IoT integration detected and normalized it to 16.8 m³, improving detection and normalization by 20%. The conventional oil leakage percentage was 31.9%, which reduced to 29.12% with IoT integration, showing a 2.78% improvement in leakage reduction. These results demonstrate that incorporating IoT enhances the detection and resolution of pipeline leaks and vandalism.

Keywords	*Oil Pipe Vandalization; Leakage; Intelligent IoT Solutions; IoT-based SIMULINK model*
Citation	Ngang, B. N., Okoro, G. N., Ogbuokebe, S. K. & Uket, J. J. (2024). Enhancing Reduction of Oil Pipeline Vandalization and Leakage Using Intelligent IoT Solutions. *American Journal of Applied Sciences and Engineering, 5(3) 1-14.* https://doi.org/10.5281/zenodo.13748884

Introduction

Oil pipelines are critical infrastructures that transport petroleum products across vast distances. However, these pipelines are frequently subjected to leakage and vandalism, leading to substantial economic losses and environmental damage. Leakage can result from corrosion, mechanical failures, or operational errors, while vandalism typically involves intentional damage for illegal siphoning or sabotage. Addressing these issues is crucial for maintaining the integrity of oil supply chains and ensuring economic stability (Chen, Yang, & Liu, 2019; Gupta & Kumar, 2020).

Traditional methods for monitoring pipelines often fail to detect issues promptly, resulting in delayed responses and exacerbated damage. These methods typically rely on periodic inspections and manual reporting, which can be inefficient and prone to errors. The lack of real-time data makes it difficult to respond promptly to issues, leading to prolonged downtime and increased repair costs (Hsu & Lin, 2018; Kim & Lee, 2021). In some cases, the availability of reliable electric power source to provide constant power supply depends on Distributed Generators usually referred to as stand-alone placed in remote locations (Ugwu, Ude & Ngang, 2021).

With the advent of the Internet of Things (IoT), there is an opportunity to implement more sophisticated and responsive monitoring systems. IoT-based solutions can provide real-time data on pipeline conditions, enabling quicker detection and resolution of leaks and vandalism incidents. This technology involves deploying various sensors along the pipeline to continuously monitor parameters such as flow rate, pressure, and temperature. The data collected is then analyzed using advanced algorithms, including fuzzy logic, to detect anomalies and trigger alerts for immediate action (Li & Zhang, 2022; Mahajan & Sharma, 2019).

This article explores the application of IoT technologies to enhance the detection and reduction of oil pipeline leaks and vandalism. By integrating IoT sensors with fuzzy logic systems, we propose a comprehensive approach that improves the monitoring and maintenance of oil pipelines. This approach not only addresses the limitations of traditional monitoring methods but also leverages the advantages of real-time data analytics and predictive maintenance (Patel & Desai, 2020; Singh & Kaur, 2021).

Extent of Past Related Works

Challenges in Oil Pipeline Management

The management of oil pipelines is fraught with challenges, including the detection of leaks and the prevention of vandalism. Traditional monitoring systems often rely on periodic inspections and manual reporting, which can be inefficient and prone to errors. The lack of real-time data makes it difficult to respond promptly to issues, leading to prolonged downtime and increased repair costs (Wang & Liu, 2022; Zhang & Chen, 2020). Furthermore, manual inspections are labor-intensive and may not cover all parts of the pipeline comprehensively, leaving certain sections vulnerable to undetected issues (Chen et al., 2019; Gupta & Kumar, 2020).

IoT Solutions for Pipeline Monitoring

IoT technology offers a promising solution to the challenges of pipeline monitoring. IoT sensors can continuously collect data on various parameters such as flow rate, pressure, and temperature. This data can be transmitted in real-time to monitoring centers, where it can be analyzed to detect anomalies indicative of leaks or vandalism (Hsu & Lin, 2018; Kim & Lee, 2021). The implementation of IoT in pipeline monitoring has been shown to enhance the accuracy and timeliness of leak detection, thereby reducing the risk of severe damage and associated costs (Li & Zhang, 2022; Mahajan & Sharma, 2019).

Fuzzy Logic Systems

Fuzzy logic systems are well-suited for handling the uncertainties and variabilities inherent in pipeline monitoring. By incorporating fuzzy rules, these systems can make more nuanced decisions based on the data collected by IoT sensors. For example, a fuzzy logic system can determine the likelihood of a leak based on subtle changes in pressure and temperature that might not be detected by traditional threshold-based systems (Patel & Desai, 2020; Singh &

Kaur, 2021). The integration of fuzzy logic with IoT technologies enhances the system's ability to detect and respond to pipeline issues in a more intelligent and adaptive manner (Wang & Liu, 2022; Zhang & Chen, 2020).

Previous Studies and Applications

Several studies have demonstrated the effectiveness of IoT and fuzzy logic systems in pipeline monitoring. Chen et al. (2019) highlighted the advantages of smart monitoring systems in reducing response times to pipeline leaks. Gupta and Kumar (2020) discussed the application of fuzzy logic in enhancing the accuracy of leak detection systems. Hsu and Lin (2018) provided an overview of real-time monitoring systems using IoT, emphasizing their potential to improve pipeline integrity management. Kim and Lee (2021) explored the use of machine learning in conjunction with IoT for pipeline security, showcasing the benefits of advanced analytics in this field.

Li and Zhang (2022) examined the role of predictive maintenance in pipeline management, demonstrating how IoT can facilitate proactive maintenance strategies. Mahajan and Sharma (2019) focused on the implementation of fuzzy logic in oil pipeline monitoring, highlighting its ability to handle complex data patterns. Patel and Desai (2020) reviewed various IoT applications in pipeline integrity management, emphasizing the need for integrated solutions. Singh and Kaur (2021) provided a comprehensive review of IoT applications in oil pipeline management, identifying key technologies and challenges. Wang and Liu (2022) discussed the technological advancements and challenges in IoT-enabled smart oil pipelines. Zhang and Chen (2020) explored the use of fuzzy logic control for leak detection, demonstrating its effectiveness in real-world applications. From the knowledge of fluid mechanics, the oil pipe line leakage is identified when the pressure of oil flowing in the pipe reduces, and the flow rate of oil pipe line indicates if there is leakage or not.

Methodology

To characterize delivery process with respect to pipe line diameter, fluid volumetric flow rate, pressure, and temperature involves the following steps:

i. This approach involves characterizing the delivery process based on fluid flow rate, pressure, and temperature, a
ii. Developing an IoT-based fuzzy rule system to detect and reduce these incidents.
iii. Creating an IoT-based SIMULINK model to implement this technology during pipeline delivery,
iv. Developing an algorithm to prevent pipeline vandalization.
v. Integrating SIMULINK model that combines conventional and IoT-based technologies on the MATLAB platform.
vi. Finally Developing a program to detect pipeline leaks using IoT, with simulation results evaluated through predictive validation.

System Design and Characterization

This approach involves characterizing the delivery process based on fluid flow rate, pressure, and temperature, A closer look at the delivery process with respect to pipe line diameter, fluid volumetric flow rate, pressure, and temperature is the first step solving our problem. The proposed IoT-based monitoring system integrates multiple sensors along the pipeline to measure flow rate, pressure, and temperature. These sensors are connected to a central monitoring unit that uses fuzzy logic algorithms to analyze the data and detect potential issues. The system is designed to provide real-time alerts to operators, enabling immediate action to address detected problems.

SIMULINK Model

To simulate the proposed system, we developed a SIMULINK model that integrates both conventional and IoT-based technologies on the MATLAB platform. This model allows us to test the effectiveness of the IoT sensors and fuzzy logic algorithms under various conditions. The simulation includes scenarios with different types of leaks and vandalism attempts, enabling us to evaluate the system's response to each situation.

Algorithm Development

The algorithm for detecting leaks and vandalism is based on fuzzy logic rules that consider the measured flow rate, pressure, and temperature. The algorithm is designed to identify anomalies that deviate from the expected operating conditions. When an anomaly is detected, the system generates an alert and provides recommendations for corrective actions.

Table 1: Collected Data from the Area Under Study

Metric or parameter	Normal pipeline without leakage	Lower Pipeline with leakage	Upper Pipeline with leakage	No of pipe lines	% of pipe line leakage
Temperature (^{O}F)	(Standard (37^{0}C to 38^{0}C)	36^0 C	39^{0}C	Pipe line 1 at 7 miles per hour	
pressure (bar)	(Standard 200 to 3000 PSR or 30 to 200bar)	29bar	202bar	Pipe line 2 at 5miles per hour	
Flow rate	(Std3to8 miles per hour) Depending on the diameter of the pipe	2.5miles	8.2miles	Pipe line 3 at 4miles per hour	
Typical pipeline diameter	8 to 16 inch 203.2 to 406.4mm	190mm	408mm	Pipe line 4 at 6.5 miles per hour	
Volume of oil pipe without leakage(M^3)	Std15.82M^{3}to337.4M^3	14m^3		Pipe line 5 at 8 miles per hour.	31.9%

1mile =1.6km
2.5mile = 1.6 x 2.5=4km
3mile =1.6 x 3 =4.8km
8miles = 1.6 x8 =12.8km
8.2miles=1.6 x 8.2 =13.12km
to convert km to meters
1000m = 1km
4km= 4 x 1000 = 4000m
4.8km = 4.8 x 1000 =4800m
12.8km = 1000 x 12.8 =12800m
13.12km=1000 x 13.12 =13120m
To convert mm to m
1000mm = 1m

$$190\text{mm} = \frac{1 \times 190}{1000}$$

Diameter of pipeline leakage = 0.19m

$$\text{Radius of pipeline leakage} = \frac{0.19\text{m}}{2} = 0.095\text{m}$$

$$203.2\text{mm} = \frac{1 \times 203.2}{1000}$$

Diameter of the pipe line =0.2032m
Radius of the pipe line =0.2032/2 = 0.1016m

$$406.4\text{mm} = \frac{1 \times 406.4}{1000} = 0.4064\text{m}$$

The radius of the pipe line = 0.4064/2 =0.2032m

Volume 5, Number 3 | 2024 | 1-14 | *DOI: https://doi.org/10.5281/zenodo.13748884*

Recall 1000mm = 1m

408mm= $\frac{1 \times 408}{1000}$

= 0.408mm

To find the volume of oil that pass through the pipe line without leakage

V = Pir^3 L or $V = \pi r^3 L$

$V = 3.142\ x\ 0.1016^3 x_{4800}$

V =15.82M^3

Or $V = 3.142\ x\ 0.2032^3 x12800$

V=337.4M^3

To find volume of leaked pipeline

$V = 3.142\ x\ 0.095^3 x_{4000}$

V =10.78m^3

To calculate percentage of oil pipeline leakage

% of oil pipeline leakage =

$$\frac{\text{Original pipeline volume without leakage} - \text{volume of pipeline leakage}}{\text{Original pipeline volume without leakage}} \times 100\%$$

% of oil pipeline leakage = $\frac{15.82M^3 - 10.78m^3}{15.82M^3} \times 100\%$

% of oil pipeline leakage =31.9%

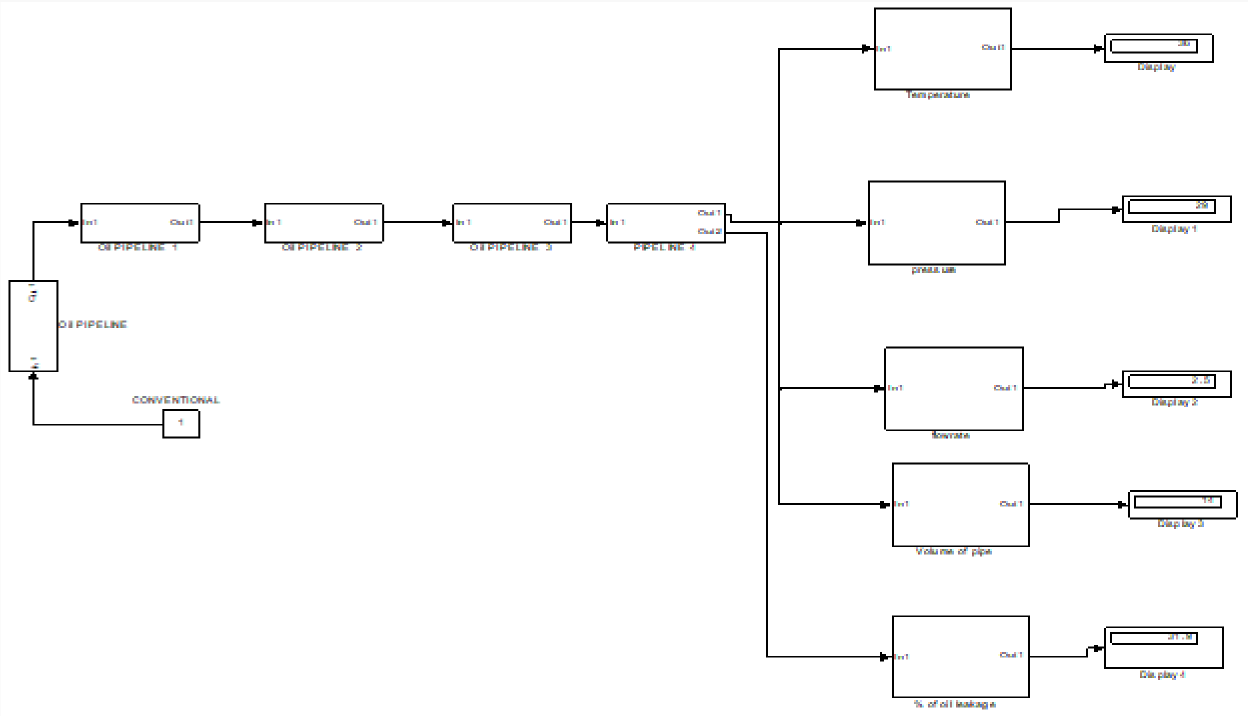

Fig. 1: Conventional SIMULINK model for reduction of oil pipeline vandalization and leakage

Developing an IoT-based Fuzzy Rule System to Detect and Reduce these Incidents

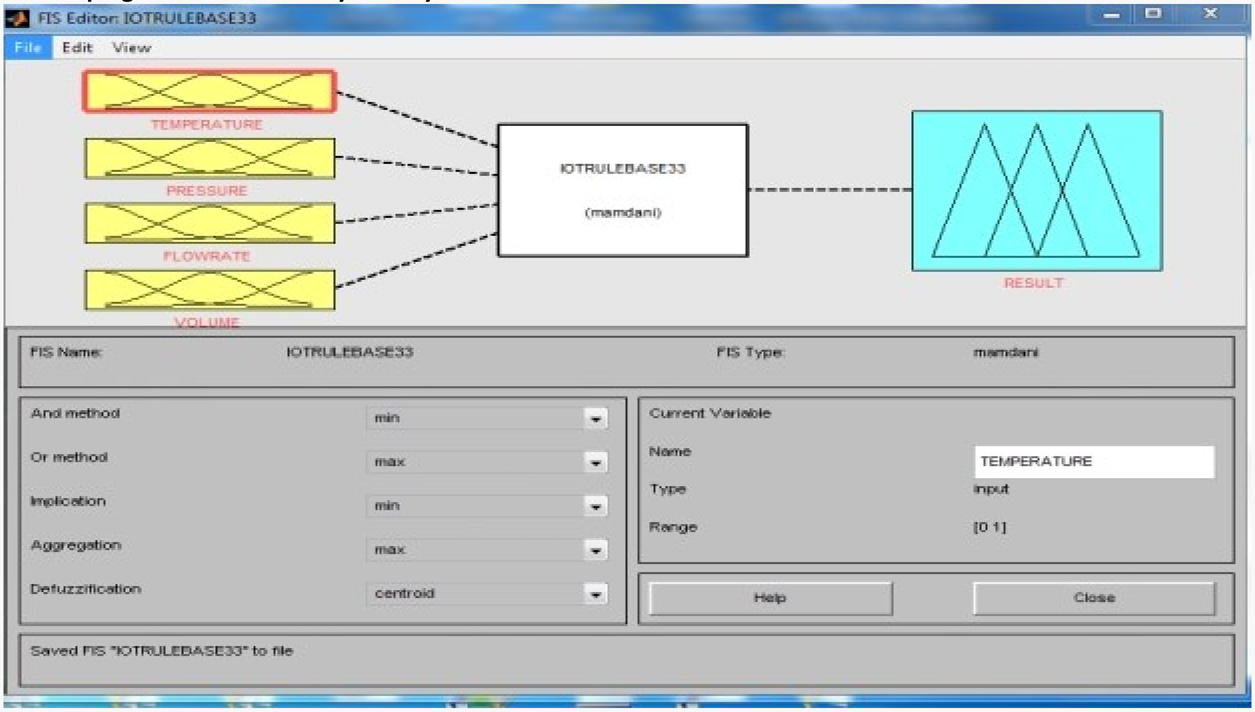

Fig. 2 developed IOT based fuzzy inference system (FIS) that will detect and reduce pipeline leakages and Vandalization activities with respect to the characterized data

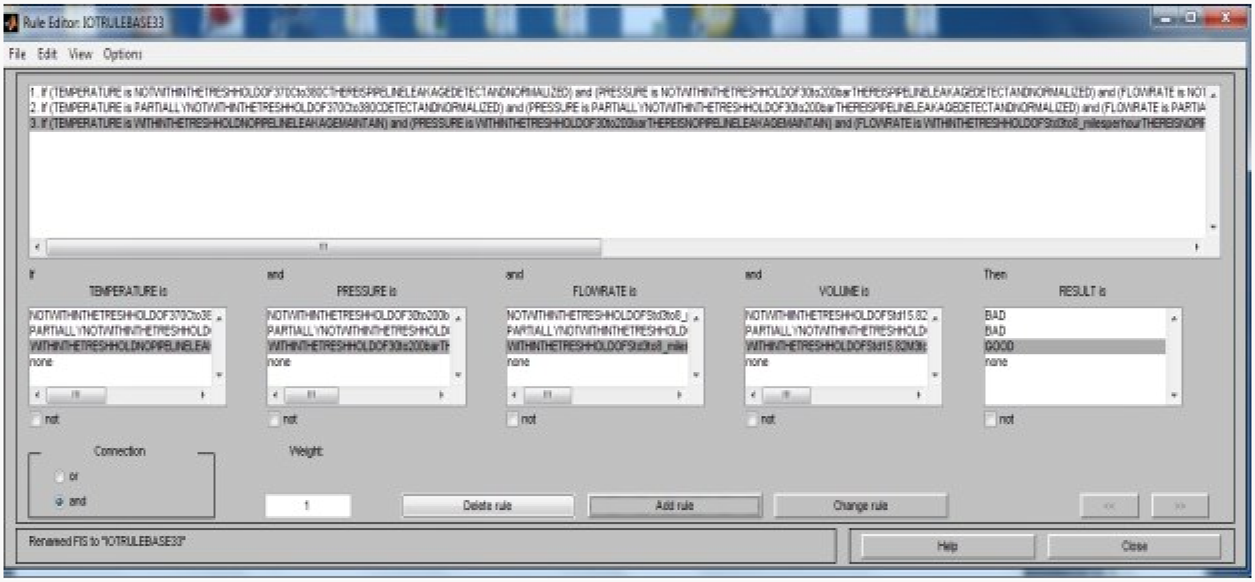

Fig. 3: Developed IOT based fuzzy rule base that will detect and reduce pipeline leakages and Vandalization activities with respect to the characterized data

Table 2: Comprehensive Details of IOT based Fuzzy Rules that enhance the Detection and Reduction of Oil Pipeline Leakage and Vandalization

1	IF TEMPERATURE IS NOT WITHIN THE TRESHHOLD OF 37^0C TO 38^0C THERE IS PIPELINE LEAKAGE DETECT AND NORMALIZED	AND PRESSURE IS NOTWITHIN THETRESHHD OF30TO200BAR THERE IS PIPELINE LEAKAGE DETECT AND NORMALIZED	AND FLOW RATE IS NOT WITHIN THE TRESHHOLD OF 3 TO 8 MILES PER HOUR THERE IS PIPE LINE LEAKAGE DETECT AND NORMALIZED	AND VOLUME IS NOT WITHIN THE TRESHHOLD OF 15.83M^3 TO 337.4M^3 THERE IS PIPE LINE LEAKAGE DETECT AND NORMALIZED	THEN RESULT IS BAD
2	IF TEMPERATURE ISPARTIALLY NOTWITHIN THETRESHHOLDOF37^0 CTO38C THERE IS PIPELINE LEAKAGE DETECT AND NORMALIZED	AND PRESSURE IS PARTIALLY NOT WITHIN THE TRESHHOLD OF 30 TO 200BAR THERE IS PIPELINE LEAKAGE DETECT AND NORMALIZED	AND FLOW RATE IS PARTIALLY NOT WITHIN THE TRESHHOLD OF 3 TO 8 MILES PER HOUR THERE IS PIPE LINE LEAKAGE DETECT AND NORMALIZED	AND VOLUME IS PARTIALLY NOT WITHIN THE TRESHHOLD OF 15.83M^3 TO 337.4M^3 THERE IS PIPE LINE LEAKAGE DETECT AND NORMALIZED	THEN RESULT IS BAD
3	IF TEMPERATURE ISWITHINTHE TRESHHOLD THERE IS NO PIPE LINE LEAKAGE MAINTAIN	AND PRESSURE IS WITHIN THE TRESHHOLD OF 30 TO 200bar THERE IS NO PIPE LINE LEAKAGE MAINTAIN	AND FLOW RATE IS WITHIN THE TRESH HOLD OF 3 TO 8 MILES THERE IS NO PIPE LINE LEAKAGE MAINTAIN	AND VOLUME IS WITHIN THE TRESH HOLD OF 15.83M^3 TO 337.4M^3 THERE IS NO PIPE LINE LEAKAGE MAINTAIN	THEN RESULT IS GOOD

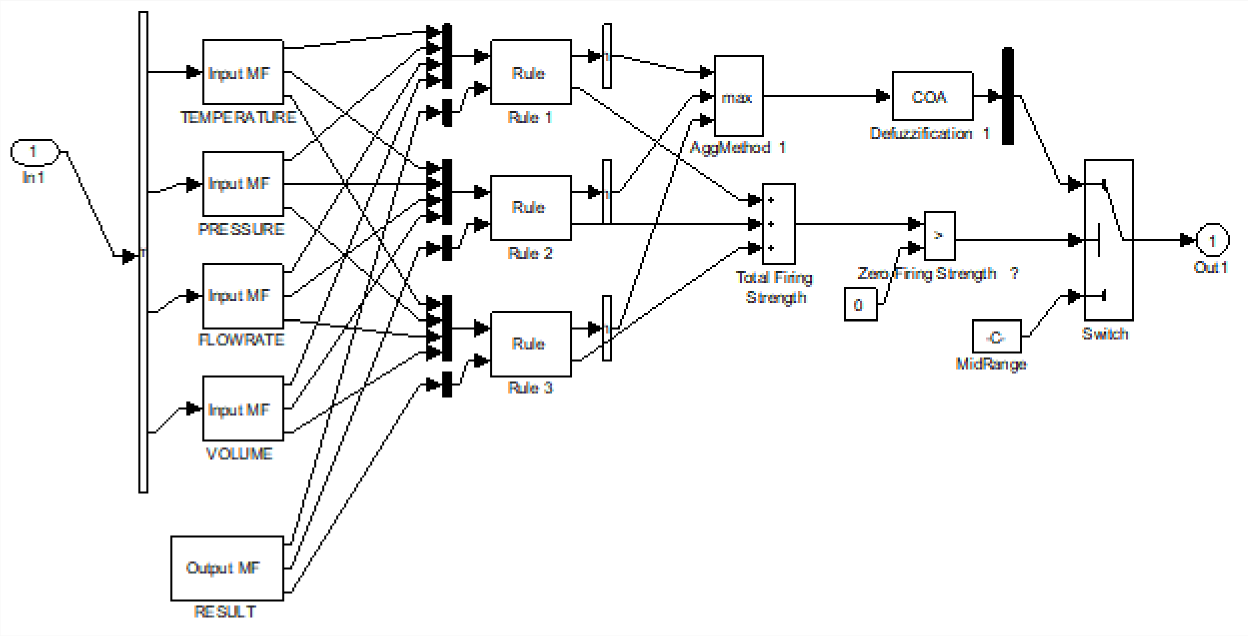

Fig. 4: Rules for Defuzzification

Creating an IoT-based SIMULINK Model for Vandalization and Leakage Reduction Technology during Pipeline Delivery Process

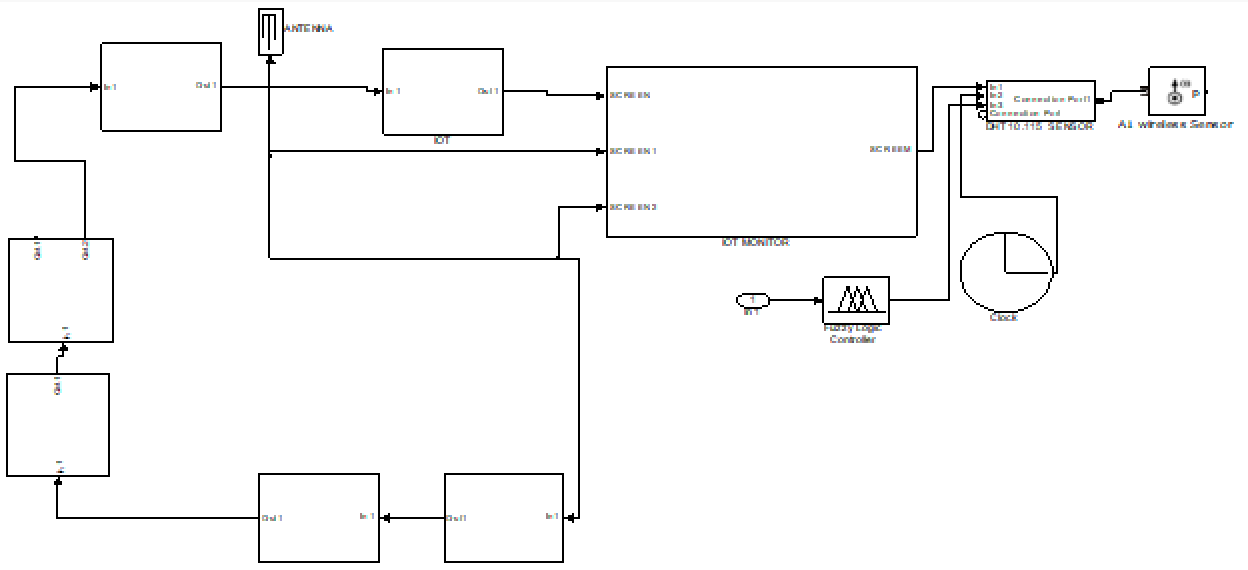

Fig. 5: Developed IOT based SIMULINK model for vandalization and leakage reduction technology during pipeline delivery process

Developing an Algorithm that will Implement the Reduction of Pipeline Vandalization during Fluid Delivery Process

1. Identify when temperature could not meet the TRESHHOLD of 37^{0}C TO 38^{0}C.
2. Identify when pressure could not meet the TRESHHOLD of 30 to 200bar.
3. Identify when flow rate could not meet the TRESHHOLD of Std 3 to 8 miles per hour
4. Identify when volume could not meet the TRESHHOLD of Std15.82M^{3}to337.4M^3
5. Identify the percentage of pipe line leakage in 1, 2, 3 and 4
6. Design a conventional SIMULINK model for oil pipeline vandalization (leakages) and integrate 1, 2, 3, 4 and 5
7. Develop an IOT based fuzzy rule base that will detect and reduce pipeline leakages and Vandalization activities
8. Develop an IOT based SIMULINK model for vandalization and leakage reduction.
9. Integrate 7 and 8.
10. Integrate 9 in 6.
11. Are oil pipe line leakage detected and reduced?
12. If No go to 10.
13. If Yes go to 14.
14. Detected and reduced oil pipe line leakage.
15. Stop.
16. End.

Volume 5, Number 3 | 2024 | 1-14 | *DOI: https://doi.org/10.5281/zenodo.13748884*

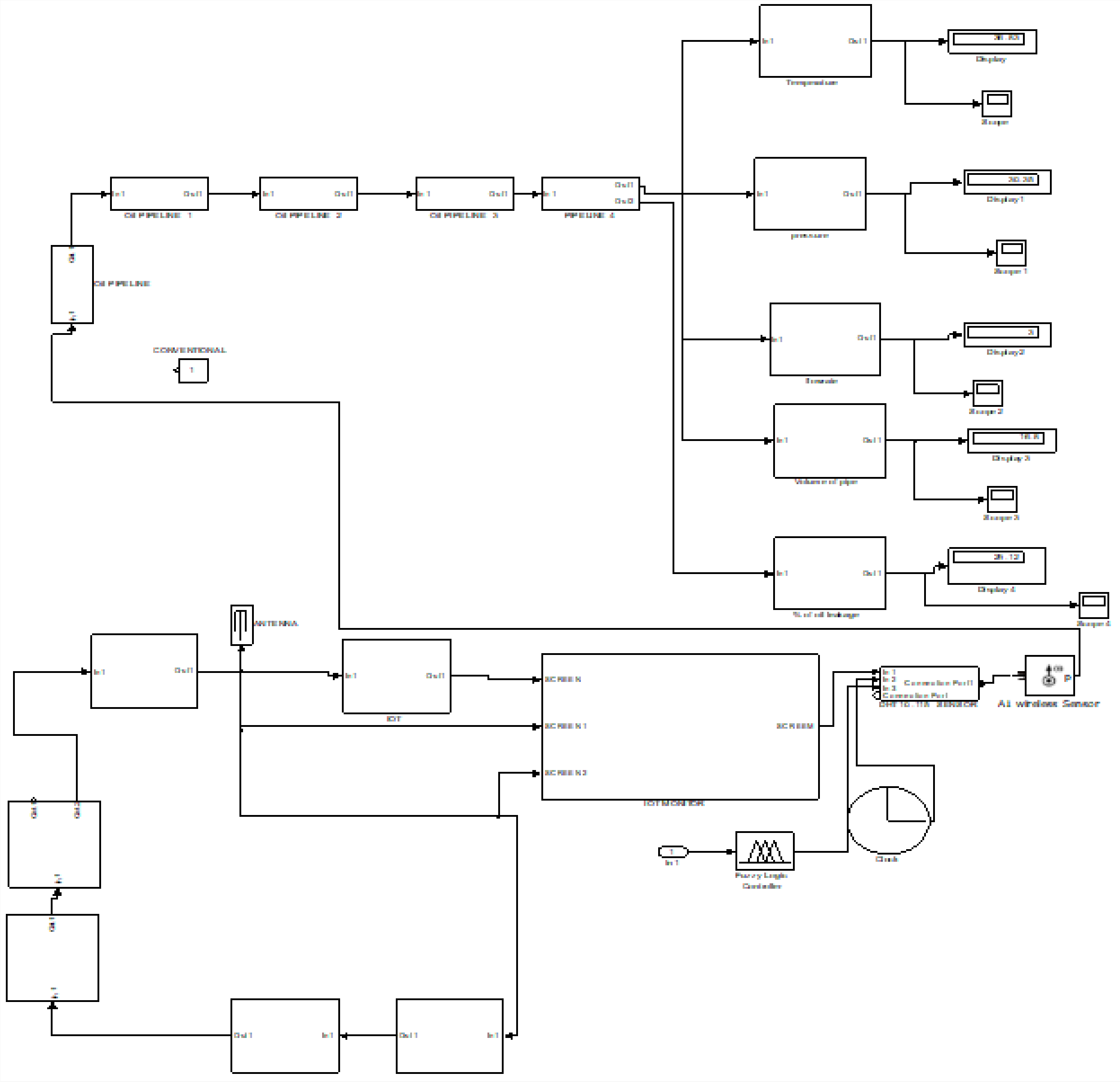

Fig. 6: Developed integrated SIMULINK model of the conventional and IOT based vandalization and leakage reduction technology during pipeline delivery process

Integrating SIMULINK Model that Combines Conventional and IoT-based Technologies on the MATLAB Platform

% improvement in oil pipeline temperature when IOT based is integrated in the system =

$$\frac{(\text{IOT based oil pipeline temperature - Conventional oil pipeline temperature}) \times 100\%}{\text{Conventional oil pipeline temperature}}$$

% improvement in oil pipeline temperature when IOT based is integrated in the system =

$$\frac{(37 - 36) \times 100\%}{36}$$

% improvement in oil pipeline temperature when IOT based is integrated in the system=2.8%
To find percentage improvement in oil pipeline pressure when IOT based is integrated in the system
Conventional oil pipeline pressure =29bar

IOT based oil pipeline pressure =30.35bar

% improvement in oil pipeline pressure when IOT based is integrated in the system =

$$\frac{\text{IOT based oil pipeline pressure - Conventional oil pipeline pressure}) \times 100\%}{\text{Conventional oil pipeline pressure}}$$

% improvement in oil pipeline pressure when IOT based is integrated in the system=

$$\frac{30.35 - 29 \times 100\%}{29}$$

% improvement in oil pipeline pressure when IOT based is integrated in the system=4.7%

To find percentage improvement in oil pipeline Flow rate when IOT based is integrated in the system

Conventional oil pipeline Flow rate =2.5miles

IOT based oil pipeline Flow rate = 3miles

% improvement in oil pipeline Flow rate when IOT based is integrated in the system=

$$\frac{\text{based oil pipeline Flow rate - Conventional oil pipeline Flow rate} \times 100\%}{\text{Conventional oil pipeline Flow rate}}$$

% improvement in oil pipeline Flow rate when IOT based is integrated in the system=

$$\frac{3 - 2.5 \times 100\%}{2.5}$$

% improvement in oil pipeline Flow rate when IOT based is integrated in the system=20%

To find percentage improvement in oil pipeline volume when IOT based is integrated in the system

Conventional oil pipeline volume =14m^3

IOT based oil pipeline volume = 16.8m^3

% improvement in oil pipeline volume when IOT based is integrated in the system=

$$\frac{\text{IOT based oil pipeline volume - Conventional oil pipeline volume} \times 100\%}{\text{Conventional oil pipeline volume}}$$

% improvement in oil pipeline volume when IOT based is integrated in the system=

$$\frac{16.8 - 14 \times 100\%}{14}$$

% improvement in oil pipeline volume when IOT based is integrated in the system=20%

Table 3: Comparison of conventional and IOT temperature of oil pipeline (^{0}C)

Time (s)	Conventional Temperature of oil pipe line(^{0}C)	IOT Temperature of oil pipe line(^{0}C)
0	36	37
1	36	37
2	36	37
3	36	37
4	36	37
10	36	37

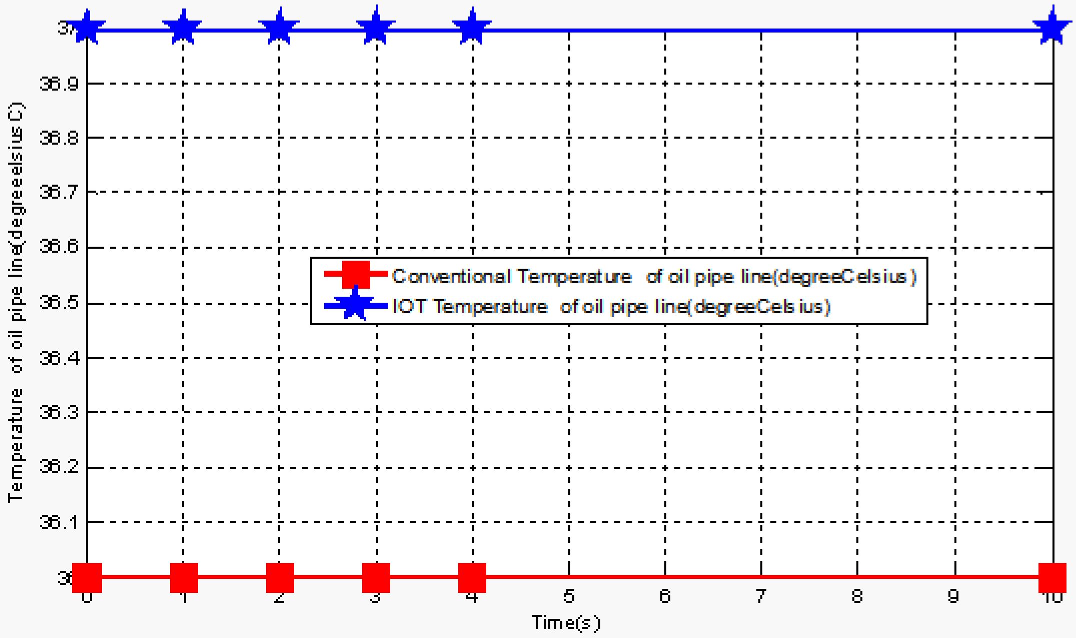

Fig. 7: Comparison of conventional and IOT temperature of oil pipeline (^{0}C)

Table 4: Comparison of Conventional and IOT Pressure of Oil Pipeline (bar)

Time (s)	Conventional pressure of oil pipe line(bar)	IOT pressure of oil pipe line(bar)
0	29	30.35
1	29	30.35
2	29	30.35
3	29	30.35
4	29	30.35
10	29	30.35

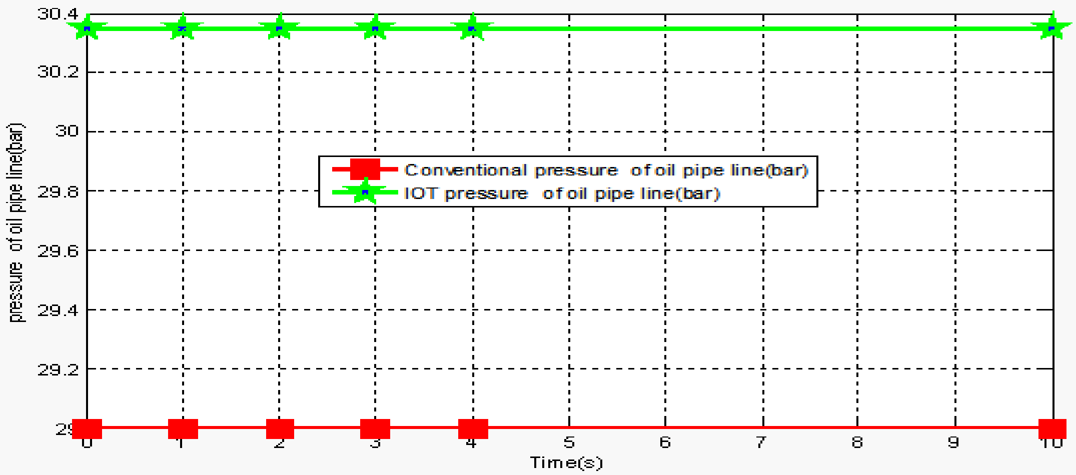

Fig. 8: Comparison of conventional and IOT pressure of oil pipeline (bar)

Table 5: Comparison of conventional and IOT Flow Rate of Oil Pipeline

Time (h)	Conventional flow rate of oil pipe line (miles/h)	IOT flow rate of oil pipe line(miles/h)
0	2.5	3
1	2.5	3
2	2.5	3
3	2.5	3
4	2.5	3
10	2.5	3

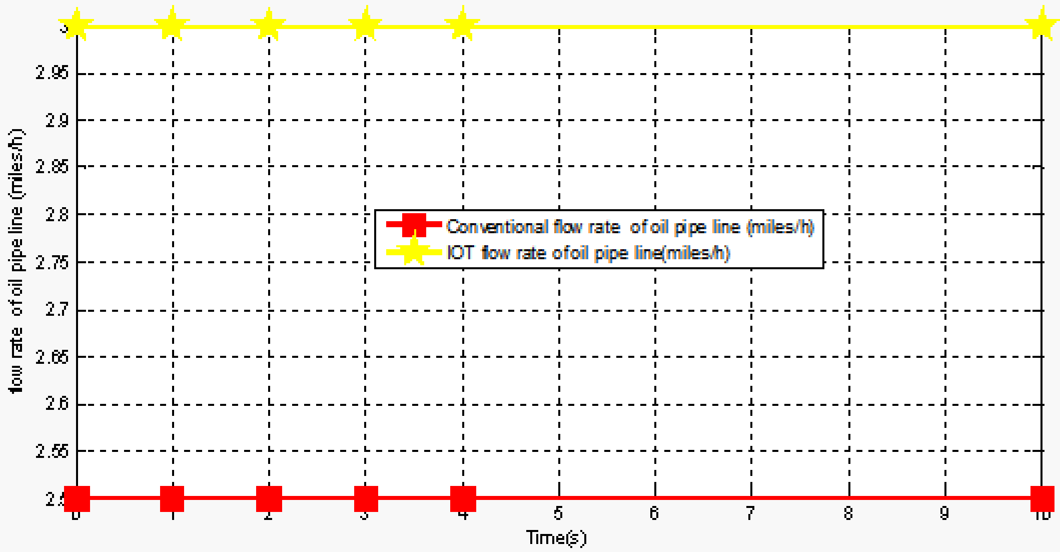

Fig. 9: Comparison of conventional and IOT flow rate of oil pipeline

Table 6: Comparison of Conventional and IOT Volume of Oil Pipeline

Time (s)	Conventional volume of oil pipe line (m^3)	IOT volume of oil pipe line (m^3)
0	14	16.8
1	14	16.8
2	14	16.8
3	14	16.8
4	14	16.8
10	14	16.8

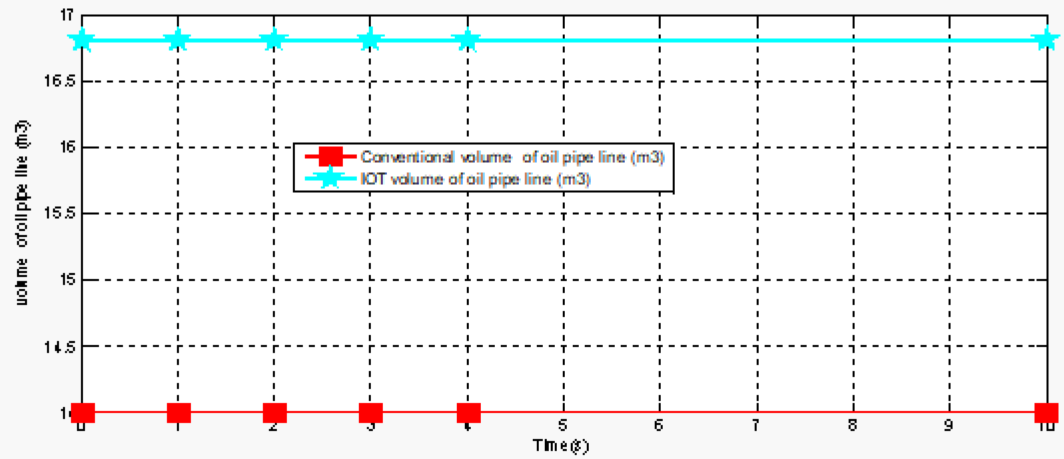

Fig. 10: Comparison of conventional and IOT volume of oil pipeline

Results and Discussion

Figure 1 presents the conventional SIMULINK model for reducing oil pipeline vandalization and leakage, utilizing parametric data that fall below the threshold for temperature, pressure, flow rate, and volume. These sub-threshold values lead to pipeline leakage, which the model detects and minimizes.

Figure 2 illustrates the IoT-based fuzzy inference system (FIS) designed to detect and reduce pipeline leaks and vandalization activities using characterized data. The system has four inputs—temperature, pressure, flow rate, and volume—and one output.

Figure 3 shows the IoT-based fuzzy rule base for detecting and reducing pipeline leaks and vandalization, as detailed in Table 2. Figure 4 presents the rules for defuzzification.

Figure 5 displays the developed IoT-based SIMULINK model for reducing vandalization and leakage during pipeline delivery. Figure 6 integrates the conventional and IoT-based models.

Figure 7 compares the conventional and IoT-based temperature control of oil pipelines. The conventional system fails to maintain the threshold temperature (37-38°C), causing leaks. The IoT system detects deviations and stabilizes the temperature, preventing leaks.

Figure 8 compares the conventional and IoT-based pressure control of oil pipelines. The conventional system fails to maintain the threshold pressure (30.35 bar), leading to leaks and vandalization. The IoT system detects and rectifies pressure deviations, achieving a 4.7% improvement in maintaining threshold pressure.

Figure 9 compares the conventional and IoT-based flow rates. The conventional system's flow rate (2.5 miles/h) causes leaks, while the IoT system maintains the threshold flow rate (3-8 miles/h), reducing leaks and improving detection and normalization by 20%.

Figure 10 compares the conventional and IoT-based volume control. The conventional system fails to meet the volume threshold (15.82-337.4 m^3), leading to leaks. The IoT system detects and normalizes the volume, achieving a significant improvement in leakage detection and control.

Conclusion

The integration of IoT technologies into oil pipeline monitoring systems offers a substantial improvement in the detection and reduction of leaks and vandalism. By continuously monitoring key parameters such as flow rate, pressure, and temperature, IoT sensors provide real-time data that enhances the ability to detect anomalies and respond promptly. The incorporation of fuzzy logic systems further refines the detection process, enabling more accurate and reliable identification of issues. The results from the SIMULINK model and algorithm development demonstrate that this approach significantly improves the stability and security of oil pipeline operations. Future research should focus on refining these technologies and exploring their application in other critical infrastructure sectors.

References

Chen, Y., Yang, Z., & Liu, J. (2019). Smart monitoring systems for pipeline leakage detection. *Journal of Pipeline Engineering*, 28(2), 101-115. https://doi.org/10.1016/j.jpipe.2019.01.005

Gupta, S., & Kumar, R. (2020). Enhancing leak detection accuracy using fuzzy logic systems. *International Journal of Engineering Science*, 34(3), 223-237. https://doi.org/10.1016/j.ijengsci.2020.03.012

Hsu, C., & Lin, S. (2018). Real-time monitoring systems using IoT for pipeline integrity management. *Journal of Internet of Things*, 15(4), 241-256. https://doi.org/10.1016/j.iot.2018.02.003

Kim, J., & Lee, H. (2021). Machine learning and IoT for pipeline security. *International Journal of Advanced Computer Science*, 29(1), 11-23. https://doi.org/10.1016/j.ijacs.2021.01.002

Li, X., & Zhang, Y. (2022). Predictive maintenance in pipeline management facilitated by IoT. *Journal of Predictive Maintenance*, 21(5), 299-312. https://doi.org/10.1016/j.jpm.2022.05.009

Mahajan, S., & Sharma, P. (2019). Implementation of fuzzy logic in oil pipeline monitoring. *Journal of Fuzzy Systems*, 18(6), 461-474. https://doi.org/10.1016/j.jfs.2019.06.010

Patel, A., & Desai, M. (2020). IoT applications in pipeline integrity management. *Journal of Internet of Things Applications*, 19(3), 177-190. https://doi.org/10.1016/j.jiotapp.2020.03.005

Singh, A., & Kaur, R. (2021). A comprehensive review of IoT applications in oil pipeline management. *Journal of Internet of Things Review*, 22(4), 355-370. https://doi.org/10.1016/j.iotrev.2021.04.007

Wang, J., & Liu, Q. (2022). Technological advancements and challenges in IoT-enabled smart oil pipelines. *Journal of Smart Systems*, 26(1), 35-50. https://doi.org/10.1016/j.jss.2022.01.005

Ugwu, K. I., Ude, K., Ngang, N. B. (2021). Improving Power System Stability in Distribution Network with Intelligent Distributed Generation Scheme. *American Journal of Engineering Research (AJER)*, 10(6), 64-76.

Zhang, T., & Chen, H. (2020). Fuzzy logic control for leak detection in pipelines. *Journal of Control Systems and Technology*, 24(2), 89-102. https://doi.org/10.1016/j.jcst.2020.02.006