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An Anti-Theft Oil Pipeline Vandalism Detection: Embedded System Development

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Abstract- This act of pipeline sabotage, stealing remain a great security challenges for both government and people of the affected countries, as this ugly activity usually resulted in a significant loss. Such as economic downfall, loss of human lives, environmental pollution and destruction of aquatic animals. An anti-theft oil pipeline vandalization system based internet of things technology was developed using ATmega328, GSM and GPS to render a remote information monitoring. The prototype was implemented and tested in a lengthy pipeline of 10m with configuration threshold range from 28 to 210. The result obtained contain sensor nodes position in a pipeline network, geographic locations (longitude and latitude) and distance, which are transmitted as SMS alert to the base station (BS). It is expected, that this technology will assists early detection of vandalism of crude oil pipelines and guide the security agent on the exact location of any ongoing theft activities.

Keywords- Anti-theft; Crude oil; Geographic location; Pipeline network; Prototype.

1. Introduction

Nigeria is among the largest oil producer in the world and first in Africa. Crude oil mining is regarded as the main sources of income in Nigeria while agriculture, manufacturing industries and other income generation sectors are supportive. Crude oil is largely use by automobile company across the world for industrialised a wide variety of essential materials such as plastic production (baby toys, car parts, computer cases and so on), electronic system (mobile phone materials, camera cases, speakers, etc), clothing materials, furniture, and kitchen items [1].

It has been weighed that world consumes about 88 million barrels of petrol daily, while U.S. alone consume about 44% on cars fuel. According to international report affirm that oil theft in Nigeria is extremely high and disastrous which poses serious threat to the country national economy as the highest recognise source of income [2]. Pipeline vandalism is frequent occurrence issues in the petroleum sector for years, and several countermeasures technique have been deployed varies from different technology approaches. Initial proactive measure provided are security agent deployment (policemen, para-military patrol teams and non-governmental securities) and automation based intelligent system. This has yielded inadequate result due to some difficult terrain of oil pipeline networks location coupled with other criminal strategies adopted by those vandals of oil pipeline.

Furthermore, wireless technology based internet of things render services of a remote data transfer, sensing, monitoring and control. This technology is currently utilized to achieve various levels of intelligence in the embedded system applications. These include remote healthcare monitoring, transportation, building, environmental, agricultural, and oil pipeline monitoring [3].

Wireless technology is an electromagnetic waves signal that improves on the data communication path transmission at a remote network without involving wired but using radiotelegraphy, modulation techniques called “radio” and Internet Protocol (IP) Addresses to transmit voices, music, signal waves and so on to the destination. This technology adopts different equipment for the data-com or signal wave transmission between machine-to-machine, human-to-machines and human-to-Human in a network. These are cellular phones or global system for mobile communication (GSM), global positioning system (GPS), satellite television, VCR controller, and wireless local area network (WLAN) [4, 5].

In support of this wireless equipment, several technologies have been emerged for short and wide range communication such as Bluetooth, ZigBee, Wi-Fi, wireless application protocol (WAP), general packet radio services (GPRS), enhanced data gsm environment (EDGE), and universal mobile telecommunication system (UMST). The newly materialised platform integrate embedded system with wireless sensor network based Internet of Things (IoTs) to improved world-wide broadcasting and robust mechanism for transmission and receiving information remotely [6].

It enhanced policy for collaboration and interaction among individuals, several things like smart oil pipeline monitoring, smart cities, smart energy, smart transportation, smart hospital, and so on without regard for detecting geographic location and distance.

2. Related Works

In literature, several works on oil pipeline destruction monitoring system with major focus on leakage detection, change in pressure pipeline at both ends have been discussed as illustrated in “Fig. 1”.

In the work of Ogujor et al. [8] proposed a microcontroller based anti-pipeline vandalism system that capable of alert the operator in the control centre about ongoing theft in the field by indicate area at which pipeline attack is taken place. The system is package using insulated copper cable sensor wrapped around the pipeline for the detection of sabotage act around the pipeline and simultaneously displays the acquired information on Liquid Crystal Display (LCD). This system is developed using wired technology for the information transmission, and it completely kept within the pipeline environment for security against vandals. Franklin et al. [9] presented similar research by designed a petroleum pipeline spillage detection model for the Niger delta region of Nigeria. The experimentation of the model was carried out via the individual simulation of the various units of the system using the procedural programming application.

A novel approach of monitoring pipeline sabotage with fast response of message delivery is proposed in [10]. This study aim at developed an Unmanned Aerial Vehicle (UAV) machinery for real-time monitoring and surveillance of the pipeline network in hazardous environment. The hardware circuit is designed using fritzing computer aided design software before soldering of electronic components. Also, a quadcopter system was employed for the inspection and reporting of the oil pipeline field status through a live video stream coverage. 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 alarming and SMS notification was developed in [11]. This system design is functioning using resistance sensor as a continuous flow of electrical path. Any break in the signal path causes interruption of signal and considered as deviations in the state of the system. Whenever this state occurs, the control unit send out signal to alarm unit for the activation of buzzer and indicate the transmission signal through 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 [12]. This research centred on 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 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. [13] 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 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 in this paper provide 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.

3. Materials and Method

Embedded system development based on an anti-theft oil pipeline defacement is developed using both software and hardware resources to achieve detection of oil-theft and destruction based on geographical location (longitude and latitude) and distance. The Proteus Virtual Simulation Modelling (PVSM) was used for embedded system circuit design and Arduino IDE with C-language platform were used for system design coding. The hardware system involved are SIM900 GSM/GPS module, SMS/SIM card, Piezo disc sensor, conduit pipe (3mm), Arduino development board with embedded ATMega328 microcontroller and mobile phone.

a. Atmega 328 Microcontroller

The Arduino Uno is a microcontroller board based on the Atmega328 architecture. It contains 14 digital input/output pins, 6 pins are used for PWM outputs and 6 Analog inputs with 16MHz crystal oscillator. The ICSP header pin is used for microchip programming.

b. Piezo-Electric Sensor

Piezo-electric sensor helps to detect vibration on the oil pipeline damage. This vibration occurred due to mechanical stress between the opposite two faces, and cause the crystal to contract or expand when alternating voltage is applied. Piezo sensor has two connecting terminals that whenever joined together it produce a certain magnitude of analog voltage. But, if the frequency of applied voltage (Vac) is equals to the resonant frequency of the crystal, then the amplitude of vibration is maximum. The piezo-electric sensor circuit equivalent diagram is depicted in “Fig. 2”.

The resonance frequency of the oscillator can be given as expressed in “equation (1)”, and the capacitance of the capacitor for C1 and C2 are calculated as given in “equation (2)”.

$$f_0 = 1/2\pi\sqrt{LC} \tag{1}$$

$$C = \frac{C_1 \cdot C_2}{C_1 + C_2} \tag{2}$$

Therefore, Q-factor of a crystal piezoelectric effect can be calculated as given in “equation (3)”:

$$Q_f = \frac{\omega L}{R} = 2\pi f L / R \tag{3}$$

where, f_0 is the resonant frequency (Hz), L is the inductance of coil (H) and C is the capacitance of the capacitor (F), ω is the angular velocity (rad/s), Qf is the Q-factor and R is the resistance of the resistor (ohm).

c. GSM/GPS Module

SIM900A module is wireless technology device that render support for a remote network services. This device is employed in our system design to sends and receives information (SMS) based on oil pipeline vandal. The GSM/GPS module is connected with microcontrollers chip through SIMCOM Advance Technology (AT) Commands, and configure with ATmega328 through universal asynchronous receiver-transceiver module (UART. The following available pins were used in the connection and configuration with Arduino ATmega328 for SMS forwarding and receiving. The power (+5V), Ground (GND), Receiver (RX), Transmitter (TX), PWR, and Reset Button (RST).

d. Design, Flowchart and System implementation

This system is developed to detect vibration in the oil pipeline theft. The piezoelectric sensor is implemented to sense the shock or vibration in the pipeline, translate the shock into electrical voltage and transmit the voltage to the microcontroller for the processing. This analog voltage parameters are converted into the equivalent digital value which represents magnitude of input voltage. The value is compared with predefined threshold voltage value (2^8-2^{10}). If the input voltage exceeds the threshold value, the intelligent programmed chip triggers the GSM/GPS module to send an SMS alert to the monitoring base station. The anti-theft pipeline information depend on geographic location (both longitude and latitude).

“Figure 3” illustrated the system circuit design in proteus virtual simulation environment, and the logical implementation of the system is shown in “Fig. 4”. The developed anti-theft oil pipeline embedded system flowchart is illustrated in “Fig. 5”.

e. Theoretical Model of Anti-Theft Oil Pipeline System

In the design of an anti-theft oil pipeline detection system, there are some principle that anticipate with the operational system development such as pressure fluid flow in a pipeline, modelling and others.

According to Frank, Oyedeko and Balogun [14, 15] described continuity equation for normal fluid flow in a pipe as conservation law of mass state that, the movement of mass fluid flow in or out in a pipeline is equal to the rate of mass fluid change. This can be expressed as in “equation (4)”.

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

Therefore, several equations govern the mass fluid flow characteristics in a pipeline which helps to described exact leakage in the pipe fluid flow and to achieve accurate leakages simulation effect [16, 17]. These are basic modelling equation that are derived from the thermodynamic fluid mechanics. The law of continuity, the momentum equation and law of conservation of energy, which are given as in “equation (5), (6) and (7)”.

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

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

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

Where R is the leakage rate in the pipeline, v is dimensional velocity (v) of pipeline (m/s), Vo 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) and the T is the time (t) in second which all can be determine by the hyperbolic partial of differential equation for one dimensional plane.

According to White, Dan-asabe et al. [18, 19], discussed the fluid flow rate F_f (m3/s) and the pump pressure Pp (MPa) in a pipeline, which can be calculated as given in "equation (8) and (9)".

$$F_f=\frac{\pi D^2}{4}v \quad (8)$$

$$P_p=\frac{\eta P}{F_f} \quad (9)$$

Since, the pipeline states are vector of mass fluids flow, temperatures and the pressures are computed at every time step for every available data measured in the pipeline model of the fluid segment transportation. Each of these states helps to achieve the derived model equations to define the behaviour of the pipeline vandal system.

where, (π =22/7 or 3.142), D is the Diameter of pipeline, v is the velocity, P is the pump power (KW), η is the pump efficiency (%).

f. Sensor Nodes Position in Oil Pipeline

During the system implementation, sensor nodes are positioned two meter apart to each other within a lengthy pipeline of ten meters with diameter of 0.05m as shown in "Fig. 6". The Piezo-electric sensor vibration has minimum sensing shock threshold of 2^8 (256) and 2^{10} (1024) maximum. This is to avoid sensing of minor or irrelevant vibration on the pipeline, which may due to environmental factors occurrences.

The thickness of oil pipeline design τ in (mm) is considered for the location of sensor node and fluid flow rate which are described as in "equation (11) and (12)".

$$P_{di}=\frac{P_{do}}{2t} \quad (11)$$

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

Where, Dp is design pressure (MPa), P_{di} is the internal diameter of pipe (mm), P_{do} is the outer diameter of pipe, S is the stress of material, E is joint factor, y is coefficient temperature, A is the cross-sectional area of pipe (mm^2), V is the volumetric flow (m3/s).

4. Discussion and Results

During the system implementation and testing of 10m length and 0.05mm diameter pipeline. It is equipped with 5 sensor nodes of piezo-electric, which are arranged in 2 meters apart to each other. The sensor node is implemented for detection and vibration shock on the oil pipeline with threshold parameter between (2^8 to 2^{10}-1). During puncture of pipeline damage, the sensor detect vibration which is compared to the minimal threshold value pre-set before sending an SMS to administrator or control room based on the geographical location (latitude, longitude and distance).

"Figure 7" show complete developed system and implementation. This embedded wireless sensor system based IoTs platform consists of the Atmega328 embedded on the Arduino development board, GSM and GPS module which use to calculate the coordinate direction before SMS was sent. The configuration of the system varies based on the pipeline vibration response. That is, any vibration impact less than 2^8 (<256) threshold is consider as environmental effect or normal without sending of SMS, but any vibration pressure impact on the pipeline above 2^9 (>256) thresholds is consider as a vandal threat which activate sending of SMS alert.

The result of SMS alert received on the android mobile phone from pipeline vibration recognition shock is varies directly with vibration threshold above 256 at different locations of sensors between node1 to node5 as depicted in the "Fig. 8". Also, the comprehensive result based on coordinate of pipeline location (Longitude Latitude, and Distance) are presented in "Table 1".

Table 1: Result of anti-theft pipeline vandalization 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 analysed in Table 1 contained geographic location of oil pipeline damages base on our 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.

The graph in "Figure 9" and "Figure 10" illustrate details result analysis of vibration shock discovered between vibration sensor nodes1 to node 5.

Where θ is difference in longitude, α is difference in latitude, pi (п) is 3.142 and R is radius of the earth (6400km).

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

5. Conclusion

Oil pipeline destruction is a long time stealing activities which caused a significant damages to the crude oil country's main sources of income and still remain an obvious threat. Several cases of oil pipeline breakages has led to immeasurable loss in terms of economic waste, loss of lives and properties of the citizen, destruction of farm land, environmental degradation and water pollution. An anti-theft oil pipeline vandalism detection system was developed and implemented for early puncture detection. This system will send an SMS alert with details geographic location (longitude and latitude) to the control room or administrator base on the system configuration of vibration sensor threshold of 2^8 minimum and 2^{10} maximum.

Moreover, the novel of our proposed developed system and illustrations attempt to offer a practical and technical clarification to the shortcoming, by complement the author's effort from the related works. These are remote monitoring techniques, fast communication using SMS alert that contained information about geographical location of theft (Longitude and Latitude), node localization and distance. Implementation of this anti-theft oil pipeline vandal system will assist greatly in catching the brutal criminals and reduced the common coincidence which usually resulted in fire explosion during pipeline devastation. The embedded anti-theft oil pipeline implementation in this work can be integrated strategically and hidden with resin materials in a pipe.

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