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Pipeline Infrastructure Vandalism Monitoring using Wireless Sensor Networks Technique

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***Abstract*– Wireless Sensor Networks are crucial substructure made up of microcontroller, sensing units and communication interfaces that is designed to enable the users possess the capability to measure, collect and responds to phenomenon within the surrounding been monitored. WSN are viewed as an edge between the physical and the virtual world. More so, the demand of fluid transportation from the production point to the region of end users has led to an increase in the number of pipelines that are fabricated globally. The paper presents architecture deployed to the pipeline structure to measure the flow rate, pressure and temperature at the inlet and outlet of the pipeline and then send the sensed data to the control centre via their communication links for immediate response. The simulation procedure carried out using MATLAB Simulink environment shows the capability of the system to detect leakage along the pipeline as evident in the flow and pressure measurement trend of the graphical output results.**

***Index Terms*– Wireless Sensor Networks, Pipeline, Pipeline Infrastructure, Nigeria and Monitoring**

I. INTRODUCTION

PIPELINES are crucial infrastructures utilised by most countries around the world for the transportation of petroleum products usually from the point of production to the point of end users with aim of developing and sustaining their economy [1]. As such shielding and observing the pipelines is necessary for the success of the economy.

Currently, Nigeria comprises a total network of about 5,000 kilometres of oil pipelines which includes multi-product pipelines of 4,315km and crude oil pipelines of 666km [2]. The pipelines are spread across the country and linked the various storage depots which are tactically spread-out throughout the country [2].

Over the years oil pipeline infrastructures have been under several attacks around the world by vandals. One of this can be seen with the oil pipeline infrastructure in Nigeria whereby between the years 1976 and 1996, the NNPC authorities have reported roughly five thousand incidents of oil pipeline damage and more between the years 2009 – 2011 where 10.9 Billion dollars was lost [3].

Oil Pipeline leakages when go undetected can result in economic, health and environmental degradation issues. These is evident through the loss of valuable product, cost of cleaning up, service disruption and as well as repair expenses [4]. Numerous methods have been used to monitor pipeline systems which include manual inspection using trained dogs and also recently advanced satellite based hyper spectral imaging methods. These methods look promising but not good for continuous monitoring activity [4].

It is in this contest that the researcher will use the technology of wireless sensors to monitor the flow rate and pressure variations to monitor the state of the pipeline system at any point in time so that any deviation from the observed measurement will result in leak alarm.

II. RELATED WORK

A technique based on acoustic sensing devices was developed by [5]. The signals produced by the acoustic sensors travel along the pipeline which can be utilized to detect defects along the pipeline like corrosion. The defects are normally revealed when there is no correlation between the generated signals and the reference signals stored for the monitored environment. On defect detection, an alarm message is send to the human operator via communication links. This method is actually based on the transmission and detection of lamb waves and also utilized an easy triangulation method centered on the time-of-arrival concept, as such a number of short comings can be examined. In the first instance, acoustic sensors are normally custom-built to the pipeline structure, thereby making the method not applicable for other types of pipeline technology. In the second instance, topology of the pipeline is made very easy thereby making the localization method ineffective for complicated topologies of pipeline.

The research carried out by [2] on Wireless Sensor Network for long distance pipeline monitoring is more of a review work with a conceptual diagram of oil distribution system and monitoring using WSN. They were able to look at WSN monitoring challenges, routing challenges and localization challenges. The work was not able to say exactly what the pipeline segment will measure along the pipeline segment. As such a limitation is observed.

A research on Fault Tolerant Wired and Wireless Sensor Network Architecture for monitoring pipeline infrastructure was carried out by [6]. In the research work, they were able to look at the capability and reliability of using both wired and wireless sensors to monitor pipeline infrastructure. However, there was no clear architecture illustrating how the individual sensor nodes will be deployed and what parameters to be measured for a specified fluid. Also security of using the Wired and Wireless sensors was not included.

A research on a Framework for Pipeline Infrastructure Monitoring Using Wireless Sensor Networks was conducted by [7]. The work was able to look at the various WSN scenarios which include network deployment, network maintenance process, network discovery phase, and data collection and communication packet structure. Generally, the work is limited technically to provide monitoring for pipeline infrastructure. That is to say there was no illustration on what data are to be measured by the sensors. More so, security of both the sensor nodes and communication links was not considered.

The work of [8] proposed system architecture for oil pipeline surveillance and security using WSN with the simulation of the proposed system. However, there was no clear and detailed explanation on what parameters are to be measured along the pipeline infrastructure. More so, there was no clear illustration regarding the sensor node and communication link security.

The research of [9] on the use of optical fibre to monitor pipeline infrastructure show that an optical fibre is a cylindrical dielectric wave guide which is made from a silica glass or a polymer material. The optical fibres attached to structures like that of pipeline tend to enlarge or shrinks by small amounts according to the temperature or strain variations. A part of the light when led down the sensor from the fibre, it is then modulated according to the amount of the expansion or contraction (that is a change in the sensor length), and then the sensor reflects back an optical signal to an analytical device which translates the reflected light into numerical measurements of the change in the sensor length. This measurement actually reveals the extent of strain or temperature along the monitored structure.

The use of the fibre optic sensing technology actually offers the capability to measure temperature and strain at thousands of points along a single fibre, which is specifically interesting for structure like that of oil pipelines. However the use of fibre optic post a number of challenges among which are:

- Damage in any section of the pipeline could put the network of fibre optic out of service in that location.
- Installation difficulty

Retro filling in the case of damage to the fibre can be difficult, uneconomic and can cause blind spots in the system [10].

The research carried out by [14] on the use of Unmanned Aerial Vehicle (UAV) for pipeline system monitoring actually involves the use of a drone (that is unmanned aircraft) that is controlled remotely utilizing pre-programmed flight plans.

The use of the UAV for monitoring and surveillance has indisputable advantages which includes its dynamic nature, independent operation and high signal rate. However a number of limitations make the technology unreliable. First, the technology is applicable for only over ground pipelines, they are secondly not suitable for continuous monitoring (in terms of operating for months or even years).

III. METHODOLOGY

Given the shortcomings of the current techniques for pipeline infrastructure monitoring, the paper therefore presents architecture of WSN for the real-time monitoring of the pipeline. The researcher believed that the use of Wireless Sensor Networks technology will significantly improve the monitoring of the oil pipeline infrastructure.

The general architecture of the system is shown in Fig. 1. The system architecture is made up of sink nodes, master nodes, base stations and a control centre that will reside at the head office to be controlled by a user usually via the internet. The system would detect and localized significant anomalies such as intentional or accidental damage of the pipeline infrastructure at run-time.

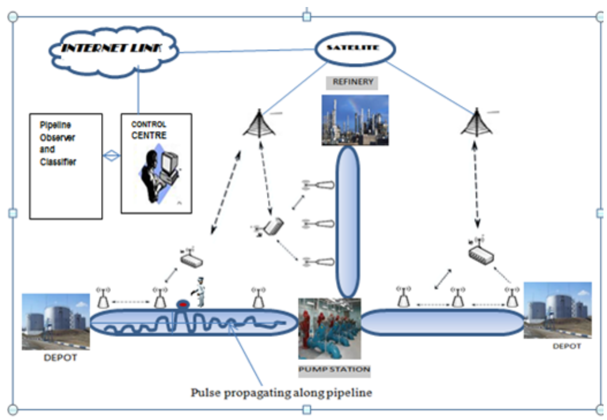

Fig. 1: System Architecture

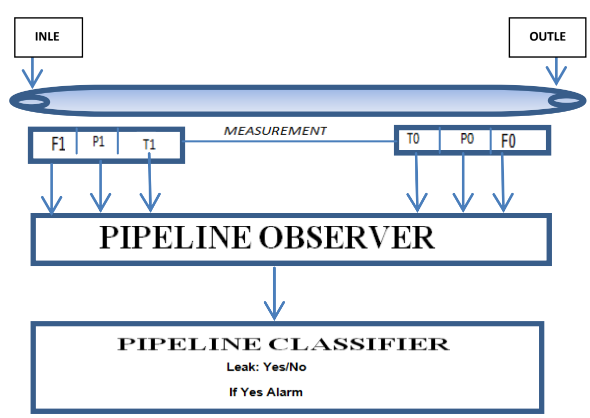

Fig. 2: Pipeline Observer and Leak Classifier

A) Flow Measurement

Flow measurement is a method which is utilized in fluid measurement for both gases and liquids. The significance of quantifying this phenomenon is because of the need to transport the fluid from one place to another [11].

The flow rate in a given fluid is the volume that passes via a given surface per unit time. That is the velocity of a certain fluid times certain surface.

Given an area A at a particular point and a fluid passing through it with an average velocity V, the flow rate is given by [12], [13]:

$$F = A.V \qquad (1)$$

where, F is the flow rate.

B) Pipeline Observer and Leak Classifier

The pipeline observer is viewed as the main part of the monitoring system essentially because it denotes the flow mechanics and thermodynamics along the entire length of the pipeline without leakage. As such the pressure P1and P0 are measured at both the inlet and outlet of the pipeline respectively. Similarly the flow rates F1 and F0 of the inlet and outlet are also measured whereby any deviations from the measured values will indicate a leak along the pipeline segment.

The main aim of the classifier is to determine whether a leak has occurred or not usually based on the various information from the pipeline observer well enough to declare a leak or not.

C) System Input Parameters

The fluid and pipeline parameters which serve as input to the developed model are given in Table I.

Table I: Fluid and Pipeline Parameters

S/N	PARAMETER	VALUE	UNIT
1.	Density	729.376	Kg/M^3
2.	Pipe internal roughness	0.000326	M
3.	Bulk modulus	1.22235e+09	Pa
4	Pipeline length	2000	M
5.	Internal diameter	0.001	M
6.	Relative amount of trapped air	0.002	
7	F1	3600	M^3/h
8.	F0	3200	M^3/h
9.	P1	10245	Pa
10.	P0	10452	Pa
11.	Viscosity	1.30934	Cst
12	Viscosity derating factor	2	
13.	T1	286.3	Kelvin
14.	T0	289.4	Kelvin

IV. RESULTS

This section presents the results of the simulation carried out using MATLAB Simulink simulation environment. The aim is to observe the effect of the leakage on flow rate and pressure drop along the pipeline segment.

A) Flow Measurement Trend

From simulation procedure, it was observed that during the leakage in the pipeline transporting fluid there was a unique changes in the flow signals. Due to the leakage along the pipeline segment, it was evident as observed in the graphical output of the Fig. 3 that fluctuations of the flow rate of both the inlet and outlet ends starts at 0 to 5 seconds and stabilizes at the 20 seconds later which in turn continues up to the 50 seconds.

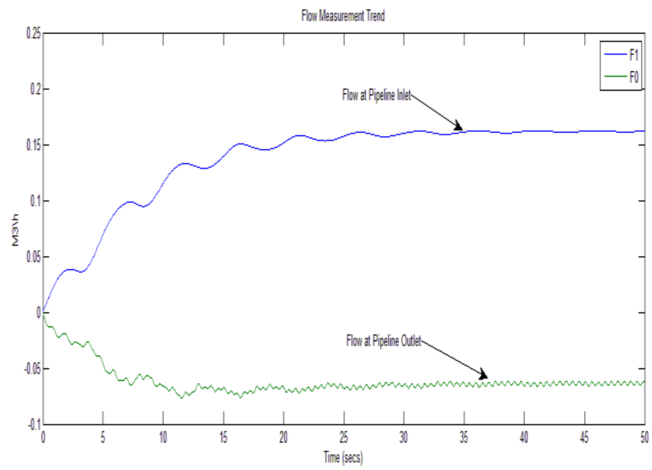

Fig. 3: Flow Measurement Curve

B) Pressure Measurement Trend

When a leak occurs along a pipeline segment, the pressure expansion waves along the line tend to travel upstream and downstream thereby resulting in unique changes of the pressure signals.

As such, the simulated pressure measurement curve as indicated in Fig. 4 of both the inlet and outlet pressure trend experience a minor fluctuations which stabilizes at 5 seconds and continues the decrease up to 50 seconds. This rapid decrease of the pressure along the line indicates a serious leakage along the pipeline segment.

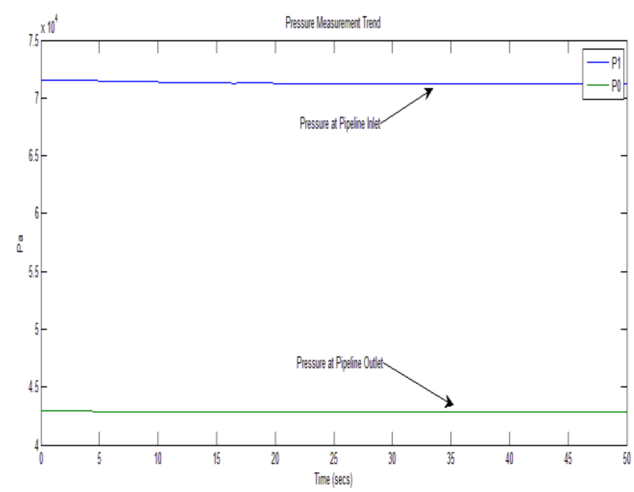

Fig. 4: Pressure Measurement Curve

V. CONCLUSION

When pipeline vandal's activities occur, it results in leakages thereby causing economic, health and environmental degradation issues. Existing technologies to monitor pipeline infrastructure against abnormalities such as leakages in the pipeline have not been clearly investigated given their various limitations and their unsuitability to provide a continuous monitoring of the pipeline system.

It is in line with this that a network of Wireless Sensor Networks was presented to provide monitoring for the critical pipeline infrastructure. The technology of WSN to tackle the menace seems promising considering the self-organizing nature and sensing capability of the network devices to act promptly at real-time when the need arises.

The pressure, flow rate and temperature measurements of the inlet and outlet of the pipeline transporting fluid enable the control Centre to know the state of the pipeline at any given time. The simulation experiment carried out considering the pressure and flow rate measurements data from the sensors indicates a leak in the pipeline as evident in the flow and pressure curves of the simulation output results.

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