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A SHORT OVERVIEW OF PIPELINE MONITORING TECHNOLOGIES FOR VANDALISM PREVENTION WITH A PROPOSED FRAMEWORK FOR A GSM BASED SYSTEM

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Abstract

Crude oil is a crucial commodity in Nigeria owing to its huge contribution to foreign exchange earning. These crude are usually transported using the pipeline

Keywords:

crude oil, GSM based system, optical fibre, pipeline, and wireless sensor network.

Introduction

Nigeria is among the largest oil producer in the world and first in Africa (Matsumoto, Voudouris, Stasinopoulos, Rigby & Di Maio, 2012). “According to the Nigerian National Petroleum Corporation (NNPC), Nigeria has a maximum crude oil production capacity of 2.5 million barrels per day and has traditionally ranked as Africa's largest producer and sixth largest in the world. Nigeria's petroleum industry is the largest in Africa with proven oil and gas reserves of 37 billion barrels and 192 trillion cubic feet respectively.” (The African Exponent, 2018). Crude oil mining is regarded as the main sources of

infrastructure across the country. Over the years there have been reported cases of pipeline vandalisation with negative consequences for man, properties and the environment. We proposed that automated pipeline monitoring technology be deployed across the nation to prevent pipeline vandalism and oil stealing. Several of the existing monitoring technologies were reviewed and a Global System of Mobile Communication based framework for a simple monitoring scheme was suggested.

Income in Nigeria while agriculture, manufacturing industries and other income generation sectors are supportive (Sanusi, 2010, Okafor, 2012).

According to Obodoeze, Asogwa & Ozioko (2014), the pipeline system is a medium of transportation usually attributed to very sensitive products such as crude oil, natural gas and industrial chemicals, in which unattended problems in their operation results in great catastrophe. These problems include terrorism attacks, vandalism and theft of the pipeline content. The need for implementing adequate security systems for pipeline management has been a key concern. While some of these attempts have recorded some level of success, others have contributed insignificantly to this outstanding challenge that is currently giving mankind sleepless nights.

Priyanka, Thangavel & Gao (2020) observed that depending on the needs of the transport centre, pipes of different diameters are used which are resistant to different pressures. Loading and unloading facilities are used in pipelines to equate distribution and demand for oil and different petroleum products.

Vandalism refers to illegal or unauthorized activities that destroy petroleum, gas and chemical pipelines. It is a negative activity aimed at getting products for personal use or sale in the black market especially in developing countries of the world where they are rampant. About 40% of the world's oil flow through pipelines which run thousands of kilometres across some of the most volatile areas of the world.

Over the years, pipeline vandalism and oil theft in the Niger Delta region of Nigeria has been a challenge to address in the country. It has destroyed arable lands in the affected areas, leading to the high cost of agricultural products as these products have to be transported from regions that are not affected by the menace of pipeline vandalism (Afinotan & Ojakorotu, 2009, Wilson, 2014, Aroh, et al. 2010, Adegboye, Fung & Karnik, 2019). The frequency of crude oil spills from 2013 -August 2020 is shown in Figure 1. it indicates vividly that sabotage constitutes the far major cause of spills.

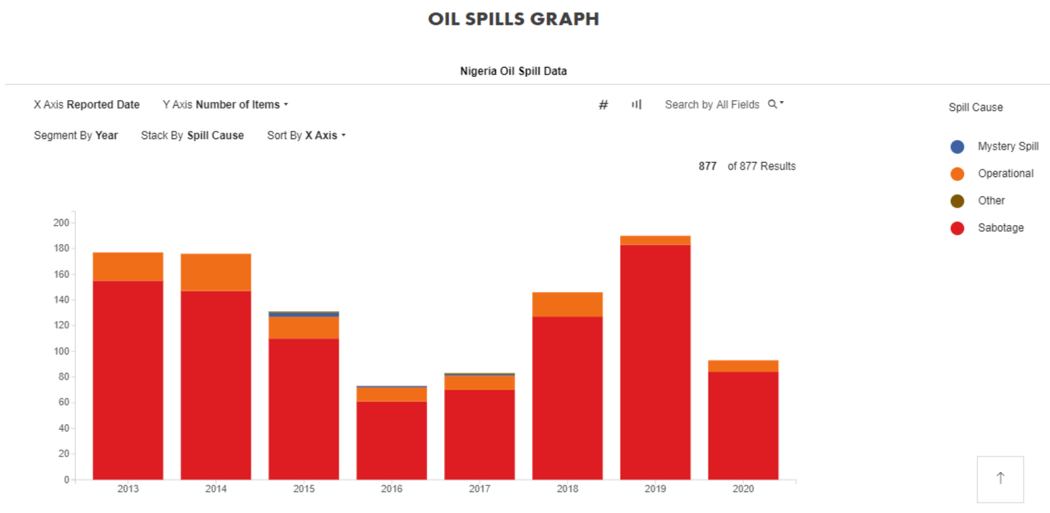

Figure 1: Oil Spill data in Nigeria 2013-2020. (Source: https://www.shell.com.ng/sustainability/environment/oil-spills.html)

Overview of Pipeline Monitoring Technology

In this part of the article, we present a quick overview of some of the technologies used in monitoring failure of pipeline irrespective of whether the failure is deliberate sabotage or otherwise. This review will help key decision-makers in the petroleum industry to come up with technological means of protecting the pipelines. It will also assist researchers to come to the awareness of the state-of-the-art in pipeline monitoring for breach and corrosion detection. Previous surveys in this regard include the works of Abass et al. (2018) and Adegboye, Fung, & Karnik (2019).

Abass et al. (2018) presented an extensive survey on the factors affecting pipeline monitoring techniques and provides novel classification in terms of classifying them into different strategies, sensor types, sensing coverage, communication methods, and monitoring types , shown in Figure 2. The authors also made comparisons of some pipeline monitoring technologies and consequently the need to utilised wireless sensor network (WSN) in pipeline monitoring schemes owing to their ease of deployment and flexibility. Another, review work related to this is the work of Adegboye, Fung, & Karnik (2019). Here, the authors examined the strengths and weaknesses of selected monitoring technologies. Davis & Brockhurst

(2015) presented a pipeline monitoring technology selection framework that consists of three key stages. In stage one, failure pathway diagrams are designed to emphasis the issues and interactions resulting in deterioration and failure of subsea pipelines and related components in operation. In stage two, some monitoring technologies are noted. In stage three, a Multi-Criteria Assessment (MCA) procedure is employed to examined technologies against industry-agreed performance metrics. Utilizing the "the framework, a prioritised subset of high-value technologies" were identified to solve the following problems: corrosion, deformation, erosion, flow control, fatigue and blockage issues in underwater pipeline networks.

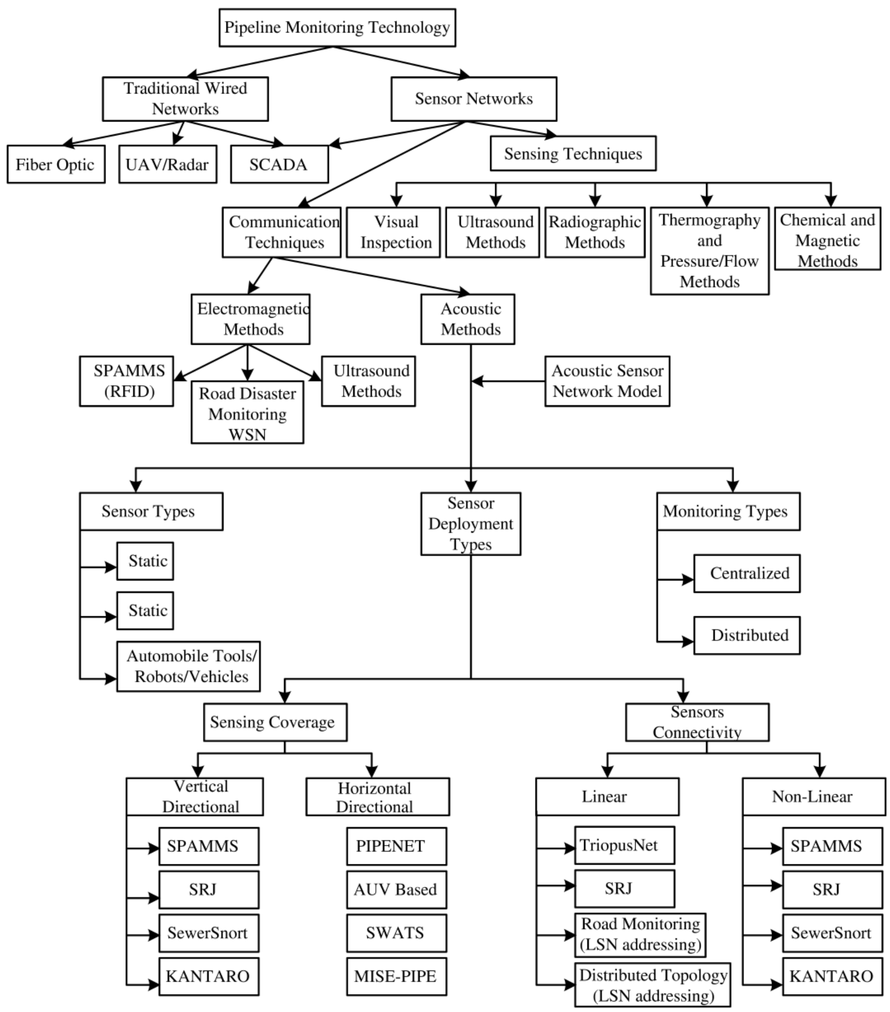

Figure 2: Classes of pipeline monitoring technology (Abass et al., 2018)

The technologies reviewed include a system based on fibre optics, ultrasound, wireless sensor nodes and Unmanned Aerial Vehicle (UAV).

Fibre Optics Based Monitoring Technologies

An approach to pipeline monitoring is corrosion detection and anticipated prevention using fibre-based systems (Ren et al., 2017 and Ren et al. 2018). Ren et al. 2017 came up with a novel non-destructive method to identify corrosion in pipelines. The authors think that pipeline corrosion will induce changes in the pipe's circumferential strain. The proposed detection technique was based on Fiber Bragg Grating (FBG) hoop-strain sensor, with the capability to observe the circumferential strain of a pipeline accurately. Tests were carried out on three steel pipes to determine the propriety of this technique in terms of accuracy and effectiveness. The obtained result indicated “that the FBG hoop-strain sensor has good performance in the circumferential strain measurement and is sensitive to the variation of the circumferential strain caused by different corrosion level”. In another research by the authors (Ren et al. 2018), an Optical Frequency Domain Reflectometry (OFDR) method was proposed to detect pipeline leakage and corrosion. By conception, OFDR is a technique that is utilized to analyse light paths and reflection characteristics in fibre optics. A collection of *optical fibre sensors* were bonded to the pipe surface with equal spacing for corrosion testing. Using the collection of *optical fibre sensors*, a *hoop strain* me was created to show the corrosion level and corrosion location

For leakage monitoring, Distributed Optical Fiber Sensors chanis (DOFS) were used by Ren et al. (2018), Ravet, Niklès & Rochat (2017) and Inaudi & Glisic (2010). Inaudi & Glisic (2010) observed that DOFS permit the remote observation “of 60 km of pipeline from a single instrument and of up to 300 km with the use of optical amplifiers”. The authors also presented several field applications DOFS in deformation, temperature monitoring along with detection of leakage pipelines used in conveying brine and gas pipelines. Ravet, Niklès & Rochat (2017) presented case studies of pipeline deformation monitoring using distributed fibre sensing in the Arctic, Siberian environment and the Andes. They showed evidence of early detection and location of subsidence, landslide, erosion and pipe deformation. And as earlier observed by Chen, Li, Liu & Jin (2010), the conventional methods of monitoring are not convenient to establish sensing network and realize automatic data acquisition, hence, the safety of long-distance oil and gas pipelines is seriously threatened. Therefore, a remote monitoring and early-warning system for landslides and associated pipelines are put forward by Chen, Li, Liu & Jin (2010) using fibre brag grating(FBG) sensors to monitor a huge slowly moving landslide and the pipelines affected by it in Sichuan Province. The station collected the deformation data during the Wenchuan earthquake successfully.

Wireless Sensor Networks Based Monitoring Technologies

Wireless sensor networks (WSNs) have seen applications in diverse fields such as structural health monitoring, precision agriculture and body sensor network. It has also been applied to pipeline monitoring owing to their cheapness, deployment ease and scalability (Jawhar, Mohamed & Shuaib, 2007, Owojaiye & Sun, 2013, Henry & Henry, 2015, Ehiagwina, Kehinde, Iromini, Nafiu & Punetha, 2018). The issues and challenges in the use of WSNs in the protection and monitoring pipelines were examined by Jawhar, Mohamed & Shuaib (2007). Jawhar and co further presented the architectural model, which can be used to provide both monitoring and control. The model included an overview of networking and routing protocols that can be used to provide the necessary communications. Owojaiye & Sun (2013) classified WSN "design issues into five different categories namely; sensing modality, power efficiency, *energy harvesting*, network reliability and *localization*". The authors examined the idea of cooperative communication for pipeline-monitoring sensor networks deployed in subsea environments and the utilization of sensor networks for monitoring underground pipelines. Anupama et al. 2014 proposed the development of a remote condition-based monitoring application for oil and gas pipelines using over 100 WSN motes along with the experimental protocols needed for the design of a cross-layered protocol stack for the application. The proposed protocol stack consists of routing, topology control, time synchronization, and media access control protocols. Meritorious features of the protocol stack are low energy consumption and low memory usage essential requirements in the development of WSN scheme. Henry & Henry (2015) noted that while there are several applications of the WSN across the globe, it has not been utilized in monitoring Nigeria's pipeline network despite the country facing regular pipeline vandalisation and oil spillage.

Ultrasonic Based Monitoring Technologies

Advancements in structural health monitoring (SHM) using ultrasonic guided waves (UGW) technology for metallic structures to support their integrity and maintenance management were described by Dhutti, Lowe & Gan (2019). These advanced technologies permit the inspection of pipes without downtime, and "generate diagnosis and prognosis data for condition-based maintenance, hence increasing safety and operational efficiency". Lee, Yang & Sohn (2012) proposed an optical fibre–guided laser ultrasonic system and baseline-free damage detection method useful in observing pipelines deployed in nuclear power plants characterised by high temperature. The authors developed optical fibres and fixing devices that will enable the laser beams employed for ultrasonic excitation and sensing could be transmitted between laser sources and target pipe surfaces through the optical fibres. This developed product was embedded on the pipe surface. Moreover, a monitoring scheme capable of noticing damage was designed to point out pipe deformations while not using previous baseline data.

The principle of Lee and co scheme was based on the fact "that multiple identical wave paths exist in an intact axisymmetric pipe, but the similarity among the ultrasonic signals obtained from these identical wave paths breaks down when there is a nonaxisymmetric defect". Yang, Li, Li & Lu (2012) explored the feasibility and reliability of ultrasonic monitoring system for pipeline corrosion in oil and gas field based on ultrasonic monitoring technology. In the report, a multi-crystal ultrasonic wave sensor was used to monitor the thickness of key points in the circumferential direction. Zhang, Huang, Zhao, Wang & Wang (2017) came up with "an Electromagnetic Ultrasonic Guided Wave (EUGW) long-term monitoring scheme for buried oil-gas pipelines and a data difference adaptive extraction method for the monitoring data". The T (0,1) mode guided wave was chosen owing to its non-dispersive feature. For the electromagnetic acoustic transducer, a circumferentially magnetized nickel strap is bonded on the pipe to provide the bias magnetic field and the excitation coils were wound on the nickel strap for magnetic field creation. A detection stub was then planted on the ground and the connector of buried coils was installed in the stub. The difference array was constructed and adaptive gain and attenuation were performed in the data difference adaptive extraction technique.

The EUGW long-term monitoring scheme was applied to the monitoring of the buried oil pipes in Jinan city, Shandong province, China. Guo, Chen, Zhang, Liew & Yao (2019) proposed a direct-write ultrasonic transducer, which consisted of piezoelectric polymer coatings deposited in-situ, crystallized and patterned on the pipe with the goal of monitoring. Then, Lamb ultrasonic wave signals propagating along the pipe structure were generated and measured by the direct-write transducers were used to monitor the health of the pipe. The system accurately determined defects and thickness of the pipe.

Unmanned Aerial Vehicles

Unmanned Aerial Vehicles (UAVs) are aircraft with that do not need a human pilot to be on board. The entire system consists of a ground control unit and wireless communication interface. Gómez & Green (2017) noted that Unmanned Aerial Vehicles (UAVs) technology can be a useful supplement to existing pipeline monitoring schemes. This is because portable UAVs are flexible and adaptable and with a demonstrated capacity to obtain valuable data at small to medium spatial scales. Systematic coverage of extensive areas are better completed with fixed-wing platforms and automatic flight design, whilst multirotor platforms provide flexibility in shorter and localized inspection missions. The type of sensor carried by an aerial platform determines the sort of data acquired and the obtainable information. Sensors also determine the need for specific mechanical designs and the provision of the required energy for the system. The authors went ahead to review UAV systems (see Figure 3) designed to monitor pipelines.

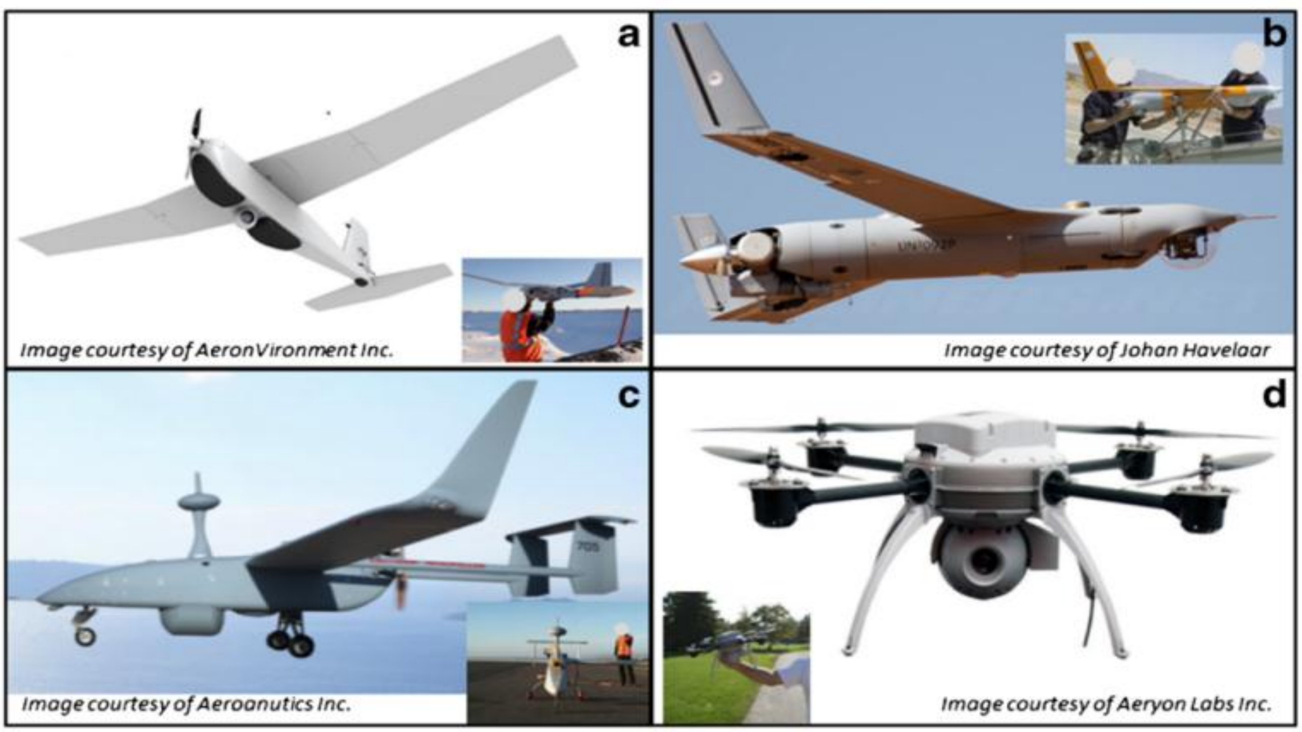

Figure 3: Platforms used in real monitoring cases. Insets are for size reference. (a) Puma™ AE (b) ScanEagle® X200 (c) Aerostar® (d) Aeryon Scout™ (Gómez & Green, 2017)

Kochetkova (2018) described the identification of pipeline leakage using UAVs. It was recommended spectral analysis be applied with input RGB signal to identify pipeline deformation and sabotage. The application of multi-zone digital images permitted the definition of a crude oil spill and soil pollution. “The method of multi-temporal digital images within the visible region” permitted the definition of variations in “soil morphology for its subsequent analysis”. The use of UAVs or Drones with Artificial Intelligence, IoT, Analytics, and other hardware and software tools will assist in monitoring pipelines located in rural areas or in the uninhabited areas which can make any type of inspection extremely difficult for operators of the pipeline (Marathe, 2019).

The integrated optimization of unmanned aerial vehicle inspection for oil and gas pipeline networks, including physical feasibility, the performance of mission, cooperation, real-time implementation and three-dimensional (3-D) space, is a strategic problem due to its large-scale, complexity as well as the need for efficiency (Yan et al., 2019). In the course of pipeline monitoring, there is the need to do an aerodynamic analysis of the UAV. Therefore, a Computational Fluid Dynamics (CFD) model for air velocity determination of the UAV was designed by Elvira-Hernández, López-Huerta, Vázquez-Leal, Hernández-Escobedo & Herrera-May (2020) to predict the UAV’s lift and drag coefficients, which depends on the angle of attack (AoA) and the Reynolds number. A quadcopter Unmanned Aerial Vehicle (UAV) system with remote sensors onboard for monitoring oil and gas pipelines was developed by Benyeogor, Olatunbosun & Kumar (2020). Two liquefied petroleum gas detectors were used as leakage detection. The Multiwii software was utilized to control, track and simulate the 3D movement of the UAV. A novel mixed-integer nonlinear programming model was proposed, which considered the “constraints of the mission scenario and the safety performance” of UAVs was developed by Yan et al. (2019). To reduce the overall length of the path taken during the inspection, the model was resolved through a two-stage solution method. Finally, a virtual pipeline network and a practical pipeline network were used to demonstrate the optimization methods performance.

Optimized Pipeline Monitoring Systems

Wan, Yu, Wu, Feng & Yu (2012) developed a “hierarchical leak detection and localization method for use in natural gas pipeline monitoring sensor networks”. The monitoring signals’ characteristic parameters and single-mode signals were extracted using wavelet transform technique. Then, a Support Vector Machine (SVM) based recognition scheme was constructed using the extracted parameters and signal and this was utilized for final decisions. Finally, a weighted average localization algorithm based on time difference of arrival was incorporated to determine the point of leakage. In

Pan, Xu, Li & Lu (2018), owing to the difficulties of installing sensors in underground pipelines, an acoustic emission sensor was initially proposed for collecting and analyzing leakage signals inside the pipeline. Four operating conditions of a fluid-filled pipeline were established and an SVM-based method was used to correctly classify the leakage condition of the pipeline. Wavelet decomposition and Empirical Mode Decomposition (EMD) methods were used in removing noise from the signals to address the problem in which original leakage acoustic emission signals contain too much noise. Signals with more information and energy are then reconstructed. The time-delay estimation method was subsequently employed to locate the leakage source in the pipeline with success.

Proposed Monitoring Framework Design

A monitoring framework is proposed using embedded systems and wireless communications and a combination of sensors to monitor the pipeline area. The framework should be able to detect intrusion into the pipeline area, pipeline leakage and alert the pipeline operator through Short Messages Service (SMS) and also take video and photo footage of the vandalism area. This will in a large way prevent vandalism and also protect the life of people around the pipeline. An overview of the required components is presented next.

Microcontroller: A microcontroller is a compact integrated circuit designed to govern a specific operation in an embedded system. A typical microcontroller includes a processor, memory and input/output (I/O) peripherals on a single chip. *Arduino Uno* shown in Figure 4 is a microcontroller board based on the ATmega328P (datasheet). It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analogue inputs, a 16 MHz ceramic resonator (CSTCE16M0V53-R0), a USB connection, a power jack, an ICSP header and a reset button.

Figure 4: A Typical *Arduino Uno.* Source: https://nirtjo.com/product/arduino-uno-r3/

Motion Sensor: A motion detector is an electrical device that utilizes a sensor to detect nearby motion. Such a device is often integrated as a component of a system that automatically performs a task or alerts a user of motion in an area. They form a vital component of security, automated lighting control, home control, energy efficiency, and other useful systems. A Passive Infrared (PIR) sensor shown in Figure 5 is an electronic sensor that measures infrared light radiating from objects in its field of view. They are most often used in PIR-based motion detectors.

Figure 5: PIR-based motion detectors. Source: https://store.steamledge.com/product/motion-sensor/

GSM Module: A GSM module or a GPRS module is a chip or circuit that will be used to establish communication between a mobile device or a computing machine and a GSM or GPRS system. Sim800l GSM Module: SIM800L GSM/GPRS module is a miniature GSM modem, which can be integrated into a great number of IoT projects. The Arduino was interfaced with the GSM module via RX port of module. The GSM module is for sending SMS when a pipeline leakage is observed. The GSM module is as shown in Figure 6.

Figure 6: Commercially available GSM module (Circuit Today, 2020)

Camera Module: A *camera module* shown in Figure 7 is an image sensor integrated with a lens, control electronics, and an interface like CSI, Ethernet or plain raw low-voltage differential signalling.TTL Camera: In photography, through-the-lens (TTL) metering refers to a feature of cameras whereby the intensity of light reflected from the scene is measured through the lens; as opposed to using a separate metering window or external hand-held light meter. Using the camera module, an intruder's image can be acquired for necessary security action.

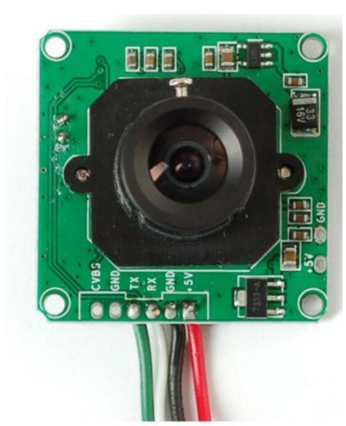

Figure 7: A *camera module.* Source: https://learn.adafruit.com/ttl-serial-camera

Gas sensor: A *gas detector* is a device that detects the presence of gases in an area, often as part of a safety system. The MQ-2 smoke sensor is sensitive to smoke and the following flammable gases: LPG, Butane, Propane, Methane, Alcohol, Hydrogen. The resistance of the sensor is different depending on the type of gas. The smoke sensor has a built-in potentiometer that allows you to adjust the sensor sensitivity according to how accurate you want to detect gas. MQ2 Gas sensor is shown in Figure 8. Through the gas sensor, crude oil fumes and liquified gas leakage from the pipeline can be detected.

Figure 8: MQ2 Gas sensor.
Source:https://robu.in/product/mq-2-mq2-smoke-gas-lpg-butane-hydrogen-gas-sensor-detector-module/

The proposed block diagram of the monitoring framework showing the interconnectivity of the main components is depicted in Figure 9.

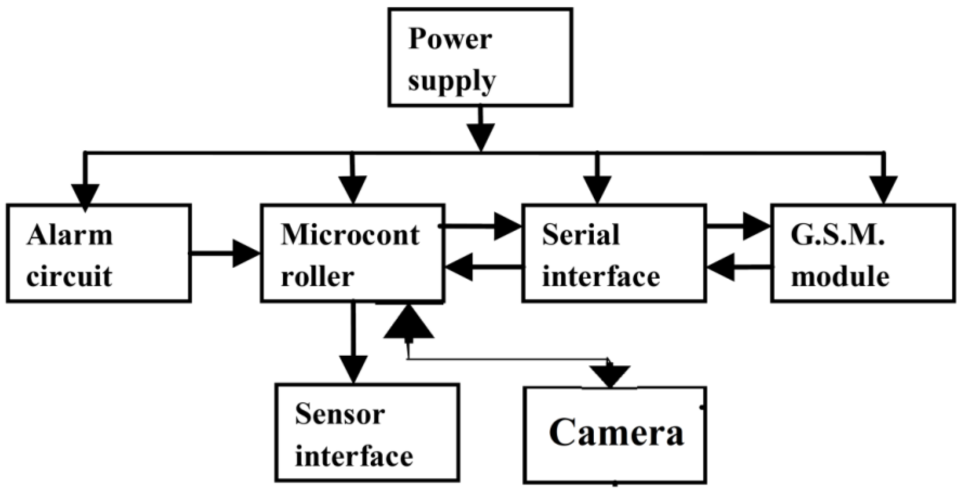

Figure 9: System block diagram

The Arduino Uno microcontroller is the brain unit of the whole project; it receives the signal from the Motion sensor when there is movement around the pipeline. The microcontroller also receives the signal from the smoke sensor, therefore if there is a movement or gas leakage along the pipeline the microcontroller will send a signal to the GSM to alert the pipeline operator.

Conclusion

This article has done a quick review of pipeline monitoring technologies based on fibre optics, ultrasound, wireless sensor nodes and Unmanned Aerial Vehicle (UAV). The review showed that pipeline monitoring is an active area of research. Nigeria needs to develop a technology-driven monitoring scheme for its network of pipelines to minimize or at the very best eliminate pipeline vandalism.

In this article, we have also proposed a framework based on GSM technology along with a combination of selected sensors for pipeline monitoring. With the use of this system, pipeline vandalism can be reduced drastically. We hope to physically realize the proposed design in the course of the on-going research.

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