Efficient Oil Pipeline Monitoring and Leakage Localization using Time Domain Reflectometer (TDR)

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Abstract
This paper presents the development of an efficient oil pipeline monitoring and leakage localizer using time domain reflectometer (TDR). Primarily, a pipeline connects two flow stations A and B to convey oil products from flow station A to flow station B. The pipeline used in this project has copper rods running the length of the pipeline and properly terminated at both flow stations and along the right of way of the pipeline, there are calibrations in meters so as to enable the responders to know point of tampering or leakage since the pipeline is buried in the ground. The flow station A has a microcontroller as the central control unit, with pump, time domain reflectometer (TDR) and sound alarm as the output devices. It equally has a start button to serve as the input device. Also flow station B has the same devices as flow station A except pump. In this project, the pipeline was monitored from flow station A to flow station B for possible leakage or cut of the copper rods along the length of the pipeline by vandals or oil thieves. The flow station A sends pulses through the copper rods using time domain reflectometer (TDR) at interval of 30 seconds. Once a cut is made on any of the copper rods surrounding the pipeline, the time domain reflectometer will detect the cut on the copper cable as a result of reflection of the sent pulse at the point where the copper cable is cut. Once there is a cut, flow station A stops the pump, and the time domain reflectometer (TDR) will determine the time interval between when the pulse was sent and when it was received back as time (t) and it will equally use the echo equation to determine the exact point of leakage or tampering on the oil pipeline. Then flow station A alerts its workers of tampering or leakage on the pipeline using sound alarm and also sends short message service (SMS) to flow station B, closest police station, heads of local security operatives that the pipeline passes through their communities to, alert them of the tampering on the pipeline and the exact location of the tampering on the pipeline for timely response. Flow station B relays the same message to its workers and responders just the same way flow station A did using the mobile phone. The developed system when tested showed very low error rate of 0.222% and precision of above 99%. This project will ensure timely intervention in the arrest of vandals before any harm is done on the pipeline. Also where leakage has already occurred, the oil company will move in immediately to carry out repairs since the exact point of leakage is known

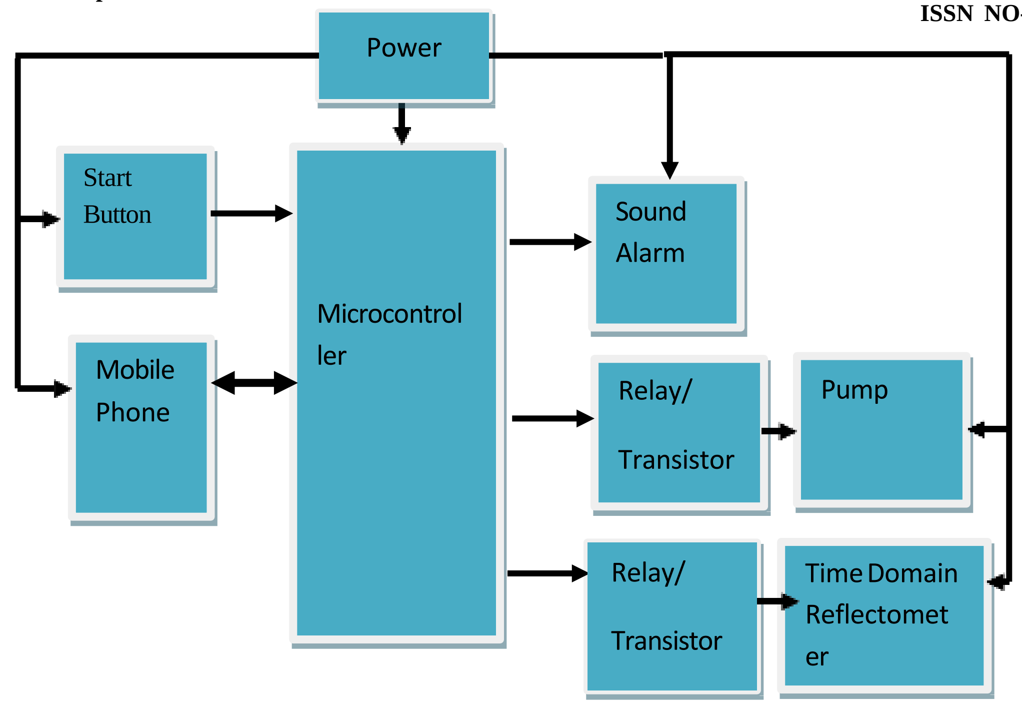
Keywords: Pipeline,Timedomain reflectometer (TDR), Short message service (SMS),Soundalarm,Leakages.

ISSN NO-2584-2706

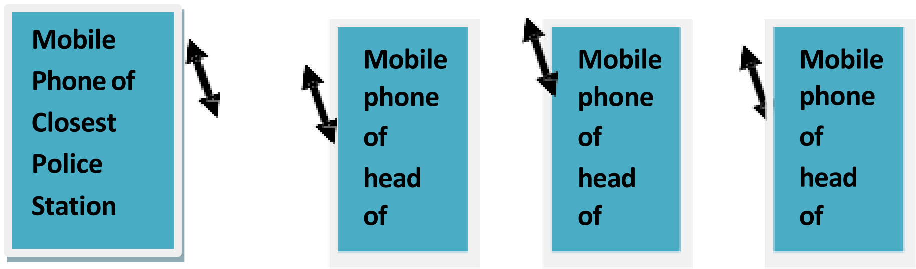
1.0.Introduction

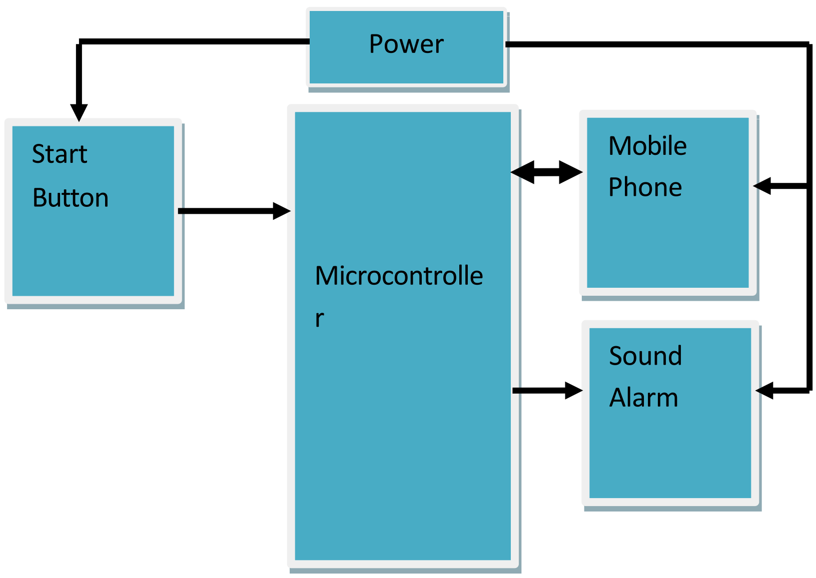
This project is designed with the intention to ensure that pipeline vandals are arrested before they actually vandalize oil pipeline. It is also designed to determine the exact point of leakage so as to ensure timely repairs and avoid time wastages in moving along the lengthy pathway of many kilometers pipeline to detect the exact point of leakage. It is no longer news in Nigeria that the activities of vandals have grossly reduced government revenue by more than 35% since Nigeria is a mono economic country which relies on the sale of crude oil for nearly 95% of the government revenue. The activities of oil pipeline vandals have made it impossible for Nigeria to reach its allotted quota by the organization of petroleum exporting countries (OPEC) and this has subsequently translated to low government revenue and also reduced standard of living among the populace. Also, the high cost of repairing pipelines have made cost of business so high in the oil industries in Nigeria compare to other oil producing countries. Some of the oil giants have employed the use of wireless sensor cameras to monitor pipelines but these vandals destroy all the cameras along the pipeline length more frequently that it becomes uneconomical to be replacing them. Also, most of these sensors fail or malfunction that they fail to monitor effectively the pathway of the pipeline. The federal government has also formed local security outfits in conjunction with government joint task force comprising of military, police and civil security personnel to monitor the various lengths of pipelines in the Niger delta oil producing of Nigeria but still the activities of the vandals are on the increase. The government security forces have a lot of pipelines to monitor and cannot be everywhere at the same time, hence, the vandals equally monitor their activities and go to areas very remote from where the security operatives are, to vandalize the pipeline so as to evacuate crude oil for sale at the illegal crude oil markets on the high sea. So, when the joint task force of the government arrives the point of leakage, the vandals must have evacuated enough products and escaped to safety. The federal government has spent billions of naira on this joint task force and yet incidences of pipeline vandalism have been on the increase. Also, there are incidences where oil thieves insert illegal pipes at the length of the pipeline and illegally evacuate crude oil through such pipes. Since, most of the crude oil pipelines are buried in the ground, the government security outfits cannot detect such and also acoustic sensors used for leakage detection on such pipelines cannot detect it as well because they insert those pipes during the maintenance periods in the oil industries since no fluid flows through the pipeline during maintenance. Also, the high incidences of gas pipeline vandalism have contributed so immensely in the epileptic power situation in Nigeria. In Nigeria today, more than 85% of the power stations are gas powered. Hence, the power infrastructures in the country depend solely on the supply of gas to the various gas power stations (turbines) for sustainable power supply in the country. The present government has spent billions of dollars in the power sector but the activities of vandals have made it almost impossible for reasonable achievements to be recorded in this sector. These activities of the vandals have stagnated the power generating capacity of Nigeria between 3500 to 4000MW over a decade and subsequently have led to closure of industries with attendant high level of unemployment. If this project is implemented in the oil and gas sector of the Nigerian economy, it will ensure that pipeline vandalism is eliminated because the vandals will be caught before they vandalize the pipeline and in case of leakage, the point of leakage will be located on time and repaired so as to put the repaired pipeline back in use for the continued evacuation of oil and gas products from one flow station to another flow station [1, 2, 3, 4, 5]. The block diagram of the system is showninfigure1.1.

DOI: https://doi.org/10.5281/zenodo.17221338



Flow Station A





Flow Station B

Figure 1.1: The block diagram of the proposed system

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2.0.Materials and Method

2.1 Materials

The materials and methods employed in this project are discussed as follows.

(a) **Microcontroller:** It is the brain house of this work. It is where all the hardware components and the control programs are contained. The microcontroller used here is AT89C2051. It has 20 pins. It contains input, output and other control interfaces [6].

(b) Start button

This is works by make and break circuit arrangement. It has a lower limit at OV and an upper limit at 5V, hence, this arrangement has two levels which are OV and 5V and hence does not require an ADC to connect it to microcontroller because it uses OV to represent O and 5V to represent 1 [7].

(c) Time domain reflectometer

A **time-domain reflectometer (TDR)** as shown in figure 2.1 is an electronic instrument that uses time-domain reflectometry to characterize and locate faults in metallic cables (for example, twisted pair wire or coaxial cable). It can also be used to locate discontinuities in a connector, printed circuit board, or any other electrical path. The equivalent device for optical fiber is an optical time-domain reflectometer [8].

Figure 2.1: Time Domain Reflectometer

(d) Pump

It is the pump that is responsible for the flow of oil from flow station A to flow station B through the pipeline [9].

2.2 Method

This project's method is divided into two sub-sections: Hardware sub-design and software sub-design [9 - 10].

2.2.1 Hardware sub-design

This involves the interconnection of all the inputs and outputs devices at the microcontrollers at the flow stations A and B as shown in figures 2.1and 2.2.

2.2.2 Software sub design

This includes all the control programs developed to ensure the implementation of the project. It covers the control programs at the flow stations A and B as shown below in figures 2.3 and 2.4 and sections 2.2.3 and 2.2.4.

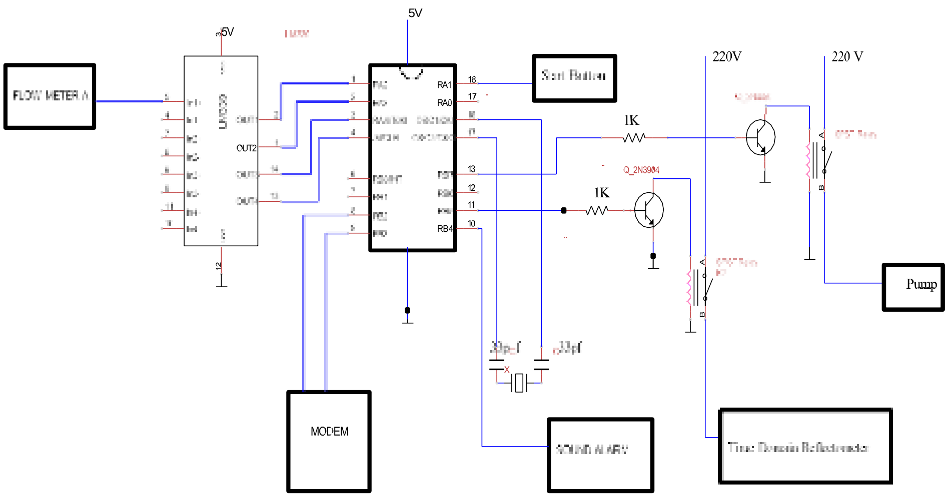

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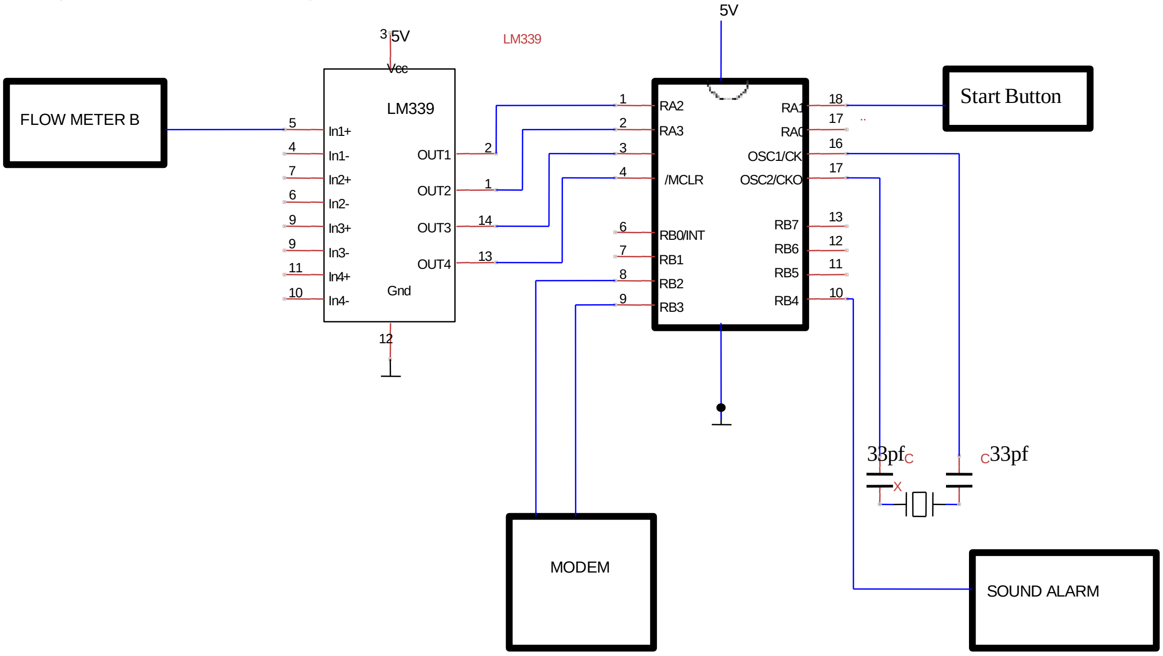
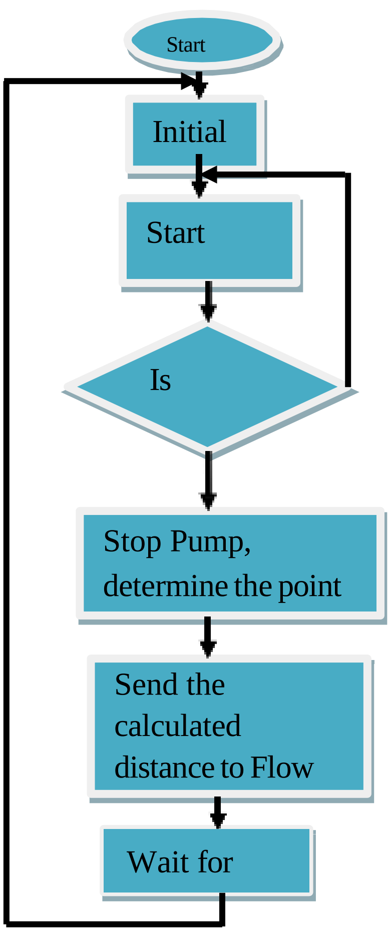
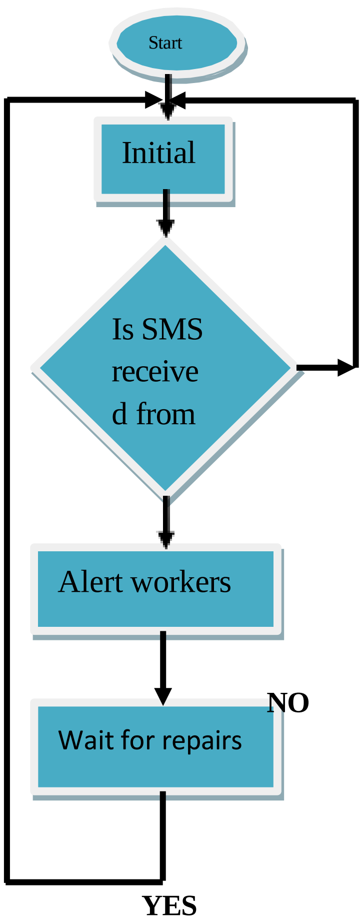
Figure 2.1: Circuit diagram at flow station A

Figure 2.2: Circuit diagram at flow station B







DOI: https://doi.org/10.5281/zenodo.17221338

International Journal of Modern Science and Research Technology
ISSN NO-2584-2706

Figure 2.3: Control program at flow station A
Figure 2.4: Control program at flow station B

2.2.3 :Control Programmes at Flow Station A
Step 1: Start
Step 2: Initialize Modem
Step 3: Start Pump and TDR
Step 4: Is copper wire cut?
No; Go back to Step 4
Yes; Go to Step 5
Step 5: Stop pump, use the TDR to determine exact point of leakage and alert workers of leakage using sound alarm.
Step 6: Send the calculated point of leakage or tampering to the flow station B, the repair engineers and security operatives (responders)
Step 7: Wait for repairs
Step 8: After repairs, go back to Step 1.

2.2.4 : Control Programmes at Flow Station B
Step 1: Start
Step 2: Initialize Modem
Step 3: Is sms message received from flow station A?
No; Go back to Step 3
Yes; Go to Step 4
Step 4: Alert Repair engineers and other responders
Step 5: Wait for repairs
Step 6: After repairs, go back to Step 1.

2.3 Implementation
The system is implemented by integrating both the physical designs of figures 2.1 and 2.2 and the control programmes of figures 2.3 and 2.4 for optimal performance as shown in plate 1. The time domain reflometer (TDR) was used in the detection of the point of leakage or tampering by observing the return of sent pulses due to impedance mismatching as a result of either leakage or tampering of the copper wire along the length of the
The time domain reflectometer (TDR) uses the echo equation (1) to determine the point of leakage or tampering on the pipeline and equation (2) to determine the coefficient of reflection.

$$V = \frac{(2X)}{t} \qquad (1)$$

Where V = Velocity of the pulse
X = point of leakage or tampering
t = Time interval between when the pulse is sent to when it was received back by the TDR due to mismatch in impedance as a result of leakage or tampering on the pipeline.

$$\rho = \frac{Z_t - Z_o}{Z_t + Z_o} \qquad (2)$$

P = coefficient of reflection
Z_t = Impedance of the destination
Z_0 = Impedance of the source

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Plate 1: A picture of the designed system

Also, the error in calculation of exact point of leakage was determined using equation (3).

$$Er = \frac{(Dp - Ap) \times 100}{Ap} \quad (3)$$

Where Er = error in the detection of actual point of leakage or tampering, Dp = Determined point of leakage,

Ap = Actual point of leakage.

4.0 Results and discussions

This project was implemented using 10 meters length of pipeline with copper rods running along its length from flow station A to flow station B. The length of the pipeline was calibrated in meters and it was tampered at some selected points along the copper rods. The point of tampering (leakage), time interval between when SMS was received by responders and when they arrived the point of tampering (leakage) were determined as shown in table 4.1 below.

Also, figure 4.1 shows the reflection of sent pulses by the TDR as a result of leakage. Figure 4.2 shows the non reflection of pulses by the TDR in a normal pipeline without leakage.

Figure 4.1: Reflection of sent pulse due to leakage or tampering on the copper wire surrounding the pipeline.

Figure 4.2: Sent pulse along the pipeline without reflection under normal condition

Table 4.1: Table showing the different cuts on the copper rods

Actual point of leakage (tampering)(m)	Time responder received SMS (s)	Responders	Distance of Responder's to the leakage (tampering) (KM)	Time to arrive point of leakage (tampering) (mins)	Estimated point of leakage (tampering) (m)
3.5	30	Closest police station	5	5.2	3.52
4.5	40	Head of village A's security	7	7.4	4.53
5.5	20	Head of village B's security	3	3.2	5.51
6.5	60	Head of village C's security	10	10.1	6.52

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7.5	40	Closest police station	8	8.0	7.51
8.5	50	Head of village A's security	12	12.02	8.52
9.0	60	Head of village B's security	15	15	9.02
9.5	70	Head of village C's security	18	19	9.52

Cuts were made at the copper rods surrounding the length of the pipeline at different lengths as shown in table 4.1 in an attempt to cut the pipeline open to evacuate products from it and the corresponding determined point of leakage (x) by the TDR, the responders' time interval of receiving sms from flow stations A and B, the distance of the responders to the pipeline leakage and the time it took each of the responders to arrive at the point of leakage were recorded as shown in figures 4.3.

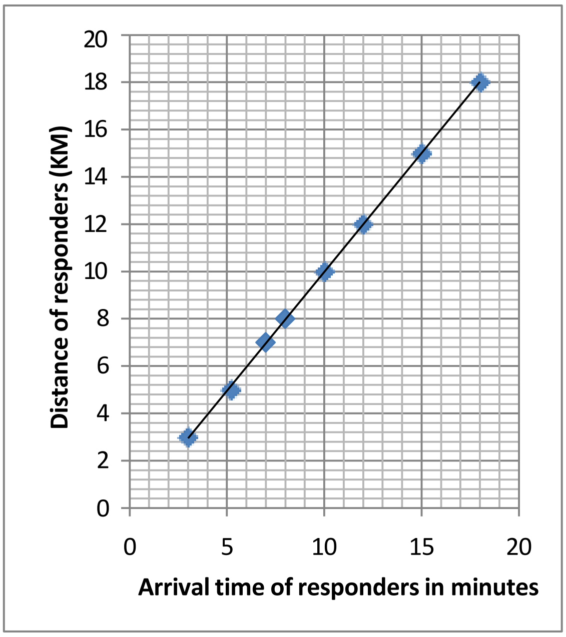

Figure 4.3: Arrival time of responders to places of oil leakages

Figure 4.3 showed that the response time of responders to point of oil pipeline tampering (leakage) is directly proportional to the responders' distance.

Also figure 4.4 showed that the actual points of leakage and the estimated points of leakage over some selected points in table 4.1 are close.

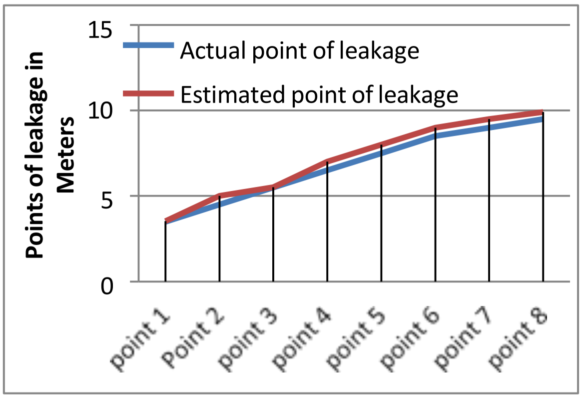

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Figure 4.4: Actual and Estimated points of leakage over the selected points.

From the table 4.1, responders as far as 1800m away from the pipeline could reach the pipeline's point of leakage or tampering in 19 minutes using a motorcycle due to the terrain at speed of 60Km/ minute. Hence, it shows that the system is timely and also from investigations and reports from joint task force security team of the government, it was discovered that arrested pipeline vandals told the security operatives during interrogation that it takes about 2 to 4 hours for a successful rupture of the pipeline to evacuate products illegally. Since the product flows under high pressure, they take a lot of precautions to avoid explosions which could take their lives. Hence, since it takes about 2 to 4 hours to successfully rupture a pipeline so as to illegally evacuate its contents by vandals, this project can lead to their detection and arrest before the actual rupturing of the pipeline.

Using table 4.1, for determined point of leakage = 4.53 meters and actual point of leakage = 4.5 meters, the error in location detection Er, using equation (3) is 0.222% with precision of about 99%. Hence, figure 4.5 showed very high and steady precision in the calculation of the different points of tampering on the pipeline.

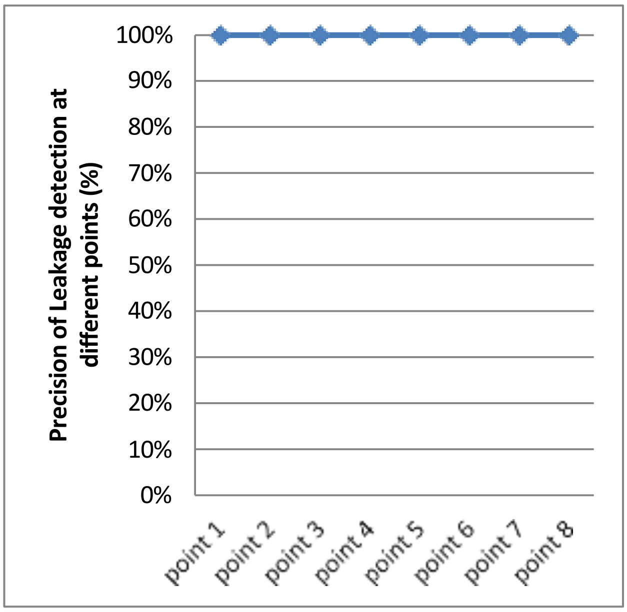
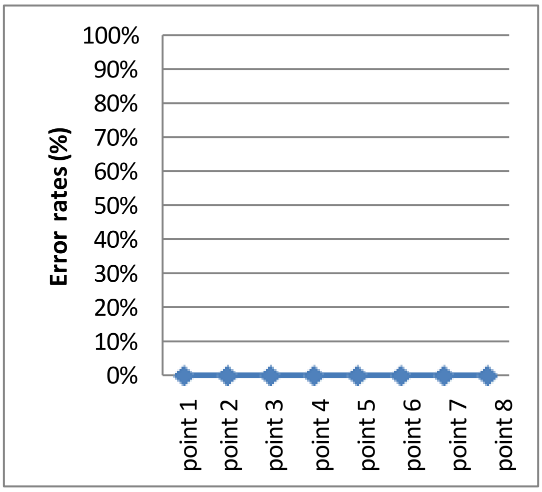


Figure 4.5: Precision in the calculation of the points of tampering on the pipeline.

Similarly, figure 4.6 showed very low steady error of 0.22% in the difference between the actual point of leakage and the estimated point of leakage.



DOI: https://doi.org/10.5281/zenodo.17221338

Figure 4.6: Error rate in the difference between the actual point of leakage and the estimated point of leakage at different points of tampering

5.0 Conclusion

The above results have shown that the responses of the responders were timely and that this system can help to monitor effectively oil and gas pipelines by ensuring prompt alert of security operatives to arrest vandals before they cause harm to the pipeline and can also detect the exact point of leakage in case it occurs. The system recorded a very low error rate of 0.222 with very high precision of about 99%. From the reports of interrogation of arrested pipeline vandals by government security operatives, the vandals confessed that for effective rupturing of the pipeline to evacuate products that it takes 2 to 4 hours because the pipeline is under high pressure and any mistake could cause explosions which could consume them as the first victims. Hence, if this system is deployed in the oil and gas industries to monitor pipelines, it will be timely enough to get pipeline vandals arrested before they rupture the pipeline.

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