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Mitigation of Oil Pipeline Vandalism Using Small-Satellites and Earth Observation Systems. A Case Study- Nigeria

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***Abstract**: Oil pipeline vandalization in Nigeria has led to: a shortage of petroleum product for end users; loss of life as a result of accompanied fire outbreak; pollution of aquatic life; and food crises in the nation. Recent studies show that the Nigerian government loses about 20 billion of dollars yearly as a result of the activities of pipeline vandals. This is aside from the monetary cost of loss of lives, property and the environment. In previous years, the main measure taken by the government to guard against pipeline vandalization was the deployment of security personnel to some of the areas that are prone to attack by vandals. However, this effort has failed to ameliorate the problem. In addition to the continued loss of revenue to the government, there have been cases of clashes between security personnel and members of the community. There are also allegations of security personnel aiding and abetting the vandals. In this paper, we propose a cost-effective technique for resolving the challenge of oil pipeline vandalism using Earth observation systems (small Satellites) in the Low Earth Orbit. The constellation of these Satellites (CubeSats) is relatively cheap, has short development time and can provide 24/7 real-time surveillance throughout its lifetime.*

***Keywords:** Small Satellite, CubeSat constellation, Oil pipelines vandalism, Oil spillage*

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I. INTRODUCTION

Since the discovery of petroleum products in commercial quantities in 1956 at the Oloibiri oil-field in the present day Bayelsa State, crude oil has continued to play a vital role in the economy of Nigeria, contributing about 90 per cent of the gross earning of the country [Adewole, 2013]. A significant quantity of the nation's oil is produced onshore, although the industry recently witnessed an increase in offshore oil production [Nwachukwu, 2013]. Offshore oil production has equally increased the rate of oil theft and the activities of vandals. Currently, it is estimated that Nigeria loses about 20 billion dollars yearly due to the nefarious activities of vandals and lost about 5 billion dollars, worth of product theft between 2009 and 2012 [Nwachukwu, 2013]**.**

Till date, the oil and gas industry has continued to suffer from pipeline vandalism both in the upstream and downstream operation. According to the former Group Managing Director of the Nigerian National Petroleum Cooperation (NNPC), Mr Andrew Yakubu, the pipeline traversing from Atlas Cova, Lagos to Ilorin, Kwara State, popularly called system 2B, experienced about 774 breakpoints in 3 months (August-October, 2012); Atlas Cova and Mosimi depot in Ogun State had about 181 break points; Mosimi to Ibadan, Oyo State, experienced also about 421 break points. Mosimi to Ore in Ondo State likewise experienced about 50 break points, and Ibadan to Ilorin had about 122 break points. All these were due to vandal activities [Nwachukwu, 2013]**.** This has led to the untimely exit of some oil companies from the oil-producing regions; this, in turn, has affected the economy of the country at large. Studies also reveal that there were fire outbreaks in most cases, which led to the burning of several buildings and loss of human lives. No industry can succeed under such sabotages.

In previous years, the main measure taken by the government to guard against pipeline vandalization and oil theft was the establishment of various legislative frameworks to govern the petroleum industry. These include: the Federal Environment Protection Agency Act, 1990; National Oil Spillage Detection and Response Agency Act, 2006; National Emergency Management Agency, Ministry of Niger Delta, among others. Currently, security personnel who work based on tip-offs monitor oil spillage and theft manually. In areas that are prone to frequent attack by vandals, high surveillance towers have been erected and Circuit Cable Television

(CCTV) installed on jetties, for monitoring of the areas [Nwachukwu, 2013]. However, this effort has failed to ameliorate the problem because the security personnel often get to vandalized areas hours after the vandals must have broken the pipelines. In a few (un)fortunate cases, the vandals are arrested, detained or even prosecuted, but this has not deterred them from making further attempts.

An Affordable Pico-satellite-based Oil-pipeline Surveillance System (APOSS) can provide continuous/ daily surveillance on the oil pipeline networks from the vandal activity. The reach of the system is as large as a 5000 km vast network of an oil pipeline across Nigeria.

II. LITERATURE REVIEW

2.1 Earth Observation Satellites

Many years ago, the great philosopher, Socrates, stated that "humankind must rise above the Earth – to the top of the atmosphere and beyond - for only thus will he fully understand the world in which he lives." Since man could not permanently live above the Earth, he has developed 'eyes in the sky' with which he uses in his pursuit to understand his world. These 'eyes in the sky' are known as satellites.

There are many uses and applications of satellites. The satellites that are used to monitor and study the Earth are called Earth-Observation satellites. Earth Observation satellites are also used to monitor the resources, infrastructure and on-going activities on the Earth.

2.2 Small-Satellite Technology

Considering the cost and time involved in the design and development of satellites, in 1998, at the University Space Systems symposium held in Hawaii, Professor Bob Twig from California Polytechnic State University proposed the development of much smaller satellites called CubeSats [Twiggs, B., 2010]. His proposal was hinged on the need to enable students to experience all the processes involved in the design, development and operating of a satellite. Since then, University students and countries that do not have many funds have designed and launched these systems for different science missions.

Each of this Satellite has a dimension of 10 x 10 x 10 centimetre and a mass that is less than 1.5 kg, according to the standard developed by California Polytechnic State University [Twiggs, B., 2010]. One of the driving philosophies of this class of satellite (Pico-Satellite) design is the use of standard, easy to use commercial off the shelf components designed for non-space applications; this allows for fast and inexpensive construction, reducing satellite complexity and further shortens the development process.

In 2004, with its relatively small size, Pico-Satellite could be developed and launched for an estimated sum ranging from 65,000 - 80,000 dollars [Leonard, 2004]. This price tag, which is far lower than most Satellite launches, has made Picosatellites a viable option for Universities across the World to have access to space [Twiggs, 2010]. Presently, and as a result of its small size and weight, several CubeSat are mounted (piggyback), as secondary payloads onboard a rocket launching a big satellite to low earth orbit, this will greatly reduce the launch cost of APOSS constellation.

2.3 Using Small-Satellites for Earth Observation

Most small satellites are located within the Low Earth Orbit. Equipped with sensitive sensors, these satellites have the ability to view the Earth with a very high resolution; hence most of the current CubeSats in operation are used for Earth observation. Applications include monitoring of atmospheric conditions for weather forecasting, ocean monitoring, land use/land cover mapping, among others.

The use of small satellites has equally helped hitherto non-spacefaring nations to be able to participate in space activities. In some cases, the owners (mostly universities) were able to create start-up companies from the initial endeavour. Examples are South Africa, where the University of Stellenbosch designed and launched 'SunSat' and then established SunSpace (Spaceteq). Also, University of Surrey established Surrey Satellite Technology Limited (SSTL) after the success of her first CubeSat series.

III. APOSS SYSTEM DESIGN

3.1 System Architecture

The system is made of two segments - the space segment and ground segment. The space segment consists of a constellation of 12 satellites (plus 2 spare satellites) orbiting at about 600km above the Earth. This is shown in Figure 1. This orbital plane and height were chosen in order to avoid the Van Allen inner belt, mitigate drag perturbation and atomic oxygen damage. This location also facilitates ease of deployment and would cover the entire geographical area of the country.

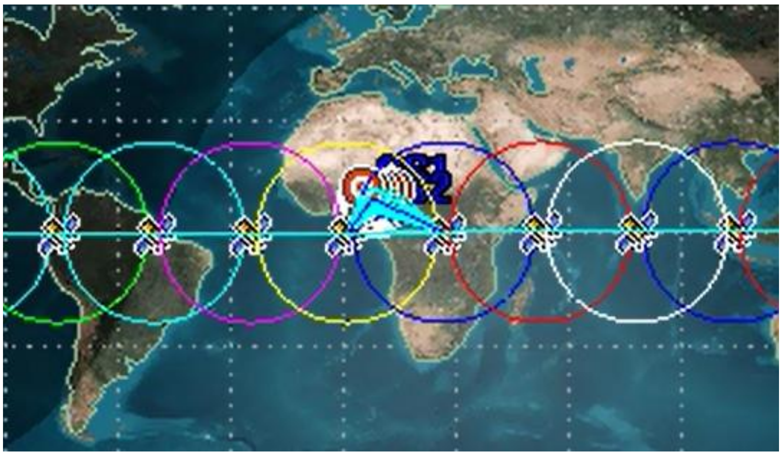

Figure 1: The Space based segment (Simulation using STK-AGI 2009)

The ground segment consists of about 3400 nodes called Ground Terminal Nodes (GTN). Each node is made up of crash/vibration sensor; transmitter/transceivers, Global Positioning System (GPS) chip and power pack. Figure 2 shows the black-box node location on the pipeline.

Figure 2: The ground segment

3.2 Mode of Operation

The ground segment will use the same principle of operation as a car airbag system. When designing this system, the elastic strength of the materials used for oil pipeline will be used to program the crash/vibration sensors such that as soon as the resistance threshold of the pipeline is exceeded, the transceiver automatically transmits the GPS coordinates of that location to the 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. Figure 3 shows a screen that highlights the location of an illegal activity on the oil pipeline. The section marked bold red-star shows the ongoing vandal activity spot.

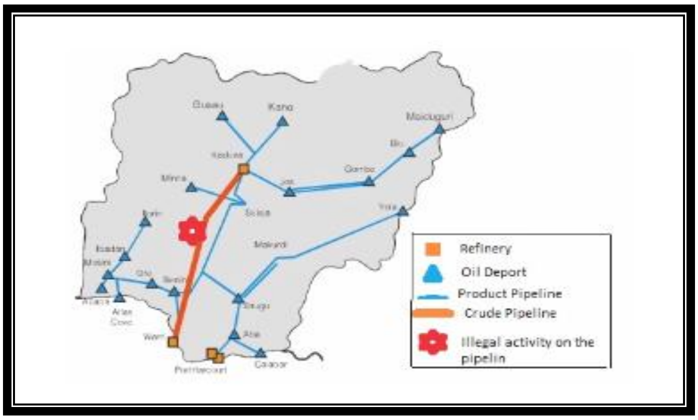

Figure 3: Ground Station (GS) screen showing illegal activity on the oil pipeline

APOSS will be able to provide real time surveillance on the oil pipeline network across the nation. This could be achieved by installing the GTN units at regular intervals (about 150 meters apart) on the pipelines. The GTN would detect any impact made by vandals to the ground station (host terminal) from where the information will be transmitted to the security personnel via the space segment for a quick response to salvage the situation.

In order to ensure that the system would work as expected and to avoid false alarm, the degree of unnatural impact that would make these oil pipeline to buckle will be considered when designing the sensor, such that the sensor would only send information when the impact is about to exceed certain values. Figure 4 shows APOSS network over the country.

Figure 4: APOSS network acquiring data from its GTN (Simulation using STK-AGI 2009)

3.3. Maintenance

The APOSS system would require minimal maintenance and servicing, apart from the one-time installation/calibration of the ground sensor networks. This will reduce the needed cost for sending experts to remote areas where these pipelines are located.

3.4 Cost Analysis

The cost model used for this study is based on Jos H. 2009 and Chris E. 2000 analysis. Table 1 shows a summary of the total cost for hardware and deployment cost for the APOSS systems

Hardware		**Cost**
Satellite (1U)	Development and launch	~ $70,000 per unit
	Total unit required (14)	~ **$980, 000**
Ground Sensor Network (GTN)	Development and deployment of the field	~$1000 per unit
	Total unit required (34,000 placed at 150m interval)	~ $34M
	Total one-time cost	**$34,980,000. 00**

In 2014, the Federal Government of Nigeria spent about six billion Naira (approximately $30 million) in contracts for the monitoring of pipelines [wall street journal]. Again, in 2011, the government also spent about fifteen billion Naira (approximately $75 million) for the same purpose [Isine, 2014].

Whilst the lifespan of the satellite constellation is proposed to be three (3) years, the one-time cost for the whole system will be approximately $35 million. Thus, APOSS system will cost the government approximately $35 million for development, installation and maintenance for 3 years, which is less compared to what the nation lost yearly (economy, environmental degradation and associated death) as a result of vandal activities on the oil pipelines.

IV. CONCLUSION

This paper highlights a novel strategy for monitoring of oil pipelines across the country. The space segment consists of low-cost, affordable small-satellites. The ground segment consists of a network of sensors that send signals to a control station when there are attempts to break the pipeline. This system is cost-effective, requires less manpower and ensures an accurate and prompt response to attempts of pipeline vandalisation.

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