UNIABUJA Journal of Engineering and Technology

https://ujet.uniabuja.edu.ng/

Special Issue

Development of an Unmanned Ground Robot for Pipeline Vandalism Detection

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Abstract
Vandalism remains one of the biggest of threats to energy and utility companies. This, therefore, necessitates a system capable of remotely detecting and reporting pipeline vandalism. This work designed and implemented an unmanned ground robot for detecting pipeline vandalism. The system was developed using an Arduino Uno microcontroller, DC motors, a motor driver, an infrared sensor, an ultrasonic sensor, and a GSM module. The microcontroller serves the heart of the device, around which the functionalities of other components were designed using relevant algorithms. An SMS based notification status for vandalism was created via a SIM808 GSM module. The functionality of the developed system was tested using improvised pipes of different diameters-400, 600 and 1500 mm, all of which are 2 m in length. The speed of the developed system for pipe vandalism detection was also examined by creating a binary number representation of the robot speed, which was embedded within the implementation code of the microcontroller. Results showed that the developed robot for pipeline vandalism detection functioned satisfactorily. The minimum size of vandalism (artificial opening) that was detected by the system in 400, 600 and 1500 mm diameter pipes was 10, 20 and 90 mm at locations 1.20 m (7°13'40.5"N 3°27'12.7"E), 1.70 m (7°13'40.5"N 3°27'12.8"E) and 1.20 m (7°13'40.5"N 3°27'12.7"E), respectively, along the pipe. The robot, however, was unable to detect vandalism points in pipes where the diameter was greater than 1500 mm and vandalism size was less than 90 mm. The developed robot can be robustly scaled up for real-time pipeline vandalism detection, especially in developing nations such as Nigeria, seriously bedeviled with oil theft.

Keywords: *Microcontroller, pipeline, robot, ultrasonic sensor, vandalism, vandalism detection.*

1.0 Introduction

Globally, pipelines are important facility in the energy industry, as they help in the transportation of oil, gas, and other resources over long distances. Development of pipeline infrastructure lowers transportation expenses, enhancing the efficiency of the supply chain, and it facilitates faster allocation of resources, which in the long run is also a positive aspect of national growth. These pipelines are, however, vulnerable to series of defects such as vandalism, corrosion crack, fatigue crack, among others and consequently, result in leakages. These leakages are very dangerous both to the environment and human life. Oil spills of over 10,000 instances have been reported to have severe effects on ecosystems and community economic welfare for the population living along the oil pipeline routes (Ullah *et al.*, 2024; Siddique *et al*., 2023; Samaila *et al*., 2023; Ab Rashid *et al*., 2020).

According to Akande *et al.* (2021), the financial state of most economies, such as Nigeria, Libya, Angola, and Algeria, depends on the energy and utility products transferred through pipelines. Unauthorized tapping and sabotage do not only pose a threat to the security of the population and cause a drastic deterioration of the environment, but also lead to serious losses on the part of government and operators (Agara *et al*., 2025; Hongfang *et al*., 2023). Nigeria has the highest number of oil spills, resulting from illegal bunkering and interdictions rather than equipment failure (Umar *et al*., 2023), and official records attest to the prevalence of vandalism as the main source of the incidents between years 2015 and 2021 (Onwuachi and Iheagwara, 2022). The repeated attacks from illegal bunkering and interdictions have wide-range environmental consequences, including contamination of soil and water resources, destruction of biodiversity, and negative health outcomes for local populations. The attitude of the communities and the wider socio-economic systems are strongly believed to support the continuity of these challenges in oil-producing regions. As a solution to these risks, the use of advanced acoustic based monitoring system such

Received: 27-05-2026 / Accepted: 11-06-2026 / Published: 20-07-2026

https://doi.org/10.70118/ujet.2026.sp01.07

as mobile robotic inspection is becoming more popular (Hongfang *et al.*, 2023; Ozougwu *et al.*, 2023; Zhu *et al.*, 2022).

Robotic applications in recent times are becoming one of the most viable options for monitoring oil leaks in pipelines, particularly in areas that are not accessible to humans (Rusu and Tatar, 2022; Mohammed *et al.,* 2018). Pipelines typically consist of metal tubes having an internal diameter of 4 to 48 inches and are usually installed in areas that are mostly inaccessible to humans (Rusu and Tatar, 2022; Mohammed *et al.,* 2018). The active and flexible design of robots with wheels, legs, screw-like inchworm or snake locomotion permits moving to other pipe geometries and changing orientation (Rashid *et al.,* 2020; Elankavi *et al.,* 2020; Ma *et al*., 2025).

According to Kathekar *et al.* (2020), robots with flexible structures may possess the ability to adapt to ambient conditions and perform functions in areas inaccessible to humans. Mechanically inflatable structures are another type of innovative soft-robotic and bio-inspired mechanisms that makes it even more flexible to variations in tube size and shape (Atalla *et al.,* 2023). The adoption of robots as a means of defect detection, combined with non-destructive testing sensors such as ultrasonic sensors can be effective in detecting defects without destroying the structural integrity (Jeon *et al.,* 2024; Zhao, 2020). The latest developments bring autonomy with the machine learning methods, such as hierarchical reinforcement learning, which can guide a pipeline robot on the way through twisting branches and perform smart inspections (Akhyani, 2023; Botteghi *et al.,* 2021).

This study dealt with the development of an unmanned ground robot for detection of pipeline vandalism and remote reporting of the status. This system was designed to be an inexpensive, scalable system for vandalism or fault detection on critical pipeline infrastructure. Real-time monitoring via internet of things (IoT) ensures that the exact coordinates of the point of vandalism are reported. This action guarantees or quickens a swift response from the right authority.

Several attempts have been made to develop robotic and autonomous monitoring solutions for pipelines. Ayeni and Ayogu (2020) used an internet of things multi-sensor approach for monitoring oil pipelines from oil saboteurs. Odulaja and Rufai (2021) proposed the deployment of an embedded remotely monitored anti-pipeline vandalization system. The proposed system successfully applied methods of artificial intelligence to monitor, detect, and report cases of pipeline vandalism remotely. Ullah *et al.* (2023) developed a machine learning-based pipeline oil leak detector comprising of acoustic emission (AE) sensors. This system was tested on water and gas pipelines with pinholes, and higher accuracy recorded. Guo *et al.* (2024) introduced a pipeline vandalism detection system that combines convolutional neural networks with AE signals to oil leak identification and location. The system was tested on an experimental setup comprising a pressurized pipeline. Findings revealed that the system performed as desired with higher accuracy for noise cancellation. Ekeu-Wei *et al.* (2024) developed a cost-effective prototype system for identification and measurement of oil leaks. Nowakowski (2025) worked on an autonomous navigation system with high capability to traverse unstructured terrain.

A critique of the surveyed literature showed that, inspite of the various innovative techniques that have been employed for pipeline vandalism detection, limited studies have explored the adoption of non-destructive model of monitoring involving the use of approaches such as ultrasonic sensing especially in robotic systems for pipeline vandalism detection. This present study aims to bridge this gap by developing a prototype of an inexpensive unmanned ground robot that uses a microcontroller to integrate ultrasonic sensing into the system for real-time fault or vandalism detection. The remainder of this article is organized as follows: Section 2 describes the design, implementation, and testing of the robot. Section 3 deals with the presentation and discussion of the results, while Section 4 concludes the study and highlights the key findings.

2.0 Materials and Methods

2.1 The System Overview

The block diagram in Figure 1 shows the link between different units of the unmanned ground robot developed in this work. The unmanned robot's physical construction is divided into four primary parts: the unmanned mobile robot, the vandalism detection unit, the alert and messaging unit and the line follower unit. The core components include an Arduino microcontroller, an ultrasonic sensor, a GSM/GPS module and an infrared (IR) sensor. The mobile robot relies on an Arduino microcontroller to execute control decisions, process incoming data, and coordinate overall system operation. It controls the robot's movement utilizing four DC motors attached to the wheels. The ultrasonic sensor was used for detecting vandalism in the pipeline. By means of an integrated GSM/GPS chip, sensor data, location and alert messages can be transmitted in real-time to a specific control station. Moreover, the IR sensor provides line-following features that help the robot follows the pipeline path and keep it on track with the right direction.

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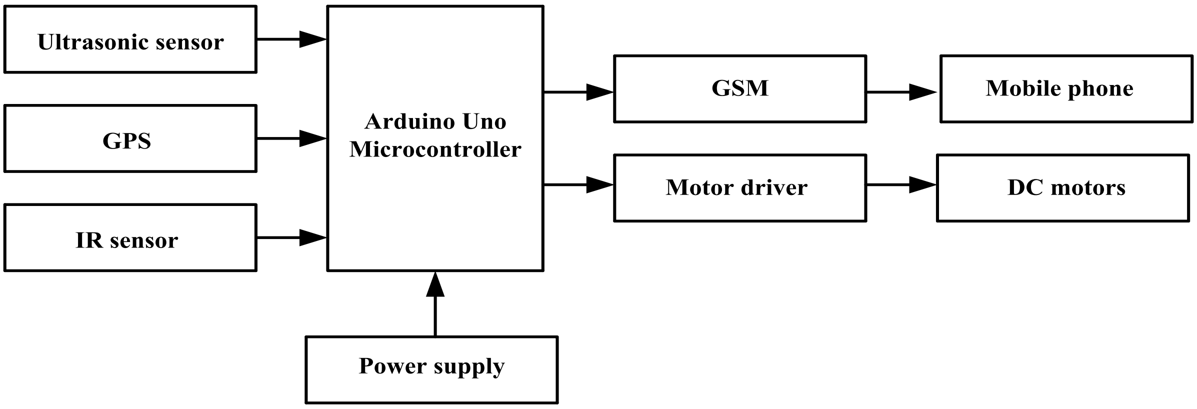

Figure 1: Block diagram of an unmanned ground robot for pipeline vandalism detection

2.2 The System Hardware Design

2.2.1 Power Supply Unit

Figures 2 and 3 show the circuit diagrams of the power supply units for the unmanned ground robot. The power supplies were designed using rechargeable 7.4 V, 2400 mAh lithium-ion cells, considering the fact that the Arduino microcontroller and the motor driver will need only a DC voltage of about 5 V to be powered and fully operational. The power supply unit in Figure 2 was used to power the Arduino microcontroller through its 12 V input pin (VIN) while the power supply unit in Figure 3 was used to power the L298N motor driver which in turn drives the wheels of the robot. The power supply units were developed as individual entities to ensure equal weight distribution on all sides of the robot.

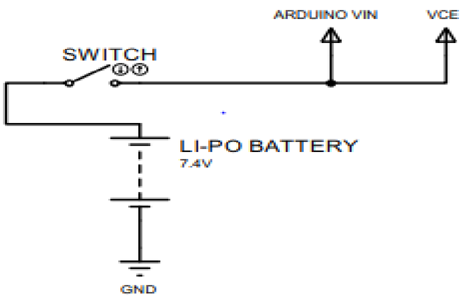

Figure 2: Power supply circuit diagram for the Arduino microcontroller

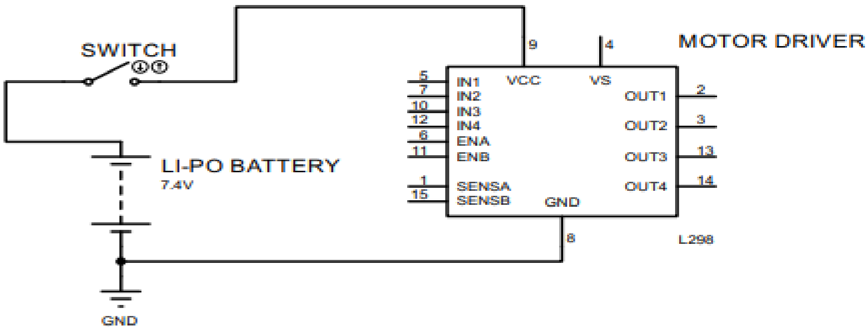

Figure 3: Power supply circuit diagram for the motor driver

2.2.2 Vandalism Detection Unit

The vandalism detection unit depicted in Figure 4 is responsible for detecting damage, cracks and vandalism in the pipeline. The ultrasonic sensor is the major component of this unit because it helps to detect geometric distortion inside the pipelines. The ultrasonic sensor (HC-SR04) deployed was able to measure the distance at which an object is located using equation 1 (Collins, 2026; Garg, 2026):

$$d_o = \frac{s \times t}{2} \tag{1}$$

where d_o is the object's distance from the ultrasonic sensor, s is the speed of sound (343 m/s) and t is the time taken.

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The ultrasonic sensor was able to detect a damage inside the pipeline by recording the time lapse between when the sound wave is transmitted and when the echo is received. This time lapse was programmed into the Arduino microcontroller. When this time lapse is exceeded that is the echo is not received by the sensor receiver, the microcontroller acknowledges it as a geometric distortion in the pipeline. The time taken for the echo to be received by the receiver was calculated using equation 2 which was derived from equation 1:

$$t = \frac{2 \times d_o}{s} \tag{2}$$

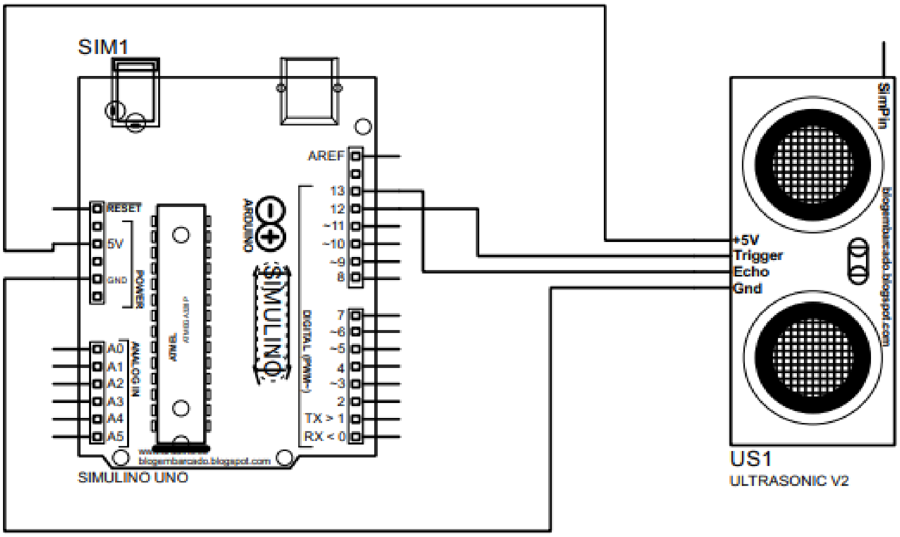

Figure 4: The vandalism detection unit

2.2.3 Mobile Robot Unit

This unit is responsible for manipulating the robot's wheels movement with the assistance of the microcontroller and an L298N motor driver. The design of the unmanned ground robot cannot be achieved in the absence of the mobile robot unit, which is sometimes referred to as the motor driver unit. The unit whose design is shown in Figure 5 consists of an L298N driver unit (motor driver and H-bridge circuit), four DC motors, an optical encoder, and a four-wheel drive car chassis, which are interfaced with the Arduino Uno.

The DC motors are responsible for moving the wheels of the robot, and they are the most important components of the mobile robot unit because without the right DC motors, the robot cannot navigate the pipeline terrain. Since the DC motors must deliver adequate torque and revolution per minute (rpm) speed, this necessitates the mass estimation in Table 1. The total weight (W) and net torque (τ) of the robot were estimated using equations 3 and 4, respectively:

$$W = M \times g \tag{3}$$

$$\tau = W \times R \tag{4}$$

where M is the total mass of the components (0.82900 kg), g is the acceleration due to gravity (9.8m/s^2) and R is the radius of the wheel (0.04 m).

Equation 4 is important for calculating the torque required for moving the robot on a flat surface. The reaction force (F_r) with the coefficient of friction (μ) on a surface exceeding 0.5 is given by equation 5:

$$F_r = \mu \times W \tag{5}$$

The F_r is related to τ by equation 6:

$$\tau = F_r \times d \tag{6}$$

where d is the robot's distance.

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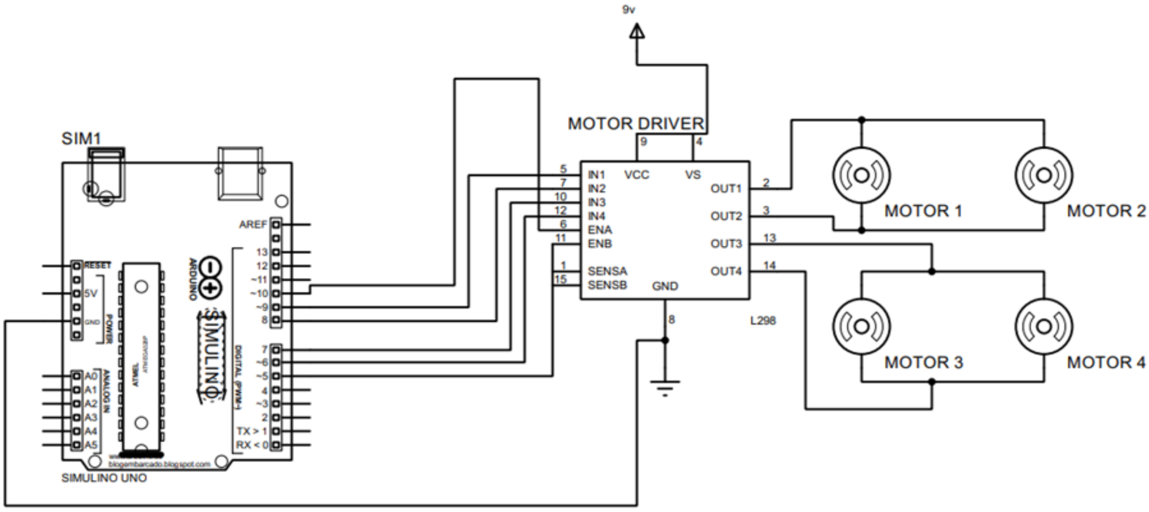

Figure 5: Circuit diagram of the mobile robot unit

Table 1: Components' mass estimation

S/N	Components	Mass (kg)
1.	Chassis and Wheels	0.50000
2.	Battery	0.10600
3.	L298N Motor Driver	0.03000
4.	Ultrasonic Sensor	0.01000
5.	SIM 808 GPS and GSM Module	0.10000
6.	Arduino UNO	0.05000
7.	Jumper Cables and Strings	0.03000
8.	Other Loads	0.00336
	Total	0.82900

Based on equations 3 to 6, a Glyduino geared DC motor with operating torque in the range of 0.05 to 0.13 Nm was selected for the work. The L298N motor driver in Figure 5 was used to control the spin direction of the wheels either in clockwise or anticlockwise to help the unmanned robot move forward, backward, spin right or left. It also helped to control the speed at which the wheels were rotating.

2.2.4 Line Tracking Unit

Figure 6 shows the circuit diagram of the line tracking unit where three IR sensors work in combination to ensure that the unmanned robot stays on course throughout its navigation in the pipeline. The sensor operates on the principle that light, when incident on a white surface, is reflected, whereas when incident on a black surface, it is absorbed. The IR sensor's operation is employed for controlling the robot wheels. If the robot drifts too much to the left, the phototransistor of the IR sensor on the robot's right side will not receive the reflected light of the LED, and the microcontroller will interpret this as an attempt by the robot to drift off its course. Table 2 shows the logic for the operation of the line tracking unit, which was based on the wiring connection of the DC motor to the L298N driver.

2.2.5 The Data Transmission Unit

The data transmission unit shown in Figure 7 is a crucial segment that facilitates the communication between the robot and the monitoring station. The microcontroller acts on the information received from the sensors to alert the monitoring station when a geometric distortion is identified via the data transmission unit. This unit uses a SIM808 GSM and GPRS modules to communicate with the monitoring station.

2.2.6 The Microcontroller Unit

The microcontroller unit controls all the other key units of the system as reflected in mobile robot, vandalism detection, line tracking and data transmission units, respectively, presented in Figures 4 to 7. It uses an Arduino Uno development board via which it communicates with the sensors and other mounted modules. The L298N ENABLE pins were connected to the pulse width modulation pin of the Arduino which controls the speed of the DC motors. The IN pins of the L298N were also integrated with the Arduino platform by linking its trigger and echo pins to the corresponding digital pins of the microcontroller.

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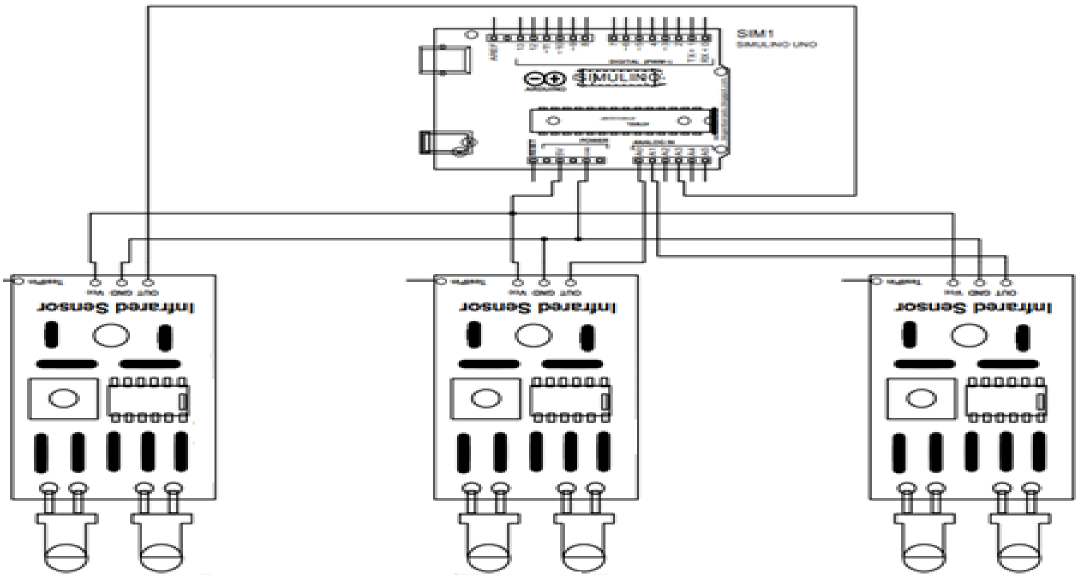

Figure 6: Circuit diagram of the line tracking unit

Table 2: Logic for the line tracking operation

S/N	IN1	IN2	IN3	IN4	Operation
1.	L	H	H	L	Forward Motion
2.	H	L	L	H	Reverse Motion
3.	H	L	H	L	Left Steering
4.	L	H	L	H	Right Steering
5.	L	L	L	L	Stationary State

where; H stands for Logic High (1) and L stands for Logic Low (0)

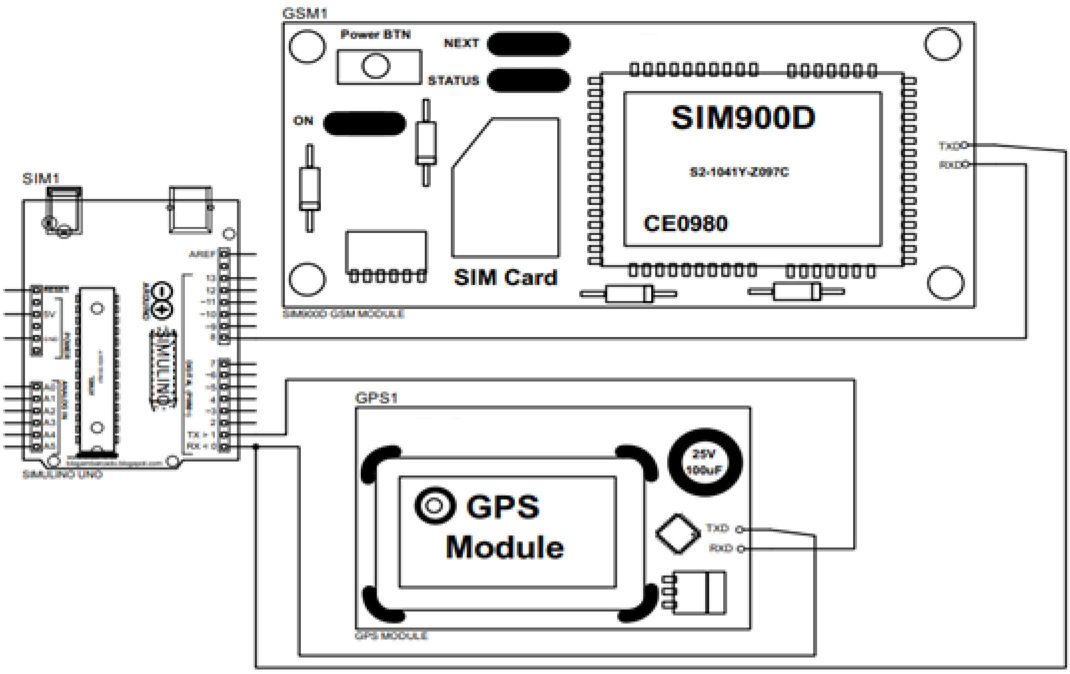

Figure 7: Circuit diagram of the data transmission unit

2.2.7 The Overall System Integration

Figure 8 illustrates the complete circuit architecture of the unmanned ground robot developed for pipeline vandalism detection. The design incorporates several functional modules, including the power supply, vandalism detection, motor control, line-tracking, and data transmission units. These modules were integrated into a unified system to realize the intended robotic platform.

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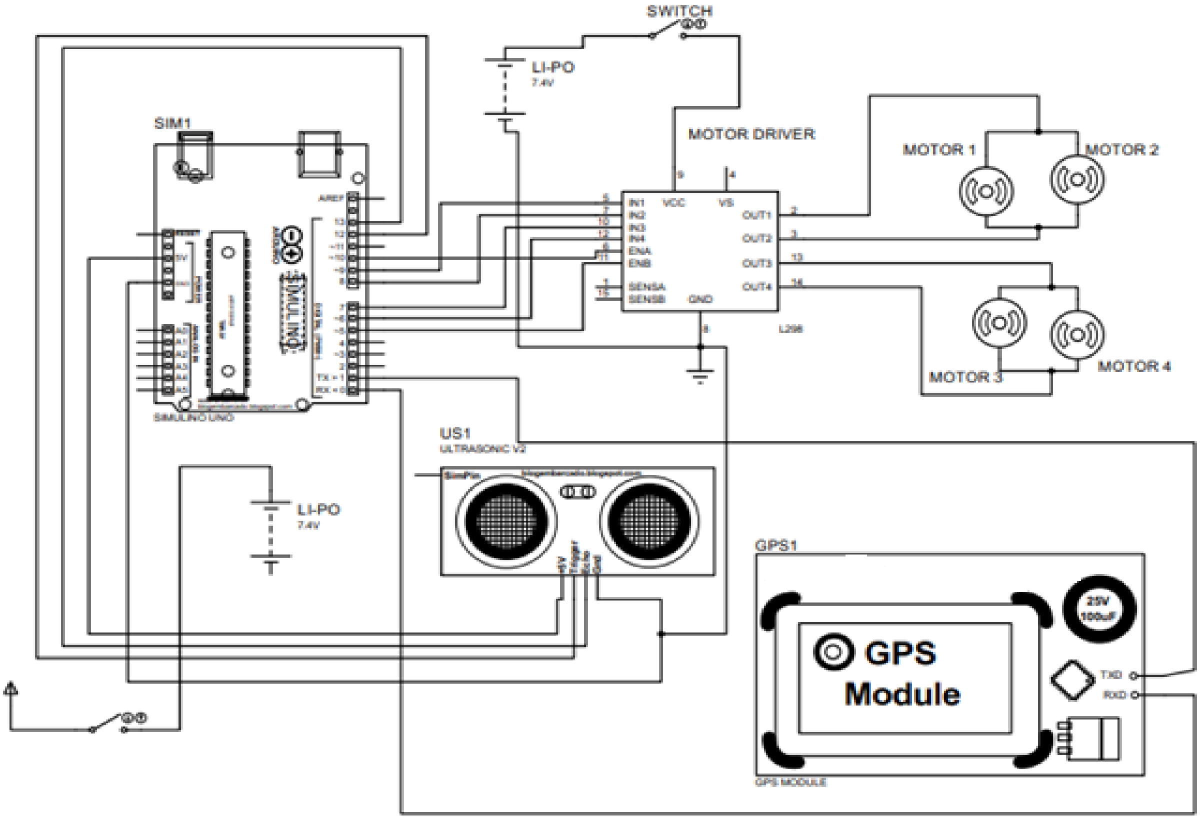

Figure 8: Circuit diagram of the unmanned ground robot for pipeline vandalism detection

2.2.8 Testing of the Developed System

The unmanned ground robot for the vandalism detection was tested after the implementation of the overall design. The performance of the subunits including vandalism detection, data transfer, mobile robot and power supply units was tested during developmental stages to assess their functionality. The testing of the overall developed robot was carried out in an improvised pipeline environment made from paper cartons. The pipe length was 2 m and of various sizes with diameters of 400, 600 and 1500 mm while the robot was operated at 140 rpm speed.

3.0 Results and Discussion

3.1 The Fully Developed System

The developed model of the unmanned ground robot for pipeline vandalism detection is presented in Figure 9. The components of the developed system such as the L298N motor driver, IR sensors, ultrasonic sensor, the microcontroller, the wiring connections, among other components are displayed in Figure 9.

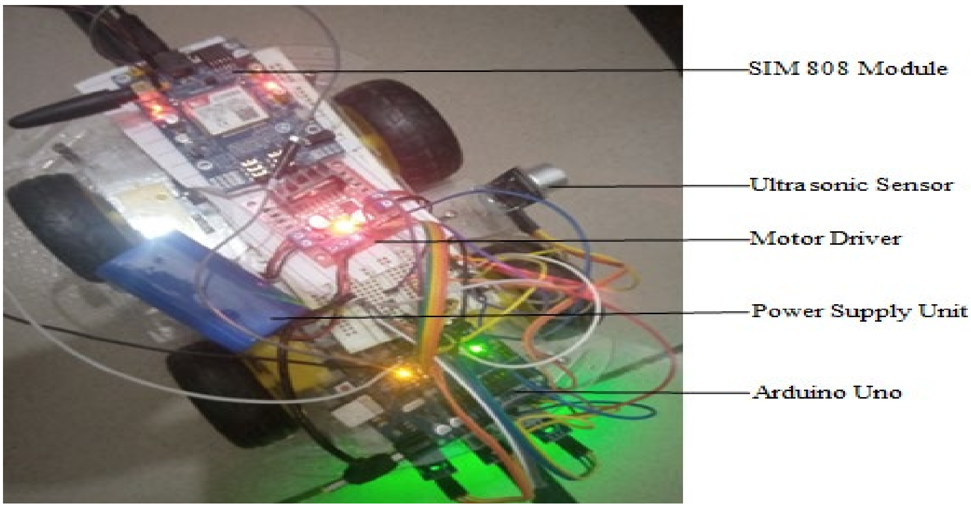

Figure 9: The developed model of the unmanned ground robot for vandalism detection

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3.2 Performance Test Results

Figures 10 to 12 show the performance test results on the various subunits of the developed robot. Figure 10 revealed correct functionality of the line tracking unit, where the lighting up and turning off of the light emitting diodes (LEDS) indicate proper functioning of this unit. Figure 11 showed that the data transmission unit of the system operated appropriately during testing, with the vandalism status "vandalization detected'' sent as a SMS to the associated mobile phone.

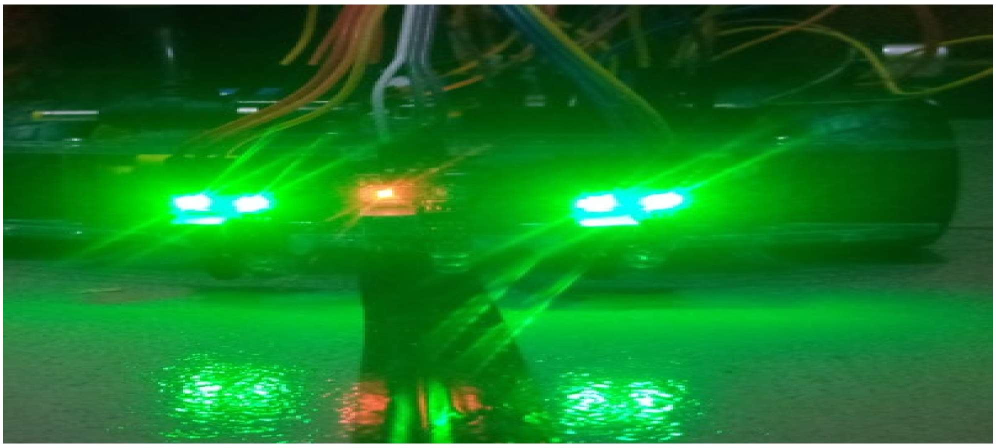

Figure 10: Performance testing of the line tracking unit

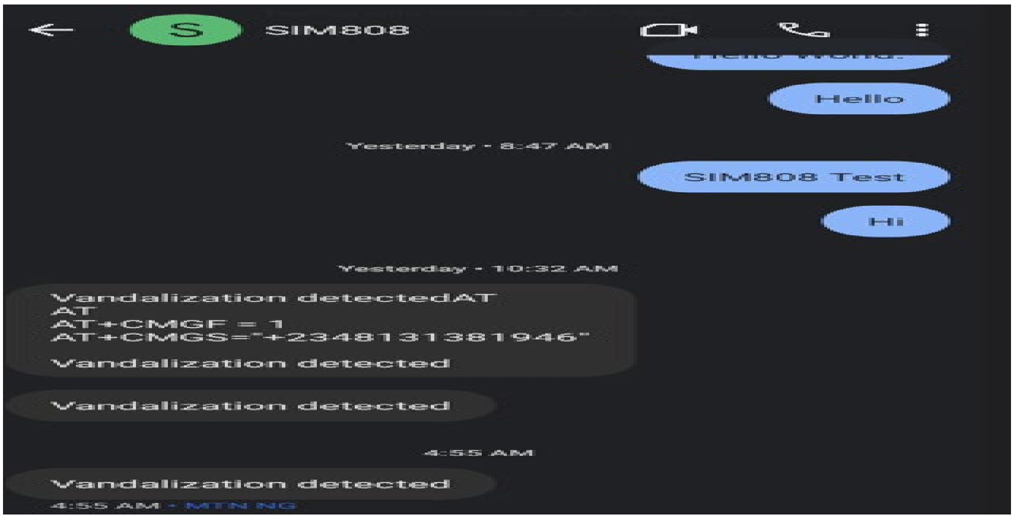

Figure 11: Performance testing of the data transmission unit

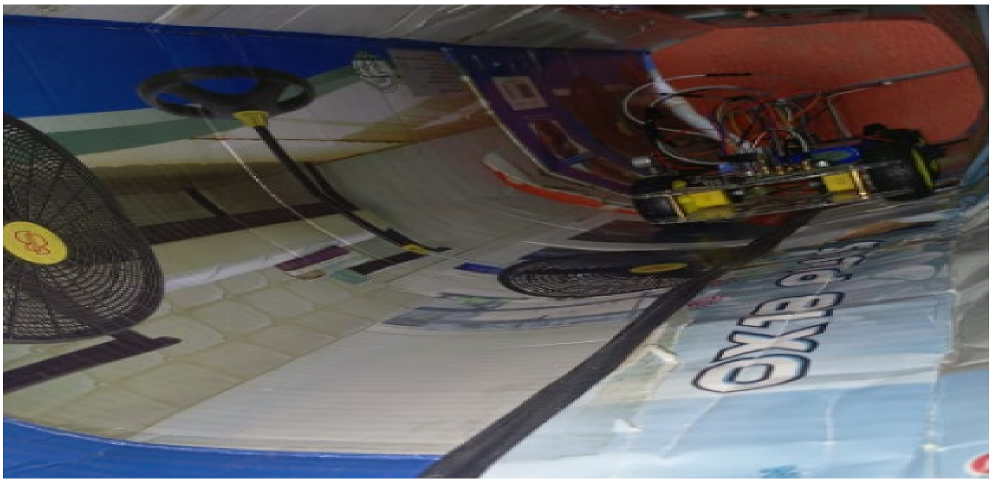

Figure 12: Performance testing of the vandalism detection unit

Figure 12 indicates that the vandalism detection unit was fully operational. The halting of motion of the robot when vandalism was detected by the ultrasonic sensor and microcontroller showed that this unit of

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the developed robot exhibited correct functionality. The results obtained in determining the effectiveness of the robot in detecting vandalism from pipes of 400, 600 and 1500 mm diameters are presented in Tables 3 to 5, respectively. From Tables 3 to 5, it can be inferred that the system's ability to detect vandalism decreased as the sizes of the vandalism became smaller in relation to the pipe's diameter.

The reason for this is that with larger pipe diameters and the forward speed of the robot, the ultrasonic sensor was able to receive echoes from the intact sections of the pipe while the robot was already passing through the vandalized point. This drawback is attributed to the fact that there is a time delay between the forwarding of a burst of sound waves from a specific ultrasonic sensor and the reflection of sound waves or their echo back. Hence, the robot was unable to detect vandalism points in pipes greater than 1500 mm in diameter when the vandalism size was less than 90 mm. Based on the results in Tables 3 to 5, the minimum size of vandalism (artificial opening) that was detected by the developed robot in 400, 600 and 1500 mm diameter pipes was 10, 20 and 90 mm at locations 1.20 m (7°13'40.5"N 3°27'12.7"E), 1.70 m (7°13'40.5"N 3°27'12.8"E) and 1.20 m (7°13'40.5"N 3°27'12.7"E), respectively.

For the ease of trend identification, the pipe diameters and vandalism sizes were represented by a line plot as shown in Figure 13. It was obvious from Figure 13 that, a near-perfect direct proportional relationship exists between pipe diameters and the sizes of the vandalism detected. Overall, Figures 9 to 12 together revealed that the power supply unit of this system was fully operational. The lightning up of various LEDs of the different subunits and movement of the robot as orchestrated by the motor driver showed that power supply reached the subunits. The outcomes of this study aligned with the outputs of the works of Ekeu-Wei and Ekeu-Wei (2024) and O'tega and Ofualagba (2016). These authors similarly worked on sensors-based pipeline vandalism detection system and were able to demonstrate the effectiveness of the developed prototype in detecting vandalism, identifying location and remotely reporting the scenario. However, they did not examine the pipe diameters-vandalism sizes relationship as established in the present study.

Table 3: Vandalism test at a 140 rpm speed for 400 mm diameter pipe

S/N	Length of Vandalism (mm)	Vandalism Status	Distance covered by robot from start of vandalism before stopping (mm)	Response Time (sec)
1.	180	Detected	50	292
2.	120	Detected	40	233
3.	80	Detected	55	321
4.	80	Detected	60	349
5.	80	Detected	50	292
6.	60	Detected	30	175
7.	60	Detected	35	204
8.	60	Detected	30	175
9.	40	Detected	40	233
10.	40	Detected	45	262
11.	40	Detected	30	175
12.	20	Detected	40	233
13.	20	Detected	15	87
14.	20	Detected	20	116
15.	10	Not Detected	-	-
16.	10	Detected	15	87
17.	10	Detected	15	87
18.	10	Detected	15	87

Table 4: Vandalism test at a 140 rpm speed for 600 mm diameter pipe

S/N	Length of Vandalism (mm)	Vandalism Status	Distance covered by robot from start of vandalism before stopping (mm)	Response time (Sec)
1.	180	Detected	50	292
2.	100	Detected	40	233
3.	80	Detected	40	233
4.	70	Detected	35	204
5.	60	Detected	40	233

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6.	40	Detected	30	175
7.	40	Detected	15	87
8.	40	Detected	20	116
9.	40	Detected	10	58
10.	20	Detected	15	87
11.	20	Not Detected	-	-
12.	20	Detected	15	87
13.	20	Not Detected	-	-
14.	20	Detected	15	87
15.	10	Not Detected	-	-

Table 5: Vandalism test at a 140 rpm speed for 1500 mm diameter pipe

S/N	Length of Vandalism (mm)	Vandalism Status	Distance covered by robot from start of vandalism before stopping (mm)	Response Time (sec)
1.	180	Detected	100	583
2.	150	Detected	100	583
3.	150	Not Detected	-	-
4.	150	Detected	90	525
5.	150	Detected	95	554
6.	150	Not Detected	-	-
7.	150	Detected	80	466
8.	120	Detected	90	525
9.	120	Not Detected	-	-
10.	120	Not Detected	-	-
11.	120	Detected	90	525
12.	120	Detected	100	583
13.	120	Not Detected	-	-
14.	90	Not Detected	-	-
15.	90	Not Detected	-	-
16.	90	Detected	90	525
17.	90	Not Detected	-	-
18.	90	Detected	100	583
19.	80	Not Detected	-	-
20.	80	Not Detected	-	-

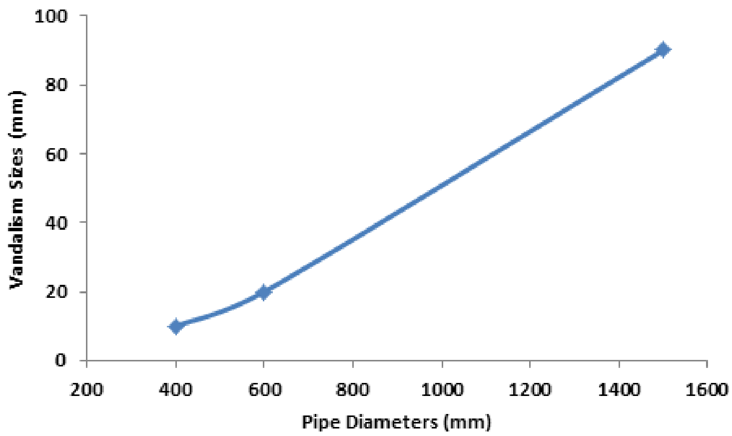

Figure 13: Plot of vandalism sizes versus pipe diameters for the developed robot

4.0 Conclusion

Globally, vandalism constitutes one of the major challenges confronting energy and utility companies. Therefore, the key to pipeline infrastructure security is effective detection of vandalism. In this study, an unmanned ground robotic system was developed and implemented for the detection of pipeline vandalism

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to support energy and utility operators in securing critical assets. The results of tests conducted proved that the developed system can be considered efficient and effective for vandalism detection. Besides the detection ability, the system is a simple, robust, and cost-effective system as economic locally sourced materials were utilized, and can be installed in pipelines of different diameters. The solution developed can provide an affordable and scalable method to reduce pipeline vandalism, especially in Nigeria where pipeline vandalism is very common. As an improvement on the prototype developed in the present study, the ultrasonic sensors in the robot can be made rotating since vandalism can occur at any location (right, left, front and back) along the pipeline. Under this condition, the effects of rate of rotation, temperature variation, and vibration on the performance of the sensors must be comprehensively examined and the impacts on the overall system efficiency can adequately assessed.

References

Ab Rashid, M. Z., Yakub, M. F. M., Bin Shaikh Salim, S. A. Z., Mamat, N., Putra, S. M. S. M., & Roslan, S. A. (2020). ''Modeling of the In-pipe Inspection Robot: A Comprehensive Review''. *Ocean Engineering*, 203, 107206.

Agara, S. A., Solomon, I. T., Adofu, I., & Gimba, O. J. (2025). ''Oil Vandalism Cost and Economic Growth in Nigeria''. *African Journal of Economics and Sustainable Development,* 8(1), 15-25.

Akande, S., Adetunla, A., Olanrewaju, T., & Adeoye, A. (2021). ''UAV and its Approach in Oil and Gas Pipeline Leakage Detection''. *Journal of Robotics*, 2021(1), 1300740.

Akhyani, M. (2023). ''Mapping Pipelines and Simultaneous Localization for Petrochemical Industry Robots''. *ArXiv preprint arXiv, 2311.11948*.

Anitha, P., & Saranya, K. (2019). ''IoT-Based Detection of Leakages in Gas Pipes''. *International Journal of Trend in Scientific Research and Development*, 3(4), 433-436.

Aslam, H., Kaur, M., Sasi, S., Mortula, M., Yehia, S., & Ali, T. (2017). ''A Conceptual Approach to Detection of Water Pipe Leakage Using Non-Destructive Techniques''. *In Proceedings of the 5th International Conference on Water, Energy and Environment, Sharjah, UAE,* 2, 12.

Atalla, M. A., Trauzettel, F., van Gelder, S. P., Breedveld, P., Wiertlewski, M., & Sakes, A. (2024). ''Mechanically-Inflatable Bio-Inspired Locomotion for Robotic Pipeline Inspection''. *In 2024 IEEE 7th International Conference on Soft Robotics*, 586-592.

Ayeni, T. P., & Ayogu, B. A. (2020). ''Intelligent Pipeline Monitoring System based on Internet-of-Things''. *Scientific Research Journal*, 8(8), 44-49.

Azeez, R. A., & Akinlolu, A. O. (2019). ''Development of an Intelligent Pipeline Vandalism Detection and Reporting System''. *Fountain Journal of Natural and Applied Sciences*, 8(2), 21-27.

Bello, S., Amadi, M. D., & Rawayau, A. H. (2023). ''Internet of Things-Based Wireless Sensor Network System for Early Detection and Prevention of Vandalism/Leakage on Pipeline Installations in the Oil and Gas Industry in Nigeria''. *Fudma Journal of sciences*, 7(5), 240-246.

Blyth, W. A. (2018). Robotic Pipe Inspection: System Design, Locomotion and Control. *Ph.D. Thesis, Imperial College London.*

Botteghi, N., Grefte, L., Poel, M., Sirmacek, B., Brune, C., Dertien, E., & Stramigioli, S. (2021). ''Towards Autonomous Pipeline Inspection with Hierarchical Reinforcement Learning''. *In International Conference on Robot Intelligence Technology and Applications*, 259-271.

Collins, D. (2026). '' Ultrasonic Sensors for Linear Position and Distance Measuring''. Accessed Online from: https://www.linearmotiontips.com/ultrasonic-sensors-for-linear-position-and-distance-measuring/

Ekeu-Wei, B. F., & Ekeu-Wei, I. T. (2024). ''Development of a Low-Cost Prototype System for Pipeline Operational and Vandalism Spillage Detection and Validation Framework''. *Advances in Internet of Things*, 14(2), 21-35.

Elankavi, R. S., Dinakaran, D., & Jose, J. (2020). ''Developments in In-pipe Inspection Robot: A Review''. *J. Mech. Contin. Math. Sci,* 15(5), 238-248.

Garg, S. (2026).'' Measuring the Speed of Sound Using an Ultrasonic Sensor and Oscilloscope''. Accessed Online from: https://www.digikey.fr/en/maker/blogs/2026/measuring-the-speed-of-sound-using-an-ultrasonic-sensor-and-oscilloscope?

Guo, P., Zheng, S., Yan, J., Xu, Y., Li, J., Ma, J., & Sun, S. (2024). ''Leak Detection in Water Supply Pipeline with Small-Size Leakage Using Deep Learning Networks''. *Process Safety and Environmental Protection, 191*, 2712-2724.

Jeon, K. W., Jung, E. J., Bae, J. H., Park, S. H., Kim, J. J., Chung, G. & Yi, H. (2024). ''Development of an In-pipe Inspection Robot for Large-Diameter Water Pipes''. *Sensors*, 24(11), 3470.

Kathekar, H. P., Gohel, H. V., Ingole, S. B., Ghadashi, O. A., & Kulkarni, R. D. (2020). ''Design and Development of Flaws Detection Method in Plant Process Pipeline by Mobile Robotic System''. *In 2020 International Conference on Advances in Computing, Communication & Materials*, 413-418.

https://doi.org/10.70118/ujet.2026.sp01.07

Le, D.V., Chen, Z., & Rajkumar, R. (2020). ''Multi-Sensors In-Line Inspection Robot for Pipe Flaws Detection''. *IET Science, Measurement and Technology*, 14(1), 71-82.

Liu, Y., & Zhou, W. (2022). ''Uncertainties in Internal Pressure of Oil Transmission Pipelines and Implications for the Reliability Analysis''. *Journal of Pipeline Science and Engineering*, 2(2), 100055.

Lu, H., Xi, D., & Qin, G. (2023). ''Environmental Risk of Oil Pipeline Accidents''. *Science of the Total Environment*, 874, 162386.

Lukman, A.A., Emmanuel, A., Chinonso, N., Mutiu, A., James, A., & Jonathan, K. (2018). ''An Anti-theft Oil Pipeline Vandalism Detection: Embedded System Development''. International *Journal of Engineering Science and Application*, 2(2), 55-64.

Ma, Q., Liang, W. & Zhou, P. (2025). ''A Review on Pipeline In-Line Inspection Technologies''. *Sensors*, 25(15), 4873.

Mazraeh, A. A., Ismail, F. B., Khaksar, W., & Sahari, K. S. M. (2017). ''Development of Ultrasonic Crack Detection System on Multi-diameter PIG Robots''. *Procedia Computer Science*, 105, 282-288.

Mohammed, M. N., Nadarajah, V. S., Lazim, N. F. M., Zamani, N. S., Al-Sanjary, O. I., Ali, M. A., & Al-Youif, S. (2018). ''Design and Development of Pipeline Inspection Robot for Crack and Corrosion Detection''. *In 2018 IEEE Conference on Systems, Process and Control,* 29-32.

Mustafa, H., & Chou, P. H. (2012). Embedded Damage Detection in Water Pipelines using Wireless Sensor Networks. *In 2012 IEEE 14th International Conference on High Performance Computing and Communication & 2012 IEEE 9th International Conference on Embedded Software and Systems*, 1578-1586.

Nayak, A., & Pradhan, S. K. (2014). ''Design of a New In-pipe Inspection Robot''. *Procedia Engineering*, 97, 2081-2091.

Nowakowski, M. (2024). ''Autonomous Navigation for Unmanned Ground Vehicles in Unstructured Terrain''. *Studia Informatica. Systems and Information Technology*, 31(2), 117-121.

Odulaja, G. O., & Rufai, K. I. (2021). ''Remotely–Monitored Anti-Pipeline Vandalization Detection Expert System''. *Journal of Science and Information Technology*, 16(1), 79-88.

Onwuachi-Iheagwara, P. N., & Iheagwara, B. I. (2022). ''Data Note: COVID-19, Social Distancing, and Pipeline Vandalism in Nigeria''. *F1000Research*, 10, 604.

O'tega, A. E., & Ofualagba, G. (2016). ''Development of an Aerial Robotic Oil Spill Surveillance (AROSS) System for Constant Surveillance and Detection of Spills from Crude Oil Pipelines''. *Int. J. Unmanned Syst. Eng.*, *4*, 19-33.

Ozougwu, P. E., Madu, C. N., Chukwuorji, J. C., Ozougwu, A. O., & Ozougwu, S. U. (2023). ''Environmental Identities and Attitude towards Crude Oil Pipeline Vandalism in Niger Delta Oil-Producing Communities''. Sustainability, 15(6), 5610.

Rusu, C., & Tatar, M. O. (2022). ''Adapting Mechanisms for In-pipe Inspection Robots: A Review''. *Applied Sciences*, 12(12), 6191.

Siddique, M. F., Ahmad, Z., Ullah, N., & Kim, J. (2023). ''A Hybrid Deep Learning Approach: Integrating Short-Time Fourier Transform and Continuous Wavelet Transform for Improved Pipeline Leak Detection''. *Sensors*, 23(19), 8079.

Ullah, N., Ahmed, Z., & Kim, J. M. (2023). ''Pipeline Leakage Detection Using Acoustic Emission and Machine Learning Algorithms''. *Sensors*, 23(6), 3226.

Ullah, N., Siddique, M. F., Ullah, S., Ahmad, Z., & Kim, J. M. (2024). ''Pipeline Leak Detection System for a Smart City: Leveraging Acoustic Emission Sensing and Sequential Deep Learning''. *Smart Cities*, 7(4), 2318-2338.

Umar, H. A., Khanan, M. A., Ogbonnaya, C., Shiru, M. S., Ahmad, A., & Baba, A. I. (2021). ''Environmental and Socioeconomic Impacts of Pipeline Transport Interdiction in Niger Delta, Nigeria''. *Heliyon*, 7(5), e06999.

Zhao, J. D. (2020). ''Robotic Non-Destructive Testing of Manmade Structures: A Review of the Literature''. *ArXiv*.

Zhu, H. H., Liu W, Wang, T., Su, J. W., & Shi, B. (2022). ''Distributed Acoustic Sensing for Monitoring Linear Infrastructures: Current Status and Trends''. *Sensors*, 22(19), 7550.

https://doi.org/10.70118/ujet.2026.sp01.07