Development of an Aerial Robotic Oil Spill Surveillance (AROSS) System for Constant Surveillance and Detection of Spills from Crude Oil Pipelines

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Development of an Aerial Robotic Oil Spill Surveillance (AROSS) System for Constant Surveillance and Detection of Spills from Crude Oil Pipelines

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Abstract: Ejofodomi OA, and Ofualagba G. (2016). Development of an aerial robotic oil spill surveillance (AROSS) system for constant surveillance and detection of spills from crude oil pipelines. *International Journal of Unmanned Systems Engineering*. ***4***(2): 19-33. Current crude oil spill detection methods can only be employed intermittently and do not detect spills at their onset. The Aerial Robotic Oil Spill Surveillance (AROSS) System is a novel system that addresses this limitation. A single AROSS system is a 550 mm x 550 mm quadcopter weighing 1.5 kg. Autonomous navigation of the system is achieved using a GY-521 gyrometer, BM085 Altimeter, HC-SRO4 ultrasound sensor, and Global Positioning System (GPS) module. Spills emanating from crude oil pipelines are detected using MQ gas sensors. An LS-Y201-Infrared camera is used to capture images of the spill site. Xbee Pro 900HP modules establish wireless connection between the system and the base station up to 45 km away for transmitting spill data to surveillance teams. The AROSS system was tested on a 100 m section of an underground crude oil pipeline in Effurun, Nigeria. The threshold voltage for spill detection by the gas sensor was determined experimentally to be 2.93 V. The system successfully detected 1 liter crude, which corresponded to an output voltage of 2.95 V. Spill GPS location and images were remotely transmitted to a manned base station 100 m away from the pipeline. The AROSS system has the ability to provide autonomous and constant surveillance for crude oil pipelines, detect spills as soon as they occur, and inform the appropriate authorities.

Keywords: Aerial robotics, Crude oil spills, Oil spill detection, Pipeline surveillance.

I. Introduction

Accidental and intentional spills from crude oil pipelines are disastrous occurrences that have plagued oil-producing countries for decades. In the United States, 217 spill incidents were reported and 43,662 barrels (6,942,258 liters) spilled in 2007 [1]. In Canada, 133 spill incidents were reported to the

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Transportation Safety Board of Canada for federally regulated pipelines in 2014 [2]. The Niger Delta region of Nigeria is considered to be one of the most severely petroleum damaged ecosystem in the world [3]. The Department of Petroleum Resources of Nigeria reported a total of 871 spill incidents and 15,552.18 barrels (2,472,796.6 liters) of oil released into the environment in 2012 [4]. In 2015, Shell Petroleum Development Company (SPDC) alone reported a total of 131 spill incidents in this region, and 17,700 barrels (2,814,300 liters) of oil was released into the environment [5].

The causes of crude oil spills in Nigeria are due to pipeline corrosion, vandalization, sabotage/theft, or operational failure. Vandalization is the destruction of pipelines by members of the communities adjacent to oil producing facilities because of their neglect by government and the oil companies. Sabotage is the damage of oil pipelines by saboteurs to steal oil. Pipeline corrosion is due to poor pipeline maintenance by oil companies and pipelines outliving their estimated lifespan. Of the 2,700 spill incidents reported by Nigerian National Petroleum Company in 2014, 3,668 were due to vandalization and 32 to pipeline rupture. Of the 131 spill incidents reported by SPDC in 2015, 120 were due to sabotage/theft, 17 to operational failure and 4 to others [5].

While the causes of crude oil spills may be operational in nature or due to sabotage and theft, the effects of oil spills are always disastrous to the environment, health, society and economy [3, 6-7]. Figure 1 shows images from the 2010 Deepwater horizon oil spill, which is considered to be the largest accidental marine oil spill in the history of the petroleum industry.

(a) (b)

Fig.1. (a) 2010 Deepwater Horizon oil spill in the Gulf of Mexico as seen from space by NASA's Terra satellite on 24 May 2010. (b) A worker cleans up oily waste on Elmer's Island just west of Grand Isle, La., May 21, 2010 [8]

Spillage rate and volume are key parameters in determining the severity of the consequences of the spill. A 1% increase in spill size raises damage incurred by about US$ 718,000 [9]. The impact of a spill is also affected by its location. When a spill occurs in water or offshore, contact and ingestion of spilled oil leads to contaminants in tissues, impacts to immune functioning, cardiac dysfunction, mass mortality of eggs and larvae, and the loss of buoyancy and insulation for birds [10-12]. When the spill occurs on land, its effects include contamination of ground water, loss of biodiversity in breeding grounds, vegetation hazards, loss of portable and industrial water resources, reduction in fishing and farming activity, poverty and rural underdevelopment [13].

Inhalation, dermal contact, and ingestion of the constituents of spilled crude oil possess acute and long-term health implications, including headaches, fatigue and lethargy, eye, nose and throat irritation, loss of concentration and co-ordination, dizziness, nervousness, insomnia, nausea, vomiting, visual disorders, drowsiness, depression, heightened anxiety, skin rashes and sores, respiratory disorders, and even cancer [7,12,14-18].

Environmental degradation due to spills result in internal displacement of communities in the Niger Delta, diminish productivity of farming and fishing in communities, and cause occupational and income losses [6,19–23]. Other social consequences include poverty, malnutrition, diseases, unclean water, little electricity, abysmal health care, unemployment, underemployment, proletarianisation, and rural-urban migration [20,24-25].

Loss of crude oil due to spills results in decrease in a nation's revenue. In 2002, Nigeria lost about ₦7.7 billion because of pipeline vandalization [26]. In 2014, 1,008,805 barrels (160,400,000 liters) of crude oil were lost from Nigeria's pipelines, resulting in a loss of ₦ 14,846,710,000 [27]. Compensatory damages to the community for disruption and degradation of their society and environment can result in losses that run in the millions. For instance, SPDC agreed to pay US $83 million in compensation to the Bodo Community in the Niger Delta for just two oil spills in 2008 [28-29]. This clearly reveals that there are currently no adequate means of detecting oil spills at their onset. If oil companies and governments are able to detect spills as soon as they occur, and take immediate action, there would be minimal damage to the environment and remediation and compensatory expenses would be drastically reduced.

There are many methods currently employed to detect crude oil spills. These include visible, ultraviolet, near infrared, mid-band infrared, thermal infrared, microwave and radar sensors. Visible sensors are passive sensors that function within the visible region of the electromagnetic spectrum. They are cost-effective, easily mounted on aircraft for airborne remote sensing, but cannot be used at night and cannot easily distinguish oil from the background [30-32]. Infrared sensors use emitted infrared radiation to detect spilled oil in water, can be used day and night, but suffer from false detection [32-33]. Ultraviolet sensors use reflected ultraviolet radiation to detect spills in water, operate only in daylight and are also susceptible to false detections [30-32].

Radar sensors use reflected radar radiation to detect oil spills in water and they can work both in inclement weather and at night. The two most common types of radar are Synthetic Aperture Radar (SAR) and Side-looking Airborne Radar (SLAR). SAR has superior spatial resolution and range and is used for space-borne oil spill detection [33]. SLAR is cheaper and used for airborne remote sensing. However, the presence of organic substances in the water results in false spill detection, and the efficiency of these sensors are highly dependent on wind speed. Microwave sensors use emitted microwave radiation to detect oil spills in water, work well in adverse weather conditions and are operational day and night. These sensors are costly, prone to false detection, complicated to use, have low spatial resolution, and require special antennae and dedicated aircrafts [33].

Laser fluorosensors are active sensors that use emitted visible light given off by objects that have absorbed ultraviolet radiation from a laser source to detect oil spills in water. They are the only sensors among those already mentioned that can detect oil spills in the presence of snow or ice [33-34], and can be used day and night. However, they require good visibility conditions to function properly. These sensors are usually mounted onboard an aircraft, such as the Scanning Laser Environmental Airborne Fluorosensor (SLEAF) [35]. Unfortunately, they require too much electrical power which is limited aboard an aircraft, and the resulting ground geometric resolution is low.

Satellite remote sensing involves utilizing sensors on a space-based platform, such as SAR. Attempts have been made to replace airborne sensing with space-based sensing, but not many of the sensors listed above can be used in space. Secondly, satellite remote sensing requires a clear sky and good weather conditions. Another issue is frequency and timing of the overpass. For instance, SAR Satellite images were not available in the first week of the Sea Empress oil spill in the United Kingdom [33,36]. It also takes a long time to process the information acquired from space-based platforms.

Majority of the spill detection methods detailed so far are primarily utilized in marine environments. There is currently no relatively inexpensive system capable of providing constant and total surveillance over regions that are susceptible to oil spills, especially for land oil spills. Detection, mapping and monitoring are problematic in regions like the Niger Delta because of canopy cover, cloud cover, inaccessible nature of the ecosystem, and insecurity [37]. There are two ways in which oil companies in the Niger Delta establish a spill has occurred: a drop in pipeline pressure or physical surveillance by staff or contractors. Most spills in this region are reported by surveillance contractors who live in the community or by members of the community [38].

Pipeline pressure loss in itself would not alert companies to all leaks. Surveillance of the right of way (the land area around pipes and other infrastructure), by local/public contract, or company personnel, to visually identify an oil release is more likely to be successful than any other release detection method [38]. If a spill is very close to a community it may be noticed immediately. However, if the spill is far from communities, or if it is in water or swamp, then a spill can flow for days before being noticed.

A new approach has been proposed to provide constant and complete surveillance for crude oil pipelines in land and swampy regions, called the Ground Robotic Oil Spill Surveillance (GROSS) System. This method involves the use of small autonomously programmed mobile robots to patrol beside sections of the pipeline. Spills as little as 0.2 liters can be detected with this approach [39]. The GROSS system is inexpensive, and a single unit has the ability to continuously check for spills emanating from 100 m of a crude oil pipeline every four minutes. Multiple units can be employed to expand the surveillance range of the system, resulting in a network of autonomous systems that report directly and immediately to the surveillance team in a control room [39]. None of the other spill detection methods mentioned in this paper are capable of providing continuous real-time surveillance for crude oil pipelines, and neither are they capable of detecting spills as little as 0.2 liters. Certain terrains may prove to be too difficult for these robots to traverse, such as swampy regions [39].

This paper presents the initial design, development and implementation of a low cost Aerial Robotic Oil Spill Surveillance (AROSS) System for constant surveillance and detection of spills from crude oil pipelines. Similar in principle and operation to the GROSS system, it shares all the promising advantages demonstrated by the GROSS system. However, since this system is designed with an airborne platform, it is less susceptible to physical tampering, and able to traverse swampy terrain that may prove too difficult for the GROSS system.

II. METHODS

Materials

1. Chassis

The frame for the system needs to be durable, sturdy and have sufficient space to incorporate all sensors and modules. The chassis of the AROSS system was made from carbon fiber, extremely durable and light weight, 550 mm x 550 mm in size and weighs about 460 g. Power supply was provided by an 11.1 V 3200 mAh Lithium Polymer battery. After mounting all the required accessories, sensor and modules, the total weight of the system was approximately 1.5 kg.

2. Brushless Motors

Four brushless motors were used to convert the battery electrical power to mechanical power to spin the propellers for system flight. Each motor was mounted on a quadcopter arm and fastened with screws and nuts.

3. Propellers

Four propellers (a clockwise pair and anticlockwise pair), 10 x 5 inches, were mounted on the four brushless motors. Care was taken to ensure the propellers were securely fastened to the motors to prevent them from slipping off mid-flight.

4. Electronic Speed Controllers (ESC)

Electronic Speed Controllers (ESC) are used for varying the speed of electric motors. Four ESCs were connected to the onboard Lithium Polymer battery. Each ESC was connected to a motor. By varying the values sent to each ESC, the AROSS system can be autonomously programmed to take off, fly forward, backward, left, right, up, or down.

5. Development Board
The development board used to program the AROSS system to perform autonomous pipeline surveillance was the Arduino Uno Rev 3.

6. Gyrometer
The GY-521 Gyrometer was used to stabilize the AROSS system during take-off, aerial patrol of the crude oil pipeline and landing. It is capable of providing acceleration, orientation, and gyrometric data for the AROSS system in 3-axis.

7. *Altitude Sensor*
The sensor used to determine the barometric altitude of the AROSS system was the BMP085. This was important because the system was autonomously programmed to fly to a certain altitude before commencing pipeline surveillance.

8. Global Positioning System (GPS)
The GPS used for system tracking assisted in two important functions carried out by the AROSS system. First, when the unit detects a spill, the GPS module is used to acquire and transmit spill site location to the surveillance team. Secondly, in between patrols, the GPS location is used to determine and alert the surveillance team if physical tampering occurs.

9. Xbee
A pair of Xbee Pro 900HP wireless modules helps establish wireless communication between AROSS system and host PC at remote base station. With a 2.1 dB antenna, this module can establish a wireless connection between the AROSS system and host PC up to a distance of 15.5 km. With a high gain antenna, this distance increases to 45 km. This wireless connection is used to relay the GPS location and images of detected oil spill sites to the remote PC of the surveillance team. The Xbee is mounted on an Xbee shield, which is stacked on the Arduino Uno (Fig. 2).

(a) (b) (c)

Fig. 2. (a) Xbee Pro 900HP on Xbee Shield stacked on Arduino Uno. (b) First Xbee connected to host PC at remote station. (c) Second Xbee mounted in AROSS system.

10. Ultrasound Sensor
The HC-SRO4 is an ultrasound sensor used for obstacle detection and avoidance and was mounted on the front of the AROSS system. If system detects an obstacle less than 35 cm in front of it during flight, it takes a detour route to avoid the object before continuing along its patrol route.

11. Oil Spill Detector
The primary method by which the AROSS system detects oil spills is through gas sesnors. When an oil spill occurs, methane is released into the environment. This unnatural increase

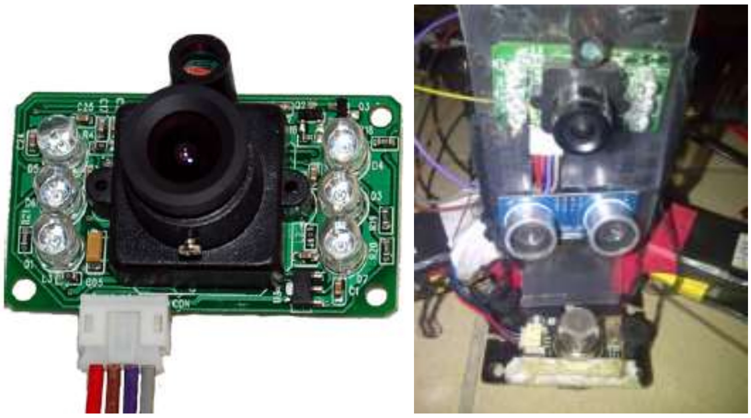
in methane is detected by the tin oxide (SnO_2) layer in the sensor, and is reflected in its output voltage. The sensor was mounted in front of the AROSS system to ensure close proximity to the ground for quick detection of crude oil spills (Fig. 3).

(a) (b)

Fig.3. (a) Gas sensor. (b) Sensor mounted in front of AROSS system.

12. Camera

The LS-Y201-Infrared camera (Fig. 4a) captures high resolution pictures, and is operational day and night. Fig. 4b shows the camera mounted on the AROSS system. When the system detects an oil spill, it stops and takes a picture of the spill site. This 320 x 240 image is transmitted wirelessly to the surveillance team in 10 seconds. Figs. 4c, d, and e show an image captured by a high resolution digital camera, the same image captured by the LS-Y201-Infrared camera during day, and at night, with virtually no difference between the daytime and nighttime images.



(a) (b)

Fig. 4: (a) LS-Y201-Infared camera. (b) Camera mounted on AROSS system.

(c) (d) (e)

Fig. 4 (cont.): (c) High Resolution Image captured by digital camera. (d) 320 x 240 image captured by LS-Y201-Infrared camera in daytime. (e) 320 x 240 Image captured by LS-Y201-Infrared camera at night [40].

Procedures

The operation of the AROSS system is shown in Fig. 5. When the system is initialized, it obtains the GPS location of its current position and the start and end points of the pipeline section it is assigned to, as well as its orientation using the GPS module and gyrometer. It goes up to a predetermined height and then slowly flies beside the pipeline, while simultaneously checking for crude oil leakage using the gas sensor. If system detects a spill, it stops and takes pictures. Images and GPS location of the spill are sent wirelessly to host PC at the base station. If the system detects an obstacle less than 35 cm in front of it, it takes a detour route.

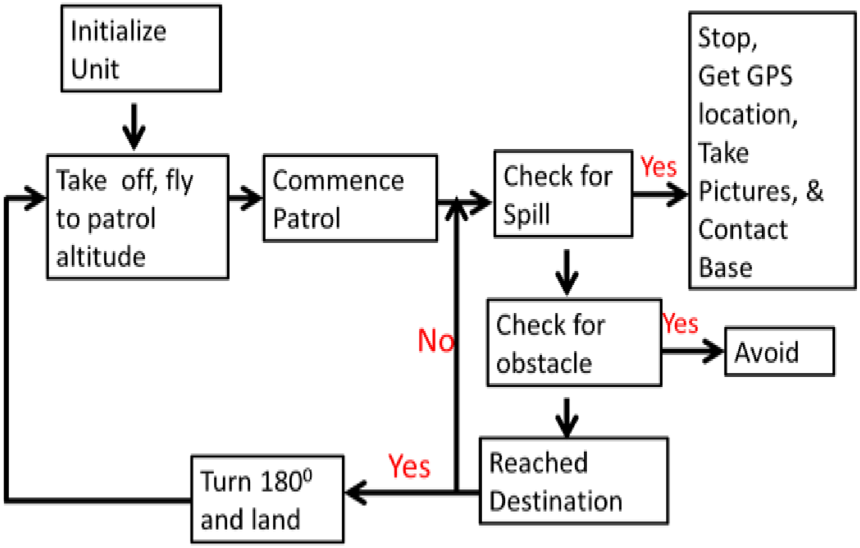


Fig. 5. Operation of the AROSS system.

After successfully patrolling the pipeline, the unit stops, turns 180^0, lands, and waits for a predetermined time interval before taking off to patrol in the opposite direction. In between pipeline patrol, the system continuously checks its GPS location, to determine if it has been physically tampered with. When this happens, the system wirelessly issues warning messages containing its current GPS location to the host PC at the remote base station to alert the surveillance team.

Test Procedure

The AROSS system was programmed to provide constant autonomous surveillance for 100 m of an underground pipeline in Effurun, Nigeria. While the system can provide constant surveillance for distances greater than 100 m, smaller distances translate to quicker detection of spills due to corrosion and vandalism. Multiple AROSS systems can be employed to provide constant surveillance for distances greater than 100 m. Time interval between patrols was set to 1 hour. Therefore every hour, the AROSS unit patrolled the 100 m pipeline section. This time interval can be reduced to provide continuous surveillance for pipelines highly susceptible to vandalism. Approximately 1 liter of crude oil was placed along the surveillance route to determine if the system was capable of detecting the simulated spill during its patrol. Fig. 6a shows the AROSS system commencing patrol of the 100 m pipeline section. Fig. 6b shows the unit along the 100 m stretch, having detected the simulated oil spill placed mid-point of the surveillance route. The remote PC with the receiving Xbee module was located in the base station approximately 100 m away from the surveillance route (Fig. 6c). For practical real-life industrial application, this distance can be increased up to 45 km. In between patrols, the unit was physically picked up and carried away from its surveillance route to test the system's ability to detect and alert the surveillance team if it has been physically tampered with.

(a) (b) (c)

Fig. 6. (a) AROSS system patrolling 100 pipeline surveillance route. (b) AROSS system detecting presence of 1 liter crude oil spill along surveillance route. (c) Host PC at remote base station 100 m away from surveillance route.

III. Results

This section presents data obtained from field tests carried out on the AROSS system. The fully constructed system is shown in Figure 7a. Three major tests were carried out to verify the system's effectiveness in crude oil spill detection: the system's ability to detect crude oil spills emanating from the pipeline section it was programmed to provide surveillance, the system's ability to transmit spill data to surveillance team at the base station, and the system's ability to detect when it has been physically tampered with and to alert the surveillance team when this occurred.

A. Oil Spill Detection

The most important ability of the AROSS system is detection of spills emanating from crude oil pipelines. Crude oil spills were simulated along the surveillance route. Approximately 1 liter of crude oil was poured generously over a large polythene bag and placed along the surveillance route of the AROSS system (Fig. 7b) to ensure that crude oil was not spilled into the testing environment. Fig. 7c shows the AROSS system during patrol approaching and detecting the spill via methods described above. This test verified the ability of the system to detect crude oil spills as little as a single liter. Previous tests have shown the sensor has the ability to detect 200 ml spills.

(a) (b) (c)

Fig. 7. (a) Fully constructed AROSS System (b). Simulated crude oil spill placed along surveillance route of the AROSS system. (c). AROSS system successfully detecting 1 liter crude oil spill. The unit stopped and acquired GPS location and image of spill site.

Fig. 8 shows the graphical data of the output of the oil spill detector as the system approached the simulated crude oil spill during pipeline surveillance. The output value of the detector ranges between 0 and 1023 (0-5 V). The threshold value for crude oil spill detection was determined experimentally and set to 600 (2.93 V). As shown in Fig. 8, the output value of the detector increases as the system approaches the simulated crude oil spill. Only when the output value of the system exceeds the preset threshold (2.95 V for Data point 5) does the system detect the presence of the crude oil spill.

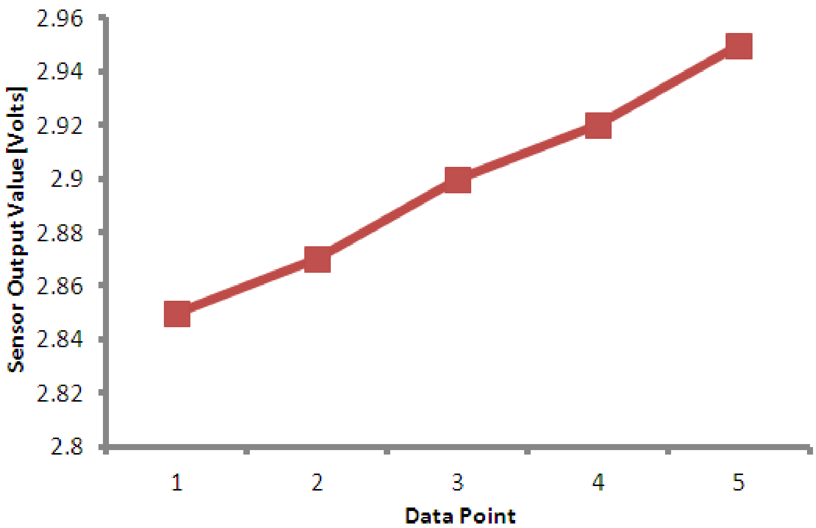


Fig. 8: Gas Sensor Output of Oil Spill Detection during Pipeline Surveillance

B. Oil Spill Data Acquisition and Transmission

After spill detection, the system is expected to acquire the GPS location of the spill and take pictures of the spill site. This data should then be transmitted wirelessly to the host PC of the surveillance team at the base station. Figure 9a is a screenshot of the host PC at the base station. The information shown was wirelessly received from the AROSS system after detecting the oil spill shown in Fig. 7b. The red arrow indicates the latitude and longitude of the spill. The acquired latitude and longitude of the spill site was 5.522390 and 5.820580 respectively. The blue arrow indicates the image data of the camera picture. Figure 9b shows the captured spill image sent to the host PC. The red arrow indicates the simulated oil spill contained within the clearly visible polythene bag. After alerting the surveillance team to the presence of the spill, the AROSS system resumed its patrol of its assigned surveillance route.

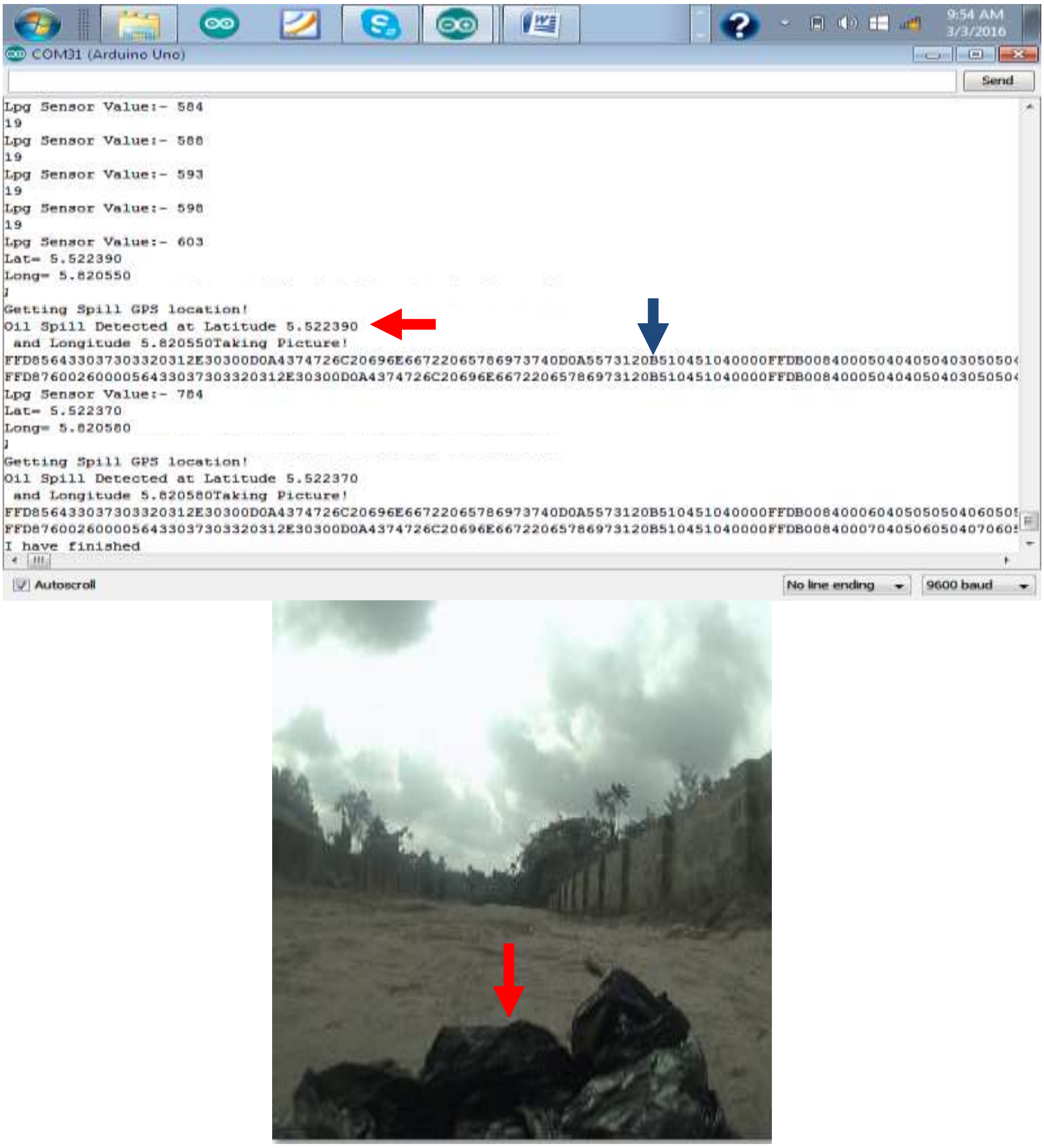


Fig. 9. Wirelessly transmitted spill GPS location and image data sent to host PC (top). Captured oil spill image sent to the host PC (bottom).

C. Tampering Detection

It is difficult to physically hold the AROSS system when it is in flight, as the spinning motors and propellers can inflict severe damage to humans. Therefore, in between patrols, the system was physically picked up and carried away from its assigned route. Figure 10a shows the AROSS system being physically transported to a location beyond its surveillance route. The GPS latitude and longitude of this new location was 5.522450 and 5.820470 respectively. As soon as its current GPS location went beyond its surveillance route, the AROSS system wirelessly issued warning messages containing its current GPS location to the host PC at the remote base station, alerting the surveillance team that it had been physically tampered with (Fig. 10b). The red arrow in Fig. 10b indicates the warning message and current GPS location sent by the AROSS system to the host PC.

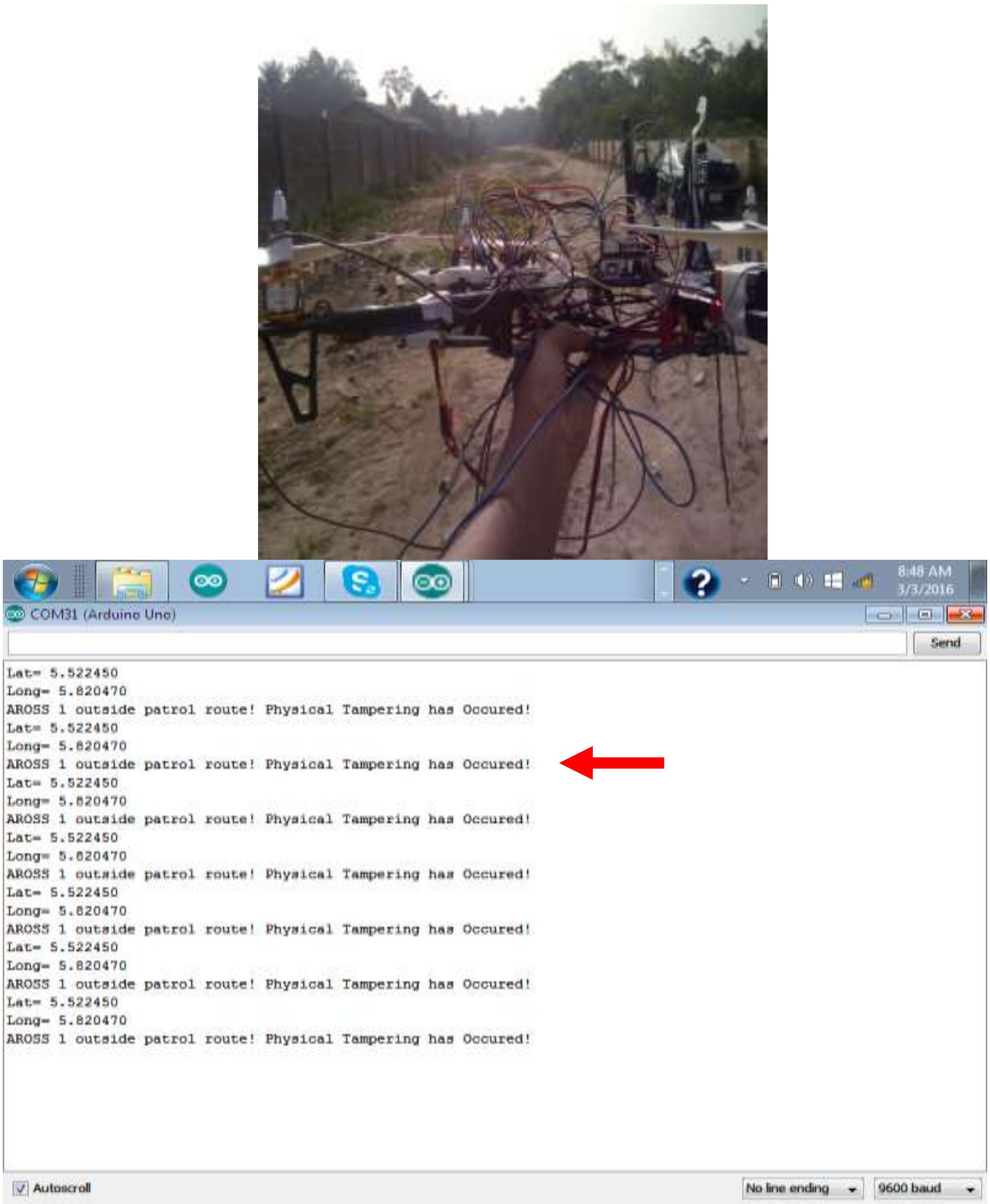


Fig. 10. AROSS system physically picked up and carried to a different location in between patrols (top). Alert messages wirelessly sent to host PC indicating the occurrence of physical tampering (bottom).

IV. Discussion

Physical surveillance of the right of way, though likely to be the most successful spill detection method, can only be done at intermittent intervals and may not provide total surveillance for the entire pipeline network [38]. This is where the advantage of continuous autonomous surveillance becomes obvious. The AROSS system presented in this paper demonstrated the ability to provide this crucial need for Nigeria's crude oil pipelines, successfully detecting the 1 liter simulated crude oil spill placed along its surveillance route. Furthermore, since this system is designed to provide continuous surveillance over a pipeline section, oil spills can be detected almost as soon as they occur, whether due to corrosion, vandalism, sabotage or theft.

When a spill is successfully detected, a message containing the spill GPS location is sent wirelessly to the surveillance team at the remote base station. This message contains the exact GPS location of the spill site, as shown in Figure 9a, and a picture of the spill site (See Figure 9b). So not only does the surveillance team know that a spill has occurred and its location, they are also able to visually see the spill, estimate its size, and immediately initiate the correct containment protocol for that particular spill. This wireless transmission of spill data between the AROSS system and the host PC at the remote base station can occur over a distance of 45 km, and wireless modules of multiple AROSS systems can be configured to transmit spill data to a single PC at the base station. There is a possibility that attempts will be made to physically remove the AROSS systems from their surveillance routes to avoid detection of theft and sabotage. This will only be possible when the system is on the ground. As demonstrated in the results section, the AROSS system has an inbuilt tampering detection algorithm to alert the base station when this scenario occurs.

Other airborne and space-borne oil spill detection systems mentioned earlier are used to periodically check for oil spills. Most are operator dependent and require active human participation to function. In the case of airborne detection systems, dedicated aircrafts are manned, very expensive and often complicated, and though the surveillance frequency can be altered, it still far from continuous. For space-borne systems, the frequency of the overpass is usually 2-3 days, so spills could go undetected for 2-3 days and large quantities of oil would already have been released into the environment before detection. In comparison, the AROSS system can provide continuous oil spill surveillance for sections of crude oil pipelines and detect spills almost as soon as they occur. The cost of the AROSS system is inexpensive, especially when compared with the other existing spill detection methods and systems. The AROSS system is autonomous and requires no human intervention after installation. All that is needed is monitoring of the host PC at the base station by members of the surveillance team.

The AROSS system bears many similarities in its operation and function to the GROSS system described above [39]. However, it has two major advantages over the GROSS system. First, since it is an aerial system, it can successfully traverse certain terrains that may prove to be too difficult for the GROSS system. Secondly, while the GROSS system was designed to remain beside the crude oil pipeline permanently, the AROSS system can be deployed directly from the base station instead of being positioned permanently beside the pipeline. Currently, the major limitation of the AROSS system is adequate power supply. Power is provided from an 11.1 V 3200 mAh Lithium Polymer battery that provides a flight time of approximately 35 minutes and needs to be recharged after that. The use of small but powerful solar panels to charge the LiPo battery during and in between patrols is currently being explored. Large panels cannot be used as they are too heavy and cumbersome.

It should be noted that the results presented here are from the initial testing of the first prototype of the AROSS system. More work is being done to improve the system's performance and to enhance its current capabilities. An additional feature to be integrated into the system is active participation in containment protocols after spill detection. Each AROSS system can be wirelessly linked to the valves of the pipeline section for which it provides autonomous surveillance. By means of a wireless link to these valves, when a spill is detected, the valves can be automatically shut off. This ability will ensure the stoppage of spills as soon as they are detected. Since the system has demonstrated its ability to detect spills as little as a liter, oil companies can be assured that large-volume spills will no longer be possible. With this new feature, when a spill is detected, the system stops, sends the GPS location and picture of the spill to the surveillance team at the base station, and a wireless message to the valves in the pipeline. Each valve is fitted with an Arduino board, a wireless Xbee module and shield for wireless communication, and a relay module that controls the power supply to the valve. By automatically opening or closing the relay, power to the valve is turned on to allow crude oil flow or turned off to prevent crude oil flow. When the Arduino attached to the valve receives a wireless message from the patrolling AROSS system indicating that a spill has been detected, it alters the power supply to the valve, closing it and providing immediate cessation of the spill. This ability will prevent the kind of disastrous environmental pollution that has plagued oil producing communities for decades.

Inability to provide continuous and adequate surveillance of the nation's pipelines is one of the key reasons why crude oil spills persist in Nigeria. The AROSS system has the potential to save oil companies and governments from the massive financial losses associated with spills. The system's ability to provide continuous surveillance for pipelines gives it the ability to quickly detect spills without any external human effort. Wireless transmission of spill GPS location and images ensures prompt response by surveillance teams, thereby minimizing environmental pollution. The AROSS system has demonstrated its ability to promptly detect crude oil spills, in addition to detecting the presence of vandals via its tampering detection algorithm. By installing these AROSS systems beside the nation's pipelines, crude oil spills can be detected as soon as they occur and pipeline vandalism and sabotage can be eradicated from the nation.

V. Conclusion

An Aerial Robotic Oil Spill Surveillance (AROSS) system has been designed to provide continuous surveillance for crude oil pipelines. Field testing of the AROSS system on an underground crude oil pipeline showed that the system can detect crude oil spills as little as a liter. In addition to successful spill detection, the system was able to wirelessly transmit the GPS location of the spill site and images of the spill site to a manned PC in the base station. It also demonstrated the ability to detect and alert surveillance teams to physical tampering by saboteurs. This system, if successfully deployed and installed to provide surveillance for crude oil pipelines, will assist in minimizing crude oil spills due to corrosion and sabotage, help in preserving the environment, socio-economic lives of indigenous communities, and prevent financial losses incurred by government and oil companies due to crude oil spills.

VI. Acknowledgement

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VII. Notation

AROSS	Aerial Robotic Oil Spill Surveillance
dB	decibel
ESC	Electronic Speed Controllers
GPS	Global Positioning System
GROSS	Ground Robotic Oil Spill Surveillance
mAh	milliampere hour
SAR	Synthetic Aperture Radar
SLAR	Side-looking Airborne Radar
SLEAF	Scanning Laser Environmental Airborne Fluorosensor
SPDC	Shell Petroleum Development Company

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