APPLICATION OF PIZOELECTRIC SMART SENSORS IN CURBING CRUDE OIL PIPELINE VANDALISM IN THE NIGER DELTA AREA

(REVIEW)

BY

OMATSONE MICHAEL OLUMARO

(ENG1407047)

A PROJECT REPORT SUBMITTED TO THE DEPARTMENT OF PETROLEUM ENGINEERING, FACULTY OF ENGINEERING, UNIVERSITY OF BENIN, IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF BACHELOR OF ENGINEERING (B.Eng.) DEGREE IN PETROLEUM ENGINEERING.

JULY 2021

CERTIFICATION

This is to certify that this project titled "Application of piezoelectric smart sensors in curbing crude oil pipeline vandalism in the Niger delta area" was carried out by OMATSONE MICHAEL OLUMARO with Matriculation number ENG1407047, at the Department of Petroleum Engineering, Faculty of Engineering, University of Benin, Edo State, Nigeria.

______________________	______________________
PROF K.O BELLO (PROJECT SUPERVISOR)	**DATE**
______________________	______________________
ENGR. TAIWO SEUN (PROJECT COORDINATOR)	**DATE**
______________________	______________________
DR IKPONMWOSA OHENHEN (HEAD OF DEPARTMENT)	**DATE**
______________________	______________________
PROF.S.O. ISEHUNWA (EXTERNAL SUPERVISOR)	**DATE**

DEDICATION

This project is dedicated to my father **Late Dr. Oristuwa Osanweren Omatsone**.

He was, still is, and forever will be my Hero. Gone a little too soon from the physical but eternally immortalized in our hearts minds and the magnificently illustrious kingdom of God.

ACKNOWLEDEGEMENT

Firstly, I would like to appreciate my supervisor PROF. K.O Bello for his understanding, patience and invaluable advice during the writing of this thesis.

Secondly, I would like to express my gratitude towards my immediate family: Mrs. Regal Dinah Omatsone, Dr. Tony Omatsone and Dr. Daniel Omatsone for their emotional, financial and relentless support towards the completion of my university education.

Then last but not least, a very noble nod and a hearty “hat tip” to my very few, good and well esteemed friends. There is nothing but love from me, and in the future I shall forget you not!........That’s a promise!

TABLE OF CONTENTS

TITLE PAGE …………………………………………………………………….……...……… i

CERTIFICATION …………………………………………………………….………... ii

DEDICATION ……………...…………………………………...………......……..... iii

ACKNOWLEDGMENT ……………………………………………….……..………. iv

TABLE OF CONTENT ……………………………………………………………… v

LIST OF TABLES ……………………………………………………………………… viii

LIST OF FIGURES……………………………………………………………………… ix

LIST OF ABRIVIATIONS…………………………………..…………………………... x

ABSTRACT………………....……………………………………………...………… xi

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND TO THE STUDY ……………………..…………….………….. 01

1.2 STATEMENT OF THE PROBLEM ……………………..……………………….... 03

1.3 AIM AND OBJECTIVES OF THE STUDY ………………..……….……………… 04

1.4 SIGNIFICANCE OF THE STUDY ..…………………….……………...……….. 04

1.5 SCOPE OF THE STUDY …....……………………..………………………………….. 05

CHAPTER TWO

LITERATURE REVIEW

2.0 DEPTH OF COVER…....……………………...…..………………………...………..06

2.1 RIGHR OF WAY…....……………………..………………….……………….………..07

2.2 THE CHALLENGE OF PIPELINE VANDALISM IN NIGERIA ……………………. 08

2.3 A REVIEW OF OTHER RELATED PIPELINE SURVEILLANCE SYSTEMS ……. 13

CHAPTER THREE

MATERIALS AND METHODS

3.1 THE ARDUINO UNO MICROCONTROLLER …………..….…………..……..…… 17

3.2 A SIMPLE TEST SCRIPT, DEIGNED TO TRIGGER AN LED ….….……..…......... 18

3.3 THE PIEZO-ELECTRIC SENSOR ……………………………………….……….……... 20

3.4 PIEZOELECTRIC SENSOR SPECIFICATIONS ……………………......……….…. 23

3.5 THE GSM/GPS MODULE (SIM 900A) SHIELD MODULE …………….…..………. 24

3.6 BASIC SMS SCRIPT FOR THE ARDUINO GPRS/GSM SHIELD MODULE ….….... 25

3.7 FLOW RATE EQUATIONS ………………………….…………...……...…….. 26

3.8 6600MAH LITHIUM ION BATTERY, SIM CARD AND MOBILE PHONE …...…. 30

CHAPTER FOUR

RESULTS AND DISCUSSION

4.0 RESULTS ………………………………………………..………..………….. 31

4.1 DISCUSSION ………………………………………………,,,,,,……………….. 32

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION …………………………………………………….………… 34

5.2 RECOMMENDATIONS …...……………………………………………..…..… 35

5.3 REFERENCES …………………………………… …………………...…. 39

LIST OF TABLES

TABLE 1 11

TABLE 2 31

LIST OF FIGURES

FIG. 1.0 DEPTH OF COVER MEASUREMENT IN A FIELD ……………………..…......... 06

FIG. 1.1 DIAGRAM OF COVER DEPTH AND OTHER RELEVANT PARAMETERS …… 06

FIG. 1.2 DIAGRAM OF RIGHT OF WAY MEASUREMENTS ……………………...…........ 07

FIG. 1.3 VOLUME OF CRUDE LOST IN BARRELS BETWEEN 1994 – 2005 ……......…. 12

FIG. 1.4 NUMBER OF OIL SPILLS BETWEEN 1994 – 2005 ……………………...…....…. 12

FIG. 1.5 AN ARDUINO UNO DEVELOPMENT BOARD ……………………...….……... 18

FIG. 1.6 A SIMPLE TEST SCRIPT, DEIGNED TO TRIGGER AN LED ……….….……...... 18

FIG. 1.7 A PIEZO DISC SENSOR …...…………………………………………….....……... 21

FIG. 1.8 WORKING PRINCIPLE OF A PIEZOELECTRIC SENSOR…………….………. 21

FIG. 1.9 AN ARDUINO GPRS/GSM SHIELD (SIM900) ……………………………………. 24

LIST OF ABBREVIATIONS

ICSP …………………………………………….... In Circuit Serial Programming

IP ……………………………………………… Internet Protocol

GSM ……………………………………………… Global System for Mobile Communication

GPS ……………………………………………… Global Positioning System

WLAN ……….....…………………………………. Wireless Local Area Network

WAP ………………………………………….... Wireless Application Protocol

GPRS ………………………………………………. General Packet Radio Services

EDGE …………………………………….....…. Enhanced Data GSM Environment

UMST ………………………………………………. Universal Mobile Telecommunication System

IoTs ……………………………………………… Internet of Things

SMS ………………………………………………. Short Message Service

PWM ………………………………………………. Pulse Width Modulation

I/O ………………………………………………. Input-Output System

LED ………………………………………………. Light Emission Diode

IDE ………………………………………………. Integrated Development Environment

UART ...……………………………………..…….. Universal Asynchronous Receiver-Transmitter

ROW ………………………………..…………. Right of way

ABSTRACT

Oil pipeline vandalism is the ugly act of drilling or cutting into the pipelines with the intent to steal its contents. Between 2010 and 2012, a total of 2,787 pipeline line breaches were reported on pipelines belonging to the Nigerian National Petroleum Corporation (NNPC), resulting in a loss of 157.81 metric tons of petroleum products worth about N12.53 billion naira, not even mentioning the loss of human lives, and environmental pollution. Hence there is a dire need for Nigeria's Oil pipelines to be monitored constantly and remotely, so as to checkmate these said acts of vandalism. An Arduino Uno board, a GSM/GPS module, and a Lithium ion battery pack enclosed in a sealed anti-corrosion container makes up the surveillance system. The prototype was tested on a 10m pipeline, buried 2m deep with piezo-electric pickup sensors of threshold range from 21 to 210 attached to the pipeline. The acquired analog signals are processed by the Arduino Uno controller board into a digital signal, using a customized algorithm that quantifies the vibrational activities going on at the surface. The results obtained contain sensor node positions in a pipeline network, geographic coordinates (longitude and latitude), date, time and distance. Which are transmitted as an SMS alert (using the GSM/GPS module shield) to the control station or relevant security officials for the proactive interception of vandalism activities.

Keywords: - **Oil theft/bunkering**; **Smart sensors**; **GPS**; **Pipeline surveillance**; **Piezoelectric**;

CHAPTER ONE

INTRODUCTION

1.0 BACKGROUND STUDY

Nigeria is one of the largest oil producers in the world and the first in Africa. Oil extraction is considered the main source of income in Nigeria, while agriculture, manufacturing and other income-generating sectors are merely auxiliary. Crude oil and their derivatives are indispensable in the manufacture of plastics (e.g. baby toys, car parts, computer cases, etc.), electronic components (materials for cell phones, cameras, speakers, etc.), materials for clothing, furniture and kitchen utensils. (M. Watts, 2004).

In general, a pipeline system as a means of transport is usually associated with very sensitive products such as crude oil, natural gas and industrial chemicals, in which unwanted disruptions in operation lead to unimaginable catastrophes.

Wireless technology is an electromagnetic wave signal that improves the transmission of the data communication path on a remote wireless network, but uses radiotelegraphy, modulation techniques known as "radio" and address (IP) to assign voices, music, signal waves, and so on to transfer data.

This technology uses various equipment for data communication or signal wave transmission between machine-to-machine, human-to-machine and human-to-human in a network. These are cell phones or (GSM), (GPS), (WLAN) etc. (L. Ajao), (M. Babamir)

Various technologies for short and long-range communication have emerged to support this wireless equipment, such as Bluetooth, ZigBee, Wi-Fi, (WAP), (GPRS), (EDGE) and (UMST).

The emerging platforms integrate embedded systems with a wireless network, based on the Internet of Things (IoT) to improve global transmission of information and also provide a robust mechanism for transmitting and receiving information remotely (S. Wandre, 2000).

This improves the policy of collaboration and interaction between individuals, and various things like smart pipeline monitoring, smart cities, smart energy, smart transportation, smart hospitals, etc. regardless of geographic location and distance.

Typically, pipeline vandals identify a section of the oil and gas pipeline from which they want to steal crude oil and approach the pipeline at a time when people are not near the targeted pipeline section, mainly during the night hours.

The excavation usually takes at least 20 minutes to allow the vandals to dig a hole deep enough to hold a large volume of the petroleum product and to sufficiently expose the buried pipeline.

These particular vandals then use saws or drills to breach and damage the pipes, destroying them so that oil begins to pour out of the pipe and into a makeshift hole dug in the ground by these vandals.

The vandals begin to pump the oil into tanker trucks. when the tanker is full, the vandals drive it to an undisclosed improvised depo for unloading and then return to collect more of the petroleum product.

This process continues until the vandals no longer consider it safe and then flee the crime scene, leaving behind oil spills and environmental pollution.

1.1 STATEMENT OF THE PROBLEM

Vandalism refers to illegal or unauthorized activity that results in the destruction of oil, gas, and chemical pipelines.

These problems include terrorist attacks, vandalism and theft of pipeline contents. The need to implement adequate security systems for pipeline management has always been addressed. While some of these attempts have succeeded to some extent, others have contributed insignificantly to providing a solution to this challenge.

Bunkering is a negative activity aimed at sourcing products for personal use or for sale on the black market, especially in the developing world where these attacks are usually prevalent.

About 40% of the world's oil flows through pipelines thousands of kilometers in length through some of the most volatile areas of the world, as reported by (Sahara Reporter, 2015) and (GN Ezeh et tal, 2014).

Shell Petroleum and Development Company (SPDC), one of many international oil companies operating in the Niger Delta region in a bid to protect its wide range of pipelines and other oil facilities scattered across the Niger Delta, led the use of the Micro Wireless Sensor Network (WSN) to help detect pressure drops if a pipeline broke and alert the company as to the exact location of the vandalism. by (T.John, 2012) and (B.Ojediran, 2005).

Economic sabotage and corruption have exacerbated the threat of pipeline vandalism and crude oil theft, leaving the Nigerian federal government perplexed at solving the problem.

The number of oil thefts in Nigeria is becoming alarming and will continue to rise unless there are revolutionary changes.

The government has taken some safety and technological measures to stop pipeline vandalism and detect pipeline leaks and failures, but due to the obvious human factor, very few of these measures and technologies has produced any significant results.

1.3 AIM AND OBJECTIVE

The surveillance system presented in this project will not only enable oil pipeline operators remotely monitor the safety and integrity of oil pipelines.

But most importantly, it is a proactive solution to the menace of crude oil pipeline vandalism. Since the intrusion of digging by the vandals would be picked up and reported to the relevant authorities, who in turn would proceed to intercept their activities before any significant damage occurs.

1.4 SIGNIFICANCE OF THE STUDY

This will go a long way in reducing the theft of pipeline products, environmental degradation and also accidental deaths which often result from the explosion of those flammable substances when there is a Breach/leakage of the pipeline by vandals.

1.5 SCOPE OF STUDY

This surveillance system is developed to proactively detect vibrations around an oil pipeline zone. The piezoelectric sensor picks up these vibrations and translates them into an analog electrical voltage signal.

These analog voltage parameters are then converted into an equivalent digital value which represents an algorithmic threshold magnitude of the original input voltage. This is processed by the Arduino Uno Microcontroller.

The value is compared with a predefined threshold voltage in the range between (28-210). If the input voltage exceeds the threshold value, the microcontroller triggers the GSM/GPS module to send a smart SMS alert to the monitoring base station. The anti-theft pipeline information depends on geographic location (both longitude and latitude).

CHAPTER TWO

LITERATURE REVIEW

2.0 DEPTH OF COVER

Depth of cover is a term that defines how deep pipelines are buried, it refers to the soil measured from the top of the pipeline, or other appurtenances, to the surface, whether that is ground level, a roadbed, a river bottom, or sea bottom [usually between 0.6m to 1.2m].

Fig. 1.0 Depth of cover measurement in a field

The Nigerian government has taken measures to guard against oil theft by burying pipelines a meter deep to avoid accidental contacts, or vandalism.

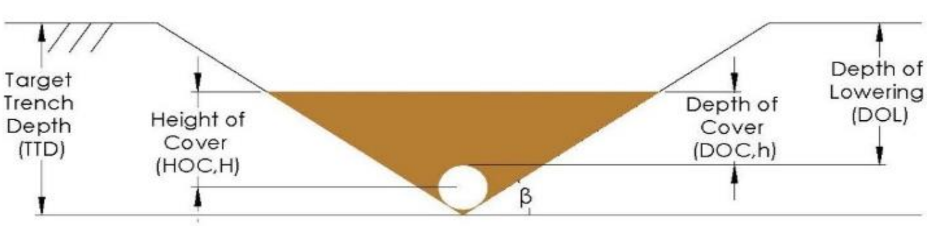

Fig. 1.1 Diagram of cover depth and other relevant parameters

Depth of cover is a critical factor in maintaining long term pipeline integrity and protecting the environment. Pipeline operators are committed to the safe and responsible delivery of energy

2.1 RIGHT OF WAY

Right of way is the surface (top side) area of land around the pipeline that should remain clear of all man made constructions and excavations.

The Nigerian government has taken measures to guard against oil theft by acquiring 3.5 m wide Right of Way (ROW) on each side of the pipelines to avoid accidental contacts, or vandalism.

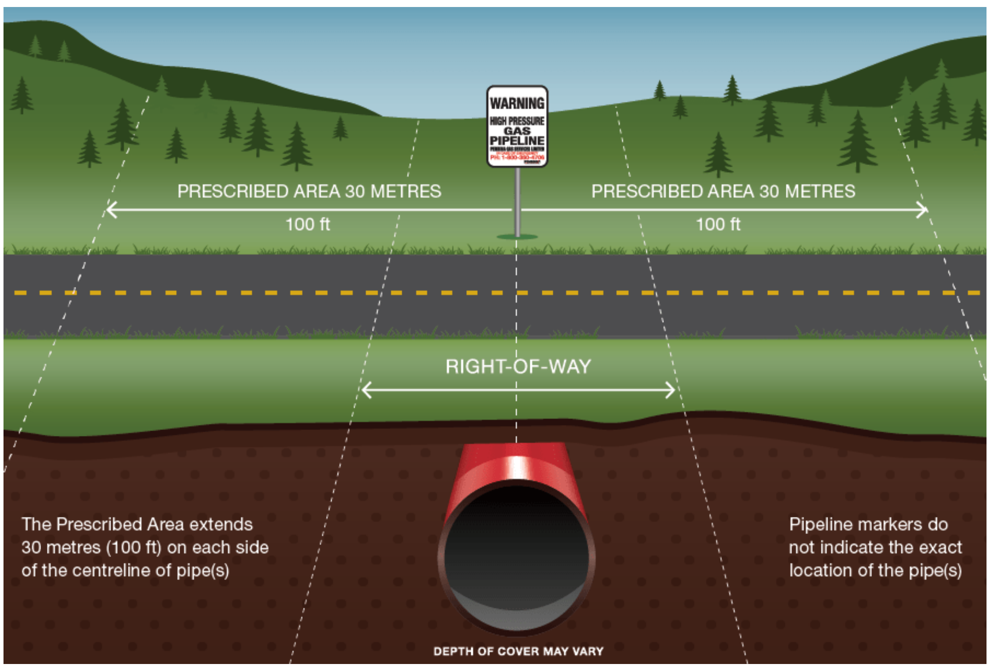

Fig. 1.2 Diagram of right of way measurements

The first activity in pipeline construction is the ROW clearing/preparation. An object-free and clearly defined ROW corridor is critically important to pipeline companies in both. An object-free and clearly defined ROW corridor is critically important to pipeline companies in both construction and operational phases. Legal rights to the ROW should be obtained before construction crews can enter the ROW to begin construction activities.

The pipeline route centerline is then staked and the ROW extremities are clearly marked. The ROW agreement allows for free and uninterrupted access to the pipeline for regular maintenance, repairs, and periodic inspection during the expected operating life of the pipeline.

A temporary ROW workspace width of about 100 ft. (30 m) is generally required during construction. The width depends on the terrain, pipe diameter, and construction methods used. The permanent ROW for a long-haul pipeline is typically 50 ft. (15 m) wide or roughly 25 ft. (7.5 m) on each side of the pipeline. This helps identify the presence of an underground pipeline. Along with aboveground markers, strategically placed over or near the pipeline, there is no better visual reminder of underground utilities in an area than a cleared and well-defined energy corridor.

This raises public awareness and attention to excavation damage prevention that provides some of the best pipeline protection. The pipeline occupies only a small portion of the (ROW). Sufficient space on each side of the ditch is required to allow safe and efficient movement of equipment and construction personnel and excavated soil.

2.2 THE CHALLENGE OF PIPELINE VANDALISM IN NIGERIA

Pipeline networks are important parts of the national energy transportation infrastructure vital to the nation’s economy. It is an indispensable means for conveying water, gas, oil and all kinds of products.

Undoubtedly, the pipeline project is one of the most important infrastructures in Nigeria as it stretches several thousands of kilometers and passes through cities, villages and rural communities across the country.

These pipelines are operated at high pressure and any failure or damage poses a great danger to human health and properties, environmental and ecological disasters and interruption of gas or oil supplies (G.N Ezeh, 2014).

The pipelines are prone to losing their functionality by any internal or external corrosion, cracking, third party intrusion and manufacturing flaws, thereby leading to damage, leakage and failure with serious economic and ecological consequences (G.N Ezeh, 2014)..

Third party mechanical damage has proven to be the most serious problem encountered by pipeline industries on their facilities located onshore (G.N Ezeh, 2014)..

Oil spill incidence through pipeline vandalism appears to be peculiar to Nigeria and has become rampant in recent times and if no urgent measures are taken by the relevant Nigerian agencies, the frequent pipeline cuts that continue to spill for weeks and months has the capacity of undermining Government’s efforts at meeting its obligations in spill management.

Pipeline vandalism and disruption of oil production activities regrettably are now integral part of oil and gas operations in Nigeria. The enormous oil installations deployed in the Niger Delta region explains their vulnerability to vandalism.

Presently, the Niger Delta region plays host to 600 oil fields of which 360 fields are onshore while 240 are offshore with over 3000 kilometers of pipelines crisscrossing the region and linking some 275 flow stations to various export terminals. It is pertinent to note that oil spills resulting from pipeline vandalism has continued to be a challenge, with most incidents along major pipelines and manifolds (Bakpo, 2009).

Table 2 shows that for the period 1995-2005 for instance, Shell Petroleum Development Company one of the major oil operators in Nigeria recorded a total of 2944 oil spill incidents. The data reveals a noticeable increase from (235) oil spill incidents in 1995 to (330) in 2000.

The least number of 224 oil spill incidents was observed in 2005. Also it was reported that about 250,000 barrels of crude is stolen daily for sale on the local and international black markets, reportedly costing the country about $6bn to $12bn annually. From 2002 to 2011, records show that about 18,667 incidences of vandalism occurred (L.P.E YO-ESSIEN, 2014).

Table 1 (below), shows Oil Spill Data: From SPDC 1995-2005 (L.P.E YO-ESSIEN, 2014).

Table 1. Oil Spill data SPDC 1995-2005

Year	Number Of Spills	Volume In Barrels
1995	235	31,000
1996	326	39,000
1997	240	80,000
1998	248	50,000
1999	320	20,000
2000	330	30,000
2001	302	76,000
2002	262	19,980
2003	221	9,916
2004	236	8,317
2005	224	11,921

Table 1 (above) shows the quantity of crude oil lost as result of pipeline vandalism from Oil Producers Trade Section (OPTS). From the table, 5 million barrels of crude oil was lost due to illegal bunkering facilitated by pipeline vandalism.

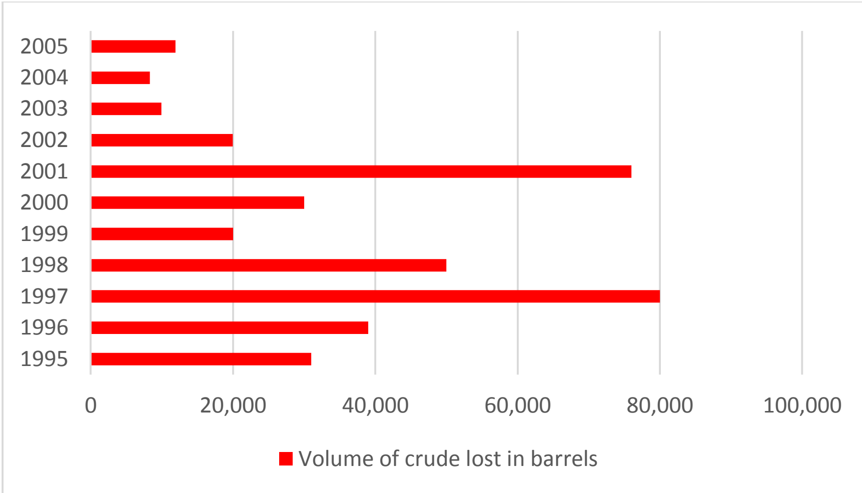

Fig 1.3 Volume of crude lost in barrels between 1994 - 2005

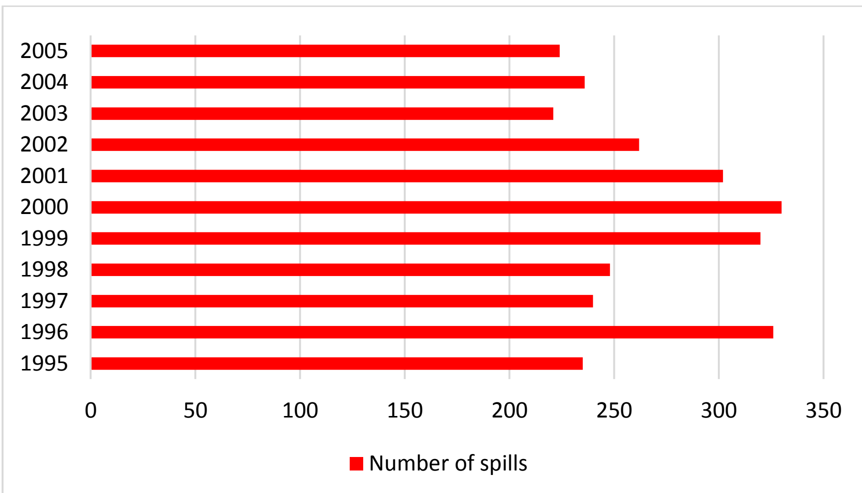

Fig 1.4 Number of oil spills between 1994 - 2005

Furthermore, Nigeria National Petroleum Corporation (NNPC) posited that Nigeria lost about N163 billion in three years to pipeline vandalism (G.N Ezeh, 2014), (Thisday, 2014) (NNPC, 2014).

Pipeline vandalism has crippled fuel supply and incurred over N174billion in product losses and pipeline repairs (NNPC, 2014).

Many lives have been lost as a result of explosions and fire coming from vandalized pipelines carrying crude oil and refined products when they become vandalized. The environment has also been degraded and many farmlands completely destroyed!

2.3 A REVIEW OF OTHER RELATED PIPELINE SURVEILLANCE SYSTEMS

In literature, there are several works on oil pipeline monitoring systems with major focus on leakage detection, change in pipeline pressure at both ends, have been discussed in the work of (Ogujor et al 2013)

A microcontroller based anti-pipeline vandalism system that is capable of alerting the operator in the control center about ongoing theft in the field by indicating the area at which a pipeline attack is taking place.

The system is packaged using an insulated copper cable sensor wrapped around the pipeline for the detection of vandalism acts via vibrations.

This system appears to be effective in monitoring a large pipeline network, however, the cost of implementation and maintenance is high. A pipeline vandalism detection system that communicates information to the control room by an SMS alert notification was developed in (N. Ezeh 2005).

This system's design functions by using a resistance sensor as a continuous path for the flow of electricity. Any break in the signal path causes an interruption of the signal and is considered as a deviation in the normal state of the system. Whenever this state occurs, the control unit will send out a signal to alarm unit for the activation of buzzer and indicate the transmission signal through a light emitting diode (LED). But, this system cannot communicate over a remote network. In a similar approach, a microcontroller based pipeline monitoring system is proposed by (A. Igbajar).

This research centered on an architectural design and modelling of oil spillage detection using both real life scenario and simulation approach. The leakage location and detection were based on imbalance between inflow and outflow pressure as the leakage of pipeline which causes low in pressure at the pipeline outlet.

The system design based on the technique such that whenever a low pressure is detected in the outlet oil pipeline, it will trigger alarm and send a short notification message to the dedicated system in a control unit.

This system can only be effective in the presence of large leakage of oil, as the small leakage may not show significant reduction in the outlet pressure and oil pipeline punctured is not considered (Obodoeze et al, 2004)

Developed oil pipeline vandal detection and surveillance system. This work based on automated electronic pipeline vandalism detection and surveillance system with feature of intruder detection module. It is developed by integrate video camera for surveillance and capturing of any criminal who intends on oil pipeline destruction.

The system seems to be efficient in capturing of criminal identities, but no provision for sabotage countermeasure. Therefore, the system developed only provides early notification of information acquired based on the ongoing criminal activities, so that oil pipeline vandalism can be prevented in advance before the process of digging a hole or illegal construction will be taken place. Okorodudu et. al. proposed a monitoring system for petroleum pipeline vandalism which required pressure sensor wires to be wrapped around the pipeline (O. Franklin).

The systems triggers an alarm at a control station if the sensor is tampered with by intruders

However, this system requires wiring sensors to be incorporated into the pipeline design and for the wiring sensors to be covered with resin to increase the reliability. Moreover, the vandals would already have accessed the pipeline by the time the system sends an alarm to the control station.

(Ezeh et al, 2004) modelled a simulation of a vandalization detection system that sends an SMS when there is a break in the continuous electrical path of a resistant sensor, which would signify cracking of the pipeline by a vandal. Similar to (Ajao . A, 2018), this technique would be difficult or impossible to implement on Nigeria's already existing Oil and Gas pipeline network.

(Ogechukwu et. Al, 2017) proposed an Affordable Pico-satellite-based Oil-pipeline Surveillance System (APOSS), consisting of 3400 Ground Terminal Nodes (GTN) spaced 150 m apart, and made up of crash/vibration sensor; transmitter/transceivers, Global Positioning System (GPS) chips and power packs.

GTNs will detect when vandalization is taking place using the vibration sensors, and will relay the GPS location to a satellite constellation, which will then relay the data to the Ground Station (GS) to alert the security that there is an illegal activity going on at a particular location (Ogechukwu et. Al, 2017).

The requirement of GTNs to be installed along the length of the pipeline means that this technique cannot be easily implemented to provide protective coverage for Nigeria's existing Oil and Gas pipelines.

(Chukwujekwu et. al, 2014) used a Passive Infrared (PIR) sensor to detect early intrusion of vandals into the pipeline system in order to communicate to the pipeline operators via SMS and email alerts so that a proactive action such as shutting down the pipeline valves or calling in the security patrol team can be initiated to mitigate loss. While this system attempts to detect vandalization attempts earlier that previously discussed systems, the major drawback for this system design is a high false alarm rate as not every motion detected by the PIR sensor would be due to vandals or even humans, and as such, the system cannot be considered effective in detecting vandalisation attempts on the country's Oil and Gas pipelines.

CHAPTER THREE

MATERIALS AND METHODS

The embedded pipeline vandalism system is developed using both software and hardware resources to achieve proactive detection of pipeline vandalism based on geographical location (longitude and latitude) and distance.

The hardware system involved is made up of the following components:

1. SIM900 GSM/GPS module,
2. SMS/SIM card,
3. Piezo disc sensor
4. Arduino Uno development board (with the ATmega328 microcontroller chip)
5. Mobile phone
6. 6600mAh lithium ion battery

3.1 Arduino Uno microcontroller board

Is a very popular and relatively cheap microcontroller board among electronic component building enthusiasts, it is based on the Atmega328 microchip architecture. It contains 14 digital I/O pins, 6 pins are used for PWM digital outputs and 6 are for analog inputs with a 16MHz crystal oscillator. The ICSP header pin is used for microchip programming, the Arduino IDE runs on basic C-language syntax.

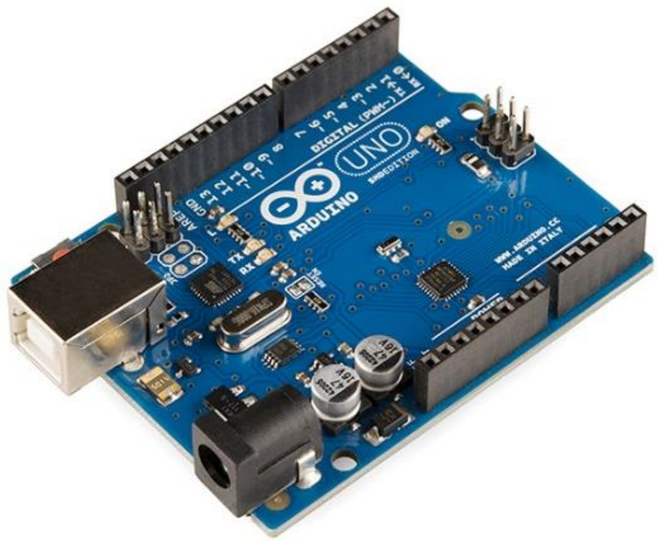

Fig. 1.5 An Arduino Uno development board

3.2 A simple test script, deigned to trigger an LED

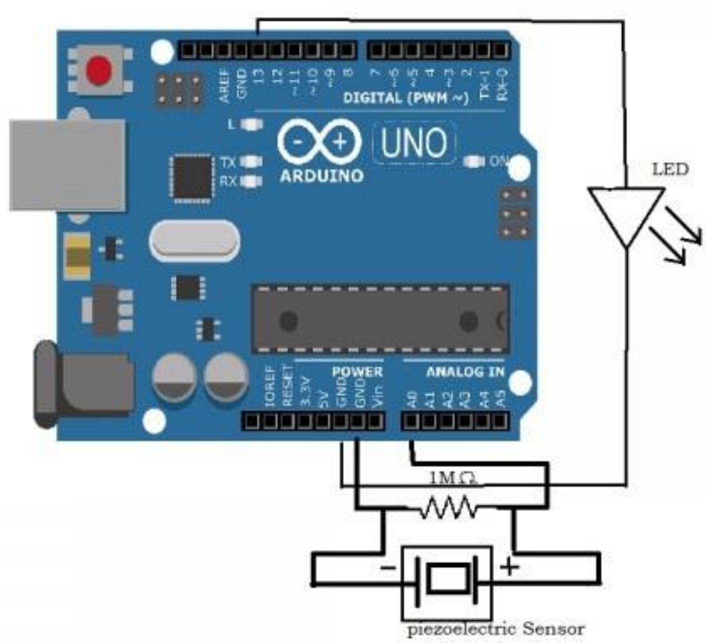

Fig. 1.6 A simple test script, deigned to trigger an LED

The above circuit triggers an LED on, based on a predetermined input voltage threshold value, in this case

The source code is displayed below:

```
const int ledPin = 13; // the positive terminal of the LED is connected to digital pin 13

const int Sensor = A0; // the piezoelectric Sensor is connected to the analog pin A0

const int threshold = 200; // Threshold is set to 200

int sensorReading = 0; //variable to store the value read from the sensor pin

int ledState = LOW; // variable used to store the last LED status, to toggle the light

void setup()
{
pinMode(ledPin, OUTPUT); // declares the led Pin as OUTPUT
}

void loop()
{
// read the sensor and store it in the variable sensor reading:
sensorReading = analogRead(Sensor);

// if the sensor reading is greater than the threshold:
if (sensorReading >= threshold)
{
// toggle the status of the ledPin:
ledState = !ledState;
```

```
// update the LED pin :
digitalWrite(ledPin, ledState);
delay(10000); // delay
}
else
{
digitalWrite (ledPin, ledState); // the initial state of LED i.e. LOW.
}
}
```

// Where the double forward sashes, indicate comments

3.3 Piezo-Electric Sensor

The piezo-electric sensor detects vibrations (in this case, vibrations caused by vandalism activity). These vibrations cause mechanical stress in the crystal found in between the opposite faces of the piezoelectric sensor terminals, which causes the crystal to contract or expand when an alternating voltage is applied.

Fig 1.7 A Piezo disc sensor

Also, the piezoelectric sensor has two connecting terminals that produce a varying magnitude of an analog voltage when a deformation is applied to the crystal, this is the phenomenon that we would be exploiting for the vibration sensor.

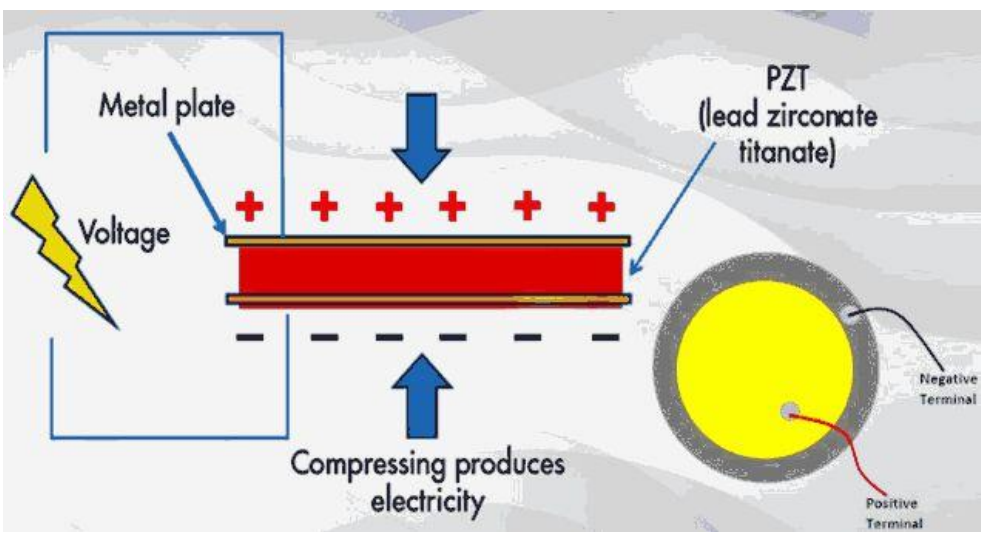

Fig 1.8 Working principle of a piezoelectric sensor

However, when frequency of the applied voltage is equal to the resonant frequency of the crystal, the amplitude of vibration is said to be maximum.

The resonance frequency of the oscillator can be expressed as in equation (1), and the capacitance of the capacitors can be calculated using equation (2):

$$f_0 = 1/2\pi\sqrt{LC} \qquad (1)$$

$$C = \frac{C_1 \cdot C_2}{C_1 + C_2} \qquad (2)$$

Q-factor for the crystal piezoelectric effect can be calculated using equation (3):

$$Q_f = \frac{\omega L}{R} = 2\pi f L / R \qquad (3)$$

Where,

f_0 is the resonant frequency (Hz)

L is the inductance of coil (H)

C is the capacitance of the capacitor (F)

ω is the angular velocity (rad/s)

Q_f is the Q-factor

R is the resistance of the resistor (ohm).

3.4 Piezoelectric Sensor Specifications

Some of the basic characteristics of piezoelectric sensors are,

a) **Range:** This range is subject to measurement limits.

b) **Sensitivity:** This is the change Ratio, of the output signal Δy to the signal that caused the change Δx.

Appropriately given by the equation (3.1), below

$$\mathbf{S = \Delta y/\Delta x} \qquad (3.1)$$

c) **Reliability:** This Refers to the sensors ability to keep certain characteristics/values of parameters, under very narrow limits of set operational conditions. It is the tolerance of the sensor

Other noteworthy specifications of piezoelectric sensors are **threshold of reaction**, **errors**, **time of indication** etc…

3.5 GSM/GPS Module SIM 900A

Is a wireless radio technology device that provides support for a remote network service. This device is used to send and receive information via SMS based on oil pipeline vandalism activities.

The GSM/GPS module is connected to the Arduino Uno Microcontroller microcontrollers chip via the SIMCOM Advance Technology (AT) Commands, and then configured with ATmega328 through universal asynchronous receiver-transceiver module (UART).

Fig 1.9 An Arduino GPRS/GSM shield (SIM900)

The following pins are used in the connection and configuration of the Arduino Uno for the functionality of SMS forwarding (and receiving) to a mobile phone.

1. Power (+5V)
2. Ground (GND)
3. Receiver (RX)
4. Transmitter (TX)
5. PWR
6. Reset Button (RST)

3.6 Basic SMS script for the Arduino GPRS/GSM shield (SIM900) module

The Arduino GPRS/GSM (SIM900) shield module, can be programmed with the following script via the IDE interface;

```
// Connect to serial device

Serial1.setup(115200, { rx: D0, tx : D1 });

var ATSMS = require("ATSMS");

var sms = new ATSMS(Serial1);

//Use sms.at.debug(); here if you want debug messages

sms.init(function(err) {

if (err) throw err;

console.log("Initialised!");

sms.list("ALL", function(err,list) {

if (err) throw err;

if (list.length)

console.log(list);

else

console.log("No Messages");

});

// and to send a message:

//sms.send('+2348037034800','Hello world!', callback)

});

sms.on('message', function(msgIndex) {

console.log("Got new message, index ", msgIndex);

});
```

3.7 Flow rate equations

In the design of a pipeline detection surveillance system, there are some principles that can predict the operational system development, such as pressure fluid flow in a pipeline and pressure modelling.

According to (Frank, Oyedeko and Balogun) described the continuity equation for normal fluid flow in a pipe as the conservation law of mass. Which states that, the movement of mass fluid flow in or out of a pipeline is equal to the rate of mass fluid change. This can be expressed as in the equation below:

$$\frac{\partial(pA)}{\partial t}+\frac{\partial(pAv_x)}{\partial x}+\frac{\partial(pAv_y)}{\partial y}+\frac{\partial(pAv_z)}{\partial z}=0 \quad (4)$$

Several equations govern the mass fluid flow characteristics in a pipeline which helps to described leakages in the pipe fluid flow (K.E Abhuliman, 2007)(S.I Kam, 2010).

These are three basic modelling equations that are derived from both thermodynamics and fluid mechanics, they are:

1. The law of continuity equation
2. The momentum equation
3. Law of conservation of energy equation

which are respectively given in equation (5), (6) and (7) respectively below,

$$\frac{\partial(pA)}{\partial t}+\frac{\partial(pAv)}{\partial x}+\Re\cdot\delta(x-x_1)=0 \tag{5}$$

.

$$\rho\frac{\partial v}{\partial t}+(\rho v\frac{\partial v^2}{\delta x})+\frac{(\partial F)}{\delta x}+\rho g\frac{\partial\varepsilon}{\partial x}+\frac{\rho f v^2}{2D}+\rho V_0=0 \tag{6}$$

$$\rho\frac{\partial r}{\partial t}+\rho v\frac{\partial r}{\delta x}+(\frac{r}{\tau}\cdot\frac{\partial P}{\delta r}\cdot\frac{\partial v}{\partial x})-\frac{\rho f v^3}{2\tau d}+\frac{4U}{\tau d}[T-T_g]=0 \tag{7}$$

Where:

R is the leakage rate in the pipeline,

v is dimensional velocity (v) of pipeline (m/s),

V_o is the outflow velocity (m/s),

µ is the dynamic frictional force,

P is the fluid density (kg/m3),

p is the fixed pressure (MPa),

x is the three-dimensional space,

H is the height (m)

T is the time (t) in second

Which can be determine by the hyperbolic partial or differential equations for a 1D plane. According to (White, Dan-asabe et al.), discussed the fluid flow rate F_f (m^3/s) and the pump pressure P_p (MPa) in a pipeline, which can be calculated as given in equation (8) and (9).

$$F_f = \frac{\pi D^2}{4} v \tag{8}$$

$$P_p = \frac{\eta P}{F_f} \tag{9}$$

Since, the pipeline states are a vector of mass fluids flow, temperature and the pressure are computed at every time step for every available data measured in the fluid segment being transported. Each of these states helps to achieve the derived model equations to define the behavior of the surveillance system.

Where:

D is the Diameter of pipeline

v is the velocity

P is the pump power in Kilowatts

η is the pump efficiency (%).

F is the sensor node positions on Oil Pipeline

п = 3.142

Sensor nodes were positioned one meter apart from each other on a pipeline of ten meters with diameter of 0.05m. The Piezo-electric sensor vibration has minimum sensing shock threshold of 28 (256) and 210 (1024) maximum. This is to screen out, minor or irrelevant vibrations on the pipeline, which may be due to environmental factors or digging activities of small borrowing animals.

The thickness of oil pipeline τ in (mm) is of great importance for the considering sensor nodes locations and fluid flow rates which are described as in equation (11) and (12) below

$$P_{di} = \frac{P_{do}}{2t} \tag{11}$$

$$\tau = \frac{D_p P_{di}}{2[SE + D_p(1-y)]} \tag{12}$$

Where, D_p is design pressure (MPa)

P_{di} is the internal diameter of pipe (mm)

P_{do} is the outer diameter of pipe

S is the induced stress of the material

E is joint factor

y is coefficient temperature

A is the cross-sectional area of pipe (mm^2)

V is the volumetric flow (m^3/s).

3.8 6600mAh lithium ion battery, SIM card and Mobile phone

A lithium-ion battery or Li-ion battery is a type of rechargeable battery. Lithium-ion batteries are commonly used for portable electronics and electric vehicles and are growing in popularity for military and aerospace applications.

A subscriber identity module or subscriber identification module (SIM), widely known as a SIM card, is an integrated circuit running a card operating system (COS) that is intended to securely store the international mobile subscriber identity (IMSI) number and its related key, which are used to identify and authenticate subscribers on mobile telephony devices (such as mobile phones and computers).

A mobile phone is a portable telephone that can make and receive calls over a radio frequency link while the user is moving within a telephone service area. The radio frequency link establishes a connection to the switching systems of a mobile phone operator, which provides access to the public switched telephone network (PSTN).

CHAPTER FOUR

RESULTS AND DISCSSIONS

4.0 RESULTS

The comprehensive result based on the coordinates of the pipeline (Longitude Latitude, and Distance) are presented in:

Table 2: Result of the piezoelectric surveillance system and geographic location

Node	Longitude (deg)	Latitude (deg)	Diff. in Long(deg)	Diff. in Lat. (deg	Distance(km)
1	6.4442	9.5327	0.4871	0.4712	54.4001
2	6.4479	9.5005	0.5208	0.4390	58.1700
3	6.4634	9.45408	0.5363	0.4793	59.9004
4	6.4578	9,5503	0.5307	0.4888	59.2811
5	6.4238	9.5220	0.4967	0.4614	55.4821

The parameters analyzed in Table 2 contains geographic locations of oil pipeline damages based on my prototype design, and distance of the pipeline punctured to the base station, which can be calculated using equation (13). The reference location of longitude and latitude are (5.9271 and 9.0615) respectively.

Where:

θ is difference in longitude,

α is difference in latitude,

π is 3.142 and

R is radius of the earth (6400km).

$$D = \frac{\theta}{360} x 2\pi R Cos\alpha \quad (13)$$

4.0 DISCUSSION

Implementation and testing on a 10m length pipeline of 0.05mm diameter.

The system was equipped with 5 sensor nodes of piezo-electric pick-ups, which are arranged two meters apart to each other. The sensor node is implemented for detection of vibration and shock on an oil pipeline with threshold parameter range between (28 to 210).

During pipeline vandalism, the sensor detects vibration which is compared to the minimal threshold value that is pre-set before sending an SMS to the administrator or control room based on the geographical location (latitude, longitude and distance).

This embedded wireless sensor system based on the Atmega328 microchip embedded on the Arduino development board, has a GSM and GPS module which is used to calculate the coordinate direction before an SMS was sent. The configuration of the system varies based on the pipeline vibration response.

That is, any vibration impact is less than 28 (<256) threshold is consider as an environmental effect or normal, and SMS is not sent

But any vibration pressure impact on the pipeline above 29 (>256) threshold is considered as a vandal threat which activates the sending of an SMS alert.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

This project provides insights into the way an automated electronic crude oil pipeline surveillance and monitoring system can be used to detect, process gathered information, and make a preprogrammed meaningful automated decision to either alert and/or dispatch further surveillance technology.

In this project, automated detection for intrusion of pipelines, with remote monitoring and coordinates gathering was achieved.

This proactive detection system will lead to a reduction in financial losses and environmental degradation, as well as the possibility of providing evidence for investigations and effective prosecution of vandals.

Technology is evolving and smart/intelligent sensors are the future, hence there is a dire need for them to be applied to problem solving and improving the efficiency and ergonomics of modern engineering.

5.2 RECOMMENDATIONS

My future recommendation, would be for the integration of automated line of site Drones equipped with image and video capturing capability, possibly even infrared technology [for night visibility enhancement].

The drones would be dispatched, from the control center's base, to the air with the locked-on geographic coordinates of the tripped piezo-electric sensor's zone. Which on visual confirmation of the vandals, the appropriately equipped security officers will be deployed to the zone.

Secondly, the addition of a voltage controller and a 12v solar panel to charge the 6600mAh battery during the day.

Lastly, I would recommend further tinkering of the script lines of codes, that will send an SMS when battery levels are critically low. So as to ensure uninterrupted surveillance or at worst, pre-functionary countermeasures and contingencies.

5.3 REFERENCES

Watts M., "Resource curse governmentality, oil and power in the Niger Delta", Nigerian Geopolitics, vol. 9,no. 1, pp. 50-80, 2004.

Aluko M. E, Sunday musings: The case for an energy emergency in Nigeria again, (2017). Retrieved fromhttp://www.nigerianmuse.com/20150607041636zg/sections/essay/sundaymusings-the-case-for-an-energy-emergency-in-nigeria-by-bolaji-aluko

Ajao L. A, Agajo J, Kolo J.G, Maliki D, and Adegboye M.A, "Wireless sensor networks based-internet of thing for agro-climatic parameters monitoring and real-time data acquisition", Journal of Asian Scientific Research, vol.7, no. 6, pp. 240-252, 2017.

Ajao L.A, Agajo J, Kolo J.G, Inalegwu,E, Edem A, "Development of a Low Power Consumption Smart Embedded Wireless Sensor Network for the Ubiquitous Environmental Monitoring using Zig Bee Module", ATBU Journal of Science and Technology Education (JOSTE), Vol. 5, No. 1, pp. 94-108, 2017.

Babamir S. M, "M2M Architecture: Can it realize Ubiquitous Computing in Daily Life?" KSII Transactions on Internet and Information Systems, vol. 6, No. 2, 2012.

Wandre S, EDGE: Enhanced Data Rates for GSM Evolution, Illinois Institute of Technology, 1-19, 2000.

Jinfeng S, Zhiyue Z, and Xiaoli S, "The intelligent crude oil anti-theft system based on IoT under different scenario", ELSEVIER, 20th International Conference on Knowledge Based and Intelligent Information Engineering Systems UK, vol. 96, pp. 1581-1588, 2016.

Ogujor E, Inegbenosa S.U, and Esenogho E,"Implementation of a prototype microcontroller based anti-pipeline vandalization system", International Journal of Emerging Technologies in Engineering Research, vol. 2,no. 1, pp. 1-14, 2013.

Franklin O.O, Philip O.O, and Ekerikevwe K.I,"A model of petroleum pipeline spillage detection system for use in the Niger-Delta region of Nigeria", International Journal of Research Granthaalayah, vol. 4, no.12, pp. 1-16,2016.

Eluwande D, and Ayo O.O, “Above ground pipeline monitoring and surveillance drone reactive to attacks”, 3rd International Conference on African Development Issues (CU-ICADI), vol. 5, no. 1, pp. 437-443,2016.

Ezeh G.N, Chukwuchekwa N, Ojiaku J.C, and Ekeanyawu E, “Pipeline vandalism detection alert with SMS”, International Journal of Engineering Research and Applications (IJERA), vol. 4, no. 9, pp. 21-25, 2014.

Igbajar, and Barikpoa A.N, “Designing an intelligent microcontroller based monitoring system with alarm sensor”, International Journal of Emerging Technologies in Engineering Research (IJETER), vol. 3, no.2, pp. 22-27. 2015.

Obodoeze F.C, Asogwa S.C, and Ozioko F.E,“Oil pipeline vandalism detection and surveillance system for Niger-Delta region”, International Journal of Engineering Research & Technology (IJERT), vol. 3, no. 7,pp. 156-166, 2014.

Frank M.W, Fluid Mechanics, 5th Edition, McGraw-Hill, 2003.

Oyedeko K.F, and Balogun H.A, “Modelling and simulation of a leak detection for oil and gas pipelines via transient model: a case study of the Niger Delta”, Journal of Energy Technologies and Policy, vol. 5, no. 1,pp. 16-27, 2015.

Abhulimen K.E, and Susu AA, “Modellin complex pipeline network leak detection systems, process safety and environmental protection”, Trans IChem E, Part B, Process Safety and Environmental Protection, vol. 85,no. B6, pp. 579-598, 2007.

Kam S.I, “Mechanistic modelling of pipeline leak detection at fixed inlet rate”, Journal of Petroleum Science and Engineering, vol. 70, no. 3, pp. 145-156, 2010.

Dan-Asabe V, Yaro S.A, Yawas D.S, Obada D.O, Salahudeen N, and Abubakar U, “Comparative assessment of the mechanical properties of a new tri-composite material”, Nigeria Journal of Engineering and Applied Science (NJEAS), vol. 2, no. 1, pp. 1-9, 2015.

Sahara reporters, “A nation in search of pipeline safety”, Accessed online at http://www.saharareproters.com/nigeria on June 18, 2014.

Ezeh G.N, Chukwuchekwa N, Ojiaku J.C and Ekeanyawu E, "Pipeline Vandalisation Detection Alert with Sms",Int. Journal of Engineering Research and Applications Vol. 4, Issue 4(Version 9), April 2014, pp.21.

John T, “TUC backs NUPENG on alleged JTF’s connivance with bunkerers”, Daily Sun, Thursday, 16, August, 2012, pp.10.

Ojediran, and Ndibe J, “Oil Spill Management: SPDC and the Environment, 2005.” Unpublished.

Ajao L.A , Adedokun E.A, Nwishieyi C.P, Adegboye, J. Agajo, J. G. kolo. An Anti-Theft Oil Pipeline Vandalism Detection: Embedded System Development. International Journalof Engineering Science and Application. Vol.2, No.2, pp. 41–46, 2018.

Godswill Ofualagba and O'tega Ejofodomi. Automated Oil and Gas Pipeline Vandalism Detection System. Automated Oil and Gas Pipeline Vandalism Detection System, Society of Petroleum Engineers SPE 2020

Thisday,“NNPC lost about N163billion in the space of three years to pipeline vandalism”, accessed online at http://www.thisdaylive.com on June 13, 2014.[9]NNPC, “How pipeline vandals cripple fuel” supply”, Accessed online at http://www.nnpcgroup.com/public relation on June 24, 2014

Ezeh G.N, Chukwuchekwa N, Ojiaku J.C and Ekeanyawu E, "Pipeline Vandalisation Detection Alert with Sms",Int. Journal of Engineering Research and Applications Vol. 4, Issue 4(Version 9), April 2014, pp.21

John T, “TUC backs NUPENG on alleged JTF’s connivance with bunkerers”, Daily Sun, Thursday, 16, August, 2012, pp.10.

Ojediran, and Ndibe J, “Oil Spill Management: SPDC and the Environment, 2005.” Unpublished.

Essien L.P.E, "Oil Spill Management in Nigeria: Challenges Of Pipeline Vandalism In The Niger Delta Region Of Nigeria”, pg.16. Accessed Online http://Ipec.Utulsa.Edu/Conf2008/Manuscripts%20&%20presentations%20received/Eyo_Essien_2.Pdf On June 23, 2014.

Stewart M, “Surface Production Operations” Volume 3, Facility Piping and Pipeline System, Gulf Professional Publishing, 2016.

Bakpo F. S and Agu M. N, "Automatic Data Collection Design ForReal-TimeDetection Of Oil-Spillage Disasters In Nigeria”, Nigerian Journal Of Technology, vol. 28 No.1, pp. 54, March 2009.