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An Exploratory Study of Techniques for Monitoring Oil Pipeline Vandalism

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***Abstract*—** Wireless Sensor Networks are crucial substructure made up of microcontroller, sensing units and communication interfaces 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. Pipeline infrastructure is generally regarded by many countries as a key element for national development, therefore shielding and observing the pipeline is essential for a successful economy. The current techniques in pipeline monitoring and surveillance include visual inspection, the use of Unmanned Aircraft, Ground Penetrating Radar, Fibre Cabling Technology, and Wireless Sensor Networks. This paper presents the various techniques, strengths and weaknesses when deployed for continuous monitoring of oil pipeline infrastructure.

Keywords - Wireless Sensor Networks, Pipeline, Oil, Pipeline Infrastructure, Monitoring

I. Introduction

The demand of fluid transportation such as oil usually from the production point to the region of end usage has given rise to the large numbers of pipelines fabrications and overlays. Many countries around the world depend on vast network of gas, oil and water pipelines for its economic development [1]. Pipeline infrastructure is often regarded by certain countries as a key element for national development [1]. As such shielding and observing the pipelines is essential for a successful economy. Pipeline infrastructure, looking at their essential spread all over a wide area, the poisonous and highly flammable fluid transported, it tends to present severe danger to the environment. More so, majority of oil pipeline infrastructures have been under incessant attacks by vandals over the years. This is the case of the oil pipeline infrastructure in Nigeria especially between the years 1976 and 1996. The NNPC authorities reported roughly five thousand incidents of oil pipeline damages for the period (2009 – 2011) leading to 10.9 Billion USD in losses [2]. Whenever oil pipeline leakages happened and undetected promptly; they have attendant negative consequences on economy, health and environment. In addition, there is loss of valuable product, increased cost of cleanups, service disruptions and massive repair expenses [3]. This paper presents the various pipeline monitoring techniques, strengths and weaknesses for monitoring of pipeline infrastructure.

II. Related Work

The Nigerian pipeline structure has been confronted by increased numbers of pipeline vandalism especially in the Niger Delta Region of the country. During the period of 2005 - 2015, a total of 16,083 pipeline damages were documented. Consequently, about 2.4 percent accounted for the pipelines ruptures while vandalisation activities were estimated at 15,685 breaks, which is about 97.5 percent of the whole incidence [4] as presented in Table 1.

Table 1: Nigeria oil pipeline vandalisation activities (2002 – 2012) [5]

System of Pipeline	Pipeline Route	No. of Incidents
2E/2EX	Port Harcourt – Aba – Enugu – Makurdi – Yola	8,105
2A	Warri Benin – Suleja/Ore	3,295
2B	Atlascove – Mosimi – Satellite – Ibadan – Ilorin	2,440
2C-1	Warri – Escravos	74
Gas	Trans – Forcados	55

In practice, the NNPC save guard the oil pipelines and installations through the police anti-pipelines task force, the Nigeria Security and Civil Defence Corps (NSCDC) and private security providers such as the Chukan Security Solutions Limited and members of the neighbouring communities against vandals ([6], [7]). Several other techniques have been developed for pipeline infrastructure monitoring which are discussed in this section.

A. Satellite Monitoring

Presently, Satellites are designed to monitor pipeline right of way for ground motion, encroachment and leakage. Synthetic aperture radar (SAR) has been used to provide Radar Satellite RADASA images to show the presence of vehicular, earthmoving equipment and leakages. There is limited application for real-time monitoring purposes and unsuitable for overcrowded urban areas [8].

B. Visual Inspection

This technology is utilized to monitor aboveground pipelines using image and video sensors to observe the pipeline infrastructure vicinity. The image and video sensors are positioned relatively at huge sensing ranges in order to provide clear visibility which enable them to detect and localized the state of the pipeline [9]. But, it is limited to underground pipelines applications only [12].

C. Ground Penetrating Radar

Ground Penetrating Radar (GPR) has been used to accurately pinpoint buried pipeline leakages without digging. The GPR can be used with other portable devices which make them easily moved, deployed and maintained. The major shortcomings of this technology are: rigorous human participation and unsuitability for real time monitoring [10].

D. Unmanned Aerial Vehicle

The research carried out by [11] on the use of Unmanned Aerial Vehicle (UAV) for pipeline system monitoring involves the use of a drone (or unmanned aircraft) controlled remotely with pre-programmed flight plans. The use of the UAV for monitoring and surveillance has indisputable advantages such as dynamic nature, independent operation and high signal rate. However, a number of limitations make the technology unreliable. Firstly, the technology is applicable for only over ground pipelines. Secondly, it is unsuitable for continuous monitoring [11].

E. Optical Fibre Technology

The work of [12] 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 pipeline infrastructure have the capacity to enlarge or shrink by small amounts according to the temperature or strain variations.

A part of the light generated by the sensor placed on the fibre is 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. These measurements actually reveal the extent of strain or temperature along the monitored infrastructure [12].

The use of the fibre optic sensing technology offers the capability to measure temperature and strain at thousands of points along a single fibre, which is specifically interesting for infrastructure such as oil pipelines. However, the use of fibre optic poses a number of challenges including:

a) Damage in any section of the pipeline could put the network of fibre optic out of service in that location.

b) Installation difficulty

c) Retro filling in the case of damage to the fibre can be difficult, uneconomic and can cause blind spots in the system [13].

F. Pipeline Infrastructure Monitoring Using Wireless Sensor Networks

The study by [14] was aimed at utilizing the network of sensors to monitor critical pipeline infrastructure. Consequently, a general architecture of pipeline monitoring system was developed which was later simulated to measure the performance. The strength of the monitoring system lies in its ability to monitor pipeline infrastructure at real-time. One major drawback of the system is the limited and fragile battery power. However, with modern batteries technologies alongside algorithms, these nodes can go to sleep when there is no activity which possibly increases the battery life of nodes.

G. Strengths and weaknesses of Wireless Sensor Networks

The strengths and weaknesses of WSNs deployed for the period for monitoring oil pipelines in Nigeria as advanced by several researchers are presented in Table 2.

Table II: Oil Pipeline Monitoring Techniques Compared

Researcher	Technique	Strengths	Weaknesses
Gary and Alfred, 2003	Satellite Monitoring	Ability to monitor entire pipeline Right of Way	Unsuitable for real-time monitoring. It is applicable for over ground pipelines only.
Yuanwei and Eydgahi, 2008	Acoustic	Detection of minimum noticeable leaks. Non-interference with the pipeline operation. The topology of the pipeline is made too simple with acoustic sensors	Custom-built for the pipeline structure. Localization method is ineffective for complicated topologies of pipeline.
Jasper, 2011	Visual Inspection	Support available commercial cameras in monitoring	Unsuitable for underground pipelines Different cameras are usually required for individual line-of-sight.
Bimpas *et al*., 2011	Ground Penetrating Radar	Ability to precisely locate underground pipelines with no digging required. It can cover quite a number of miles.	Unsuitable for real –time monitoring. Involves rigorous human participation.
Jakub, 2014	Unmanned Aerial Vehicle (Drones)	High signal rate and ability to move around along pipeline vicinity	Unsuitable for underground pipeline and continuous monitoring.
Rajeev *et al*., 2013	Fiber Technology	It provides real-time monitoring of pipeline infrastructure. Able to cover long distances.	Expensive in nature, fibre damage can render the system in operational. It must be installed across the entire length of the pipeline.
Nader and Imad, 2008	Wired and Wireless Sensor Network Architecture	It is suitable and reliable for wired and wireless sensors deployment in monitoring pipeline infrastructure	There was no clear architecture illustrating how the individual sensor nodes will be deployed and what parameters to be measured for a specified fluid.

III. Methodology

A. Wireless Sensor Networks

The latest enhancements in the area of Micromechatronics and Microfabrication technology have been shown in the accessibility of less expensive, and low power sensors connected to form sensor network. A modern-day sensor is typically made up of a sensing device, on-board memory, micro-controller, and a transceiver [15]. Wireless Sensor Network (WSN) is a self-powered computing device which normally comprises a processing unit, a transceiver and both analog and digital interfaces in which various sensing units, primarily sampling physical data such as humidity and temperature are accommodated [16]. Typically, the two sensor fields used to monitor two different geographic regions are connected their base stations through to the Internet as illustrated in Fig. 1.

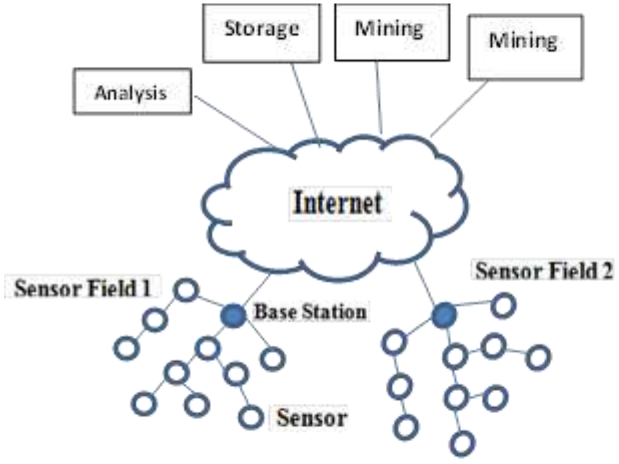

Fig. 1 Wireless Sensor Networks [12]

In general, WSN are obviously capable of functioning whenever other nodes in the network are deactivated. The potential damages arising from deactivation of certain sensor nodes can be overlooked by utilizing other available nodes alternatively. Often, the use of numerous sensor nodes in the network provides sustained connection in order to enable the sensed information to be conveyed seamlessly via the network to the required destination [17].

The sensors have the ability to instinctively organize themselves into an adhoc-network, which implies no need of any pre-existing infrastructure when compared to cellular networks such as the Global System for Mobile Communications (GSM) [18]. It offers decisive advantages over existing technologies used in monitoring the environment through the collection of physical data [17].

A transducer refers to a machine which transforms energy from one quantity to the other. A sensor can be viewed as a kind of transducer because of its capability to transform energy in a surrounding to electrical form of energy which can be forwarded to a computer for further analysis. The stages involved in the sensing activity are given in Fig. 2. Whenever the sensors capture data, the corresponding signals are not usually ready for processing; instead they go through the phase of signal conditioning phase.

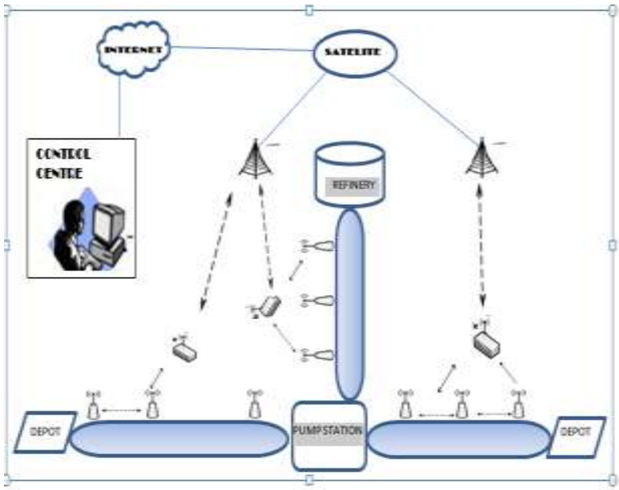

Fig. 2 Data acquisition and actuation [19]

In ensuring the safe operations of the pipeline infrastructure, regular monitoring of the pipeline is essential. Existing methods are limited in their capability to provide constant and continuous monitoring. As such the use of WSN seems promising because the individual sensors attached to the nodes in a WSN system can help with the various measurements such as the flow rate, pressure and temperature readings taken along a defective pipeline and then transmitted through Satellite links to the control Centre for immediate attention. The WSN architecture for a pipeline monitoring system is shown in Fig. 3.

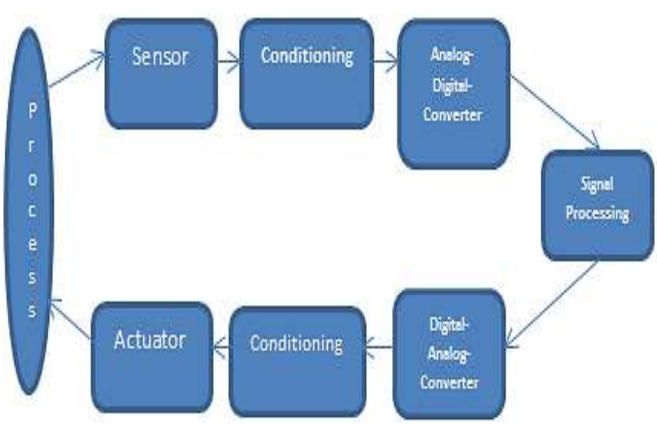

Fig. 3 Pipeline monitoring architecture using WSN [14]

IV. Results

This exploratory study exposes the weaknesses of the existing monitoring methods and presents WSN technique as an alternative for pipeline infrastructure monitoring. WSN as presented in this paper involves the collection of individual sensor nodes which are interlink by wireless communication units. The individual nodes as attached to a pipeline segment has the responsibility of gathering data from the pipeline surrounding and sending the sensed data via communication links to the control Centre.

When compared with other reviewed monitoring techniques, WSNs are capable in solving the reliability issues of some of the existing methods and also provide real-time monitoring of the pipeline with the aim of reducing or minimizing vandalisation activities in Nigeria and the world at large. Unlike in the existing methods, several nodes can be deployed in WSN which makes the network to offer sustained connectivity even if certain nodes failed to function.

The sensors have the ability to instinctively organize themselves into an adhoc-network, meaning that they do not require any pre-existing infrastructure as compared to cellular networks like the GSM. They consist of decisive advantages as compared to other previous technologies that were used to monitor the environment through the collection of physical data.

V. Conclusion

This paper highlighted the issues of oil pipeline vandalism and breaks causing major leakages; and degradation in economic, health and environment. WSN was identified to be highly favourable in remedying the failures of present-day security measures and techniques for protecting oil pipelines and installations. WSN is a self-powered computing device which normally consists of a processing unit, a transceiver with analog and digital interfaces, whereby various sensing units, primarily sample physical data such as humidity and temperature. In terms of cost and effectiveness, WSNs are suitable for securing and monitoring the vast oil installations in Nigeria and forestall incessant issues of pipeline leak detection and prevention because of sensing capability of these network devices to act promptly at real-time when the need arises.

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