Ground Robotics Oil Spill Surveillance (GROSS) System for Early Detection of Oil Spills from Crude Oil Pipelines

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Ground Robotic Oil Spill Surveillance (GROSS) System for Early Detection of Oil Spills from Crude Oil Pipelines

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ABSTRACT

Crude oil spills have significant negative effects when they occur. Prompt detection of spills would lead to swift remediation, improvement in national economy, and a reduction in the damage to the environment. The Ground Robotic Oil Spill Surveillance (GROSS) System is a novel system for early detection of oil spills using small mobile robots. A single GROSS unit is a mechanized robot employed to patrol beside designated pipelines. Gas sensors detect the presence of oil spills as the unit moves beside the pipeline. Once a spill is detected, wireless communication between the GROSS unit and the surveillance team at the base station is achieved with the use of Xbee radios. An integrated camera module is used to take pictures of the spill site. These images and the GPS location of the spill are then transferred wirelessly to the base station to enable the surveillance team initiate established containment protocols. The GROSS system has been successfully tested on an underground crude oil pipeline in Nigeria. The system's ability to provide continuous surveillance along crude oil pipelines and wireless transmission of spill GPS location and images gives it the ability to detect oil spills quickly and ensure prompt response by surveillance teams.

Keywords: Crude Oil Spills, Automated Spill Detection, Robotics systems, Pipeline Surveillance, Oil Spill Detection.

Mathematics Subject Classification: 68T40, 93C85

ACM Computing Classification : I.2.9

1. INTRODUCTION

Crude oil spills have significant negative effects on the environment, health, society and economy of the nation in which they occur [1-20]. The causes of crude oil spills in Nigeria are due to pipeline corrosion, vandalization, sabotage/theft, or operational failure. Intentional third-party interference with pipelines and other infrastructure was responsible for around 75% of all oil spill incidents and 92% of all oil volume spilled from facilities operated by the Shell Petroleum Development Company (SPDC) in Nigeria over five years (2009-2013) [21].

Prompt detection of oil spills will minimize the damage done to the environment, enable quick environmental remediation, protect the health of the indigenous communities, reduce the loss of crude oil, and prevent financial losses for the oil companies, government and indigenous communities. Several methods have been employed to detect crude oil spills when they occur. Real time remote human surveillance of pipelines has been done by flying aircrafts over pipelines. Other forms of surveillance employ various sensors such as visible sensors, infrared sensors, ultraviolet sensors, radar sensors, and laser fluorosensors, to detect oil spills [22-24]. Two prominent methods are used in the Niger Delta region of Nigeria in detecting crude oil spills: pipeline pressure monitoring and human surveillance teams. The pressure monitoring method cannot readily pick up oil spills from the pipeline promptly [25]. The human surveillance teams report oil spills when they are physically observed in their jurisdiction but these reports occur after environmental damage has occurred. Both methods do not provide adequate and constant surveillance of the crude oil pipelines.

This paper introduces a novel robotic system to provide constant surveillance over crude oil pipelines [26]. This system is defined as the Ground Robotic Oil Spill Surveillance (GROSS) system. The GROSS system uses an autonomous ground mobile robot to carry out constant surveillance on a crude oil pipeline. By employing low cost GROSS units to patrol designated pipelines, it could improve leakage detection time and minimize damage to the environment. Once the presence of oil is detected along a particular pipeline, the patrolling robot will alert the surveillance team to initiate established containment protocols, which may include shutting off that particular pipeline. In addition to reducing oil spills due to theft by saboteurs, these autonomous robots could also help in detecting early oil leakage due to other reasons, such as pipeline corrosion.

This paper presents the design, development, construction and testing of the GROSS system for detecting crude oil spills along crude oil pipelines. The GROSS system design and construction is presented in the Materials and Methods Section. The finished system was successfully tested on an underground crude oil pipeline in Effurun, Nigeria. The results of the conducted test are presented in the Results section. The challenges encountered are highlighted in the discussion and conclusion sections as well as the potential benefits of the system if it is introduced into the oil and gas industry.

2. MATERIALS AND METHODS

2.1. Materials

- Chassis

In order to provide continuous surveillance for crude oil pipelines, it is important that the GROSS unit have the ability to move on any outdoor ground terrain in which the pipeline is located [27]. Figure 1 shows the selected chassis of the GROSS system.

The chassis is an all-metal tank with high ground clearance (70 mm) and is capable of handling very rough terrain. The body is made from aluminium, while the gears, tracks, suspension struts and wheels are die cast zinc. The size of the chassis is 355 mm (L) × 265 mm (W) × 130 mm (H), with a total weight of 3.7 kg. Motion is accomplished by supplying adequate power to the 12V motor. Power supply was provided by a 12 V 9000 mAh lead acid battery.

Figure 1. Metal Tank Chassis for the GROSS system

- Development Board

The development board used in the GROSS system to perform autonomous pipeline surveillance is the Arduino Uno Rev 3.

- *Global Positioning System (GPS)*

The Arduino GPS shield is a GPS module breakout board designed for Global Positioning System tracking (see Figure 2). It requires a supply voltage of 5V and operates at a baud rate of 38,400 bps. It has an onboard SD card slot for data storage. The GPS Shield is stacked on top of the Arduino board inside the GROSS chassis. The GPS shield assists in two very important functions carried out by the GROSS unit. First, when the unit detects an oil spill, the GPS shield is used to acquire the longitude and latitude of the spill site. This information is then sent wirelessly to the remote PC of the surveillance team, providing the exact location of the spill site. Secondly, during and in between patrol, the GPS location is acquired by the unit. If the unit latitude and longitude is outside the pre-defined route, it indicates that the unit has been physically tampered with and a wireless message is sent to the remote PC to alert the surveillance team.

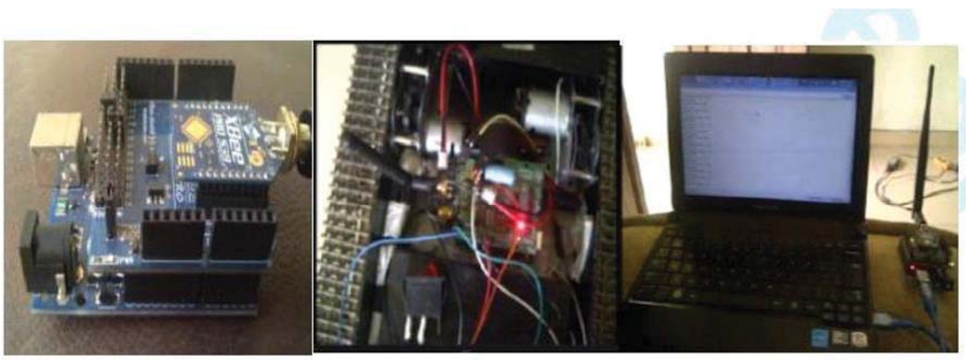
Figure 2. GPS Shield and Antenna mounted on Arduino Uno

- *XBee*

A pair of Xbee Pro 900HP wireless modules is used to establish wireless communication between GROSS unit and Host PC at remote base station. Table 1 shows the important parameters of the Xbee module. With a 2.1 dB antenna, this module can establish a wireless connection between the GROSS unit and the host PC up to a distance of 15.5 km. With a high gain antenna, this distance increases to 45 km. The GROSS unit uses this connection to notify the base station at the start of its patrol. But more importantly, this wireless connection is used to relay the GPS location of detected oil spill sites to the remote PC of the surveillance team. Captured Images of the oil spill sites acquired by the GROSS unit are also transmitted wirelessly to the surveillance team through this connection. The Xbee is mounted on an Xbee shield, which is then stacked on the Arduino Uno (see Figure 3a). One Xbee is mounted on an Xbee Shield and stacked on top of the GPS shield inside the GROSS unit, (see Figure 3b) while a second Xbee is mounted on an Xbee Shield and connected to the remote PC (see Figure 3c).

Table 1: Relevant Parameters of the Xbee PRO HP Module

PARAMETER	
RF Band Rate	900 MHz
RF Data Rate	10 Kbps or 200 Kbps
Indoor Urban Range (2.1 dB Antenna)	10 Kbps up to 2,000 ft (610 m)
	200 Kbps up to 1,000 ft (305 m)
Outdoor LOS Range (2.1 dB Antenna)	10 Kpbs up to 9 miles; (15.5 km)
	200 Kbps up to 4 miles; (6.5 Km)
Supply Voltage	2.1 – 3.6 V
Transmit Voltage	215 Ma
Receive Voltage	29 Ma

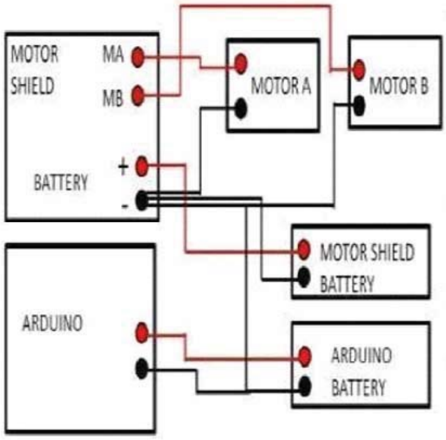


(a) (b) (c)

Figure 3. (a) Xbee Pro 900HP on Xbee Shield Stacked on Arduino Uno (b) First Xbee module mounted inside GROSS system (c) Second Xbee bee module connected to remote PC

- *Motor Shield*

A MegaMoto Motor shield for Arduino is used to connect the 12V chassis motors to the 12V lead acid battery. The motor shield is used in its half-bridge circuit configuration in the GROSS unit. A schematic of the power connection is shown in Figure 4a. Note that although the motor shield is stacked on top of the Arduino Uno (see Figure 3b), the power supply for the motor shield and Arduino are different. The motor shield draws its power supply from the 12V lead acid battery and feeds that to motors A and B of the robot chassis, depending on the logic signal it receives from the program uploaded into the Arduino Uno.



•
(b)

Figure. 4. (a) Power Connections for MegaMoto Shield (b) Megamoto Shield Stacked on Arduino uno

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- *Magnetometer*

The HMC5883L magnetometer is used to ensure the GROSS unit stays on course during patrol beside the crude oil pipeline. It is also used to ensure an accurate 180^0 turn in the opposite direction after the completion of the patrol, so the unit can patrol in the opposite direction. An image of the magnetometer is shown in Figure 5.

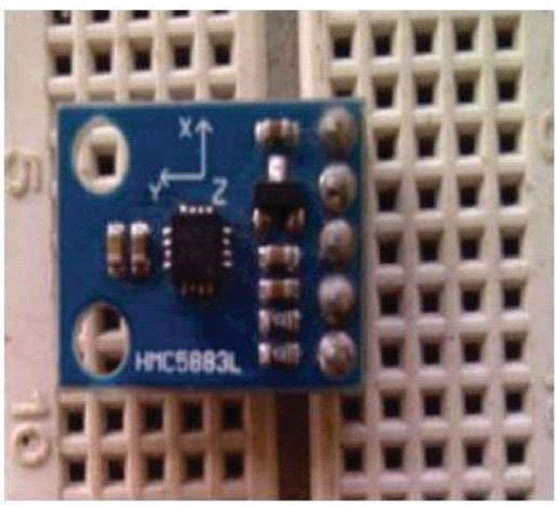


Figure. 5. HMC5883L Magnetometer

- *Ultrasound Sensor*

The HC-SRO4 is an ultrasound sensor, capable of transmitting and receiving ultrasound waves (see Fig. 6a). The time between transmitted wave and received wave is used to calculate distance between sensor and object. The HC-SRO4 sensor is mounted on the front of the GROSS unit (see Fig. 6b). Obstacle detection and avoidance is required for autonomous mobile robots [28]. During patrol, using the HC-SRO4 sensor, if the unit detects an obstacle less than 35 cm in front of it (see Fig.6c), it takes a detour route to avoid the object (see Fig. 6d), before continuing along its patrol route (see Fig. 6e).

Figure 6. (a) HC-SRO4 sensor. (b) Sensor mounted on GROSS unit. (c) GROSS unit on patrol detecting obstacle using sensor. (d) GROSS unit taking detour route after obstacle detection. (e) GROSS unit resuming patrol after successfully avoiding obstacle.

- *Oil Spill Detector*

The primary method by which the GROSS unit detects oil spills is by means of the MQ-6 gas sensor. The MQ-6 sensor has a high sensitivity to Liquified Petroleum Gas (LPG) and Methane (CH_4), which is a primary component of crude oil. 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, The layer shows marked sensitivity to the concentration of methane in the air and this is reflected in the output voltage of the sensor. The MQ-6 sensor was mounted at the bottom of the GROSS unit to ensure close proximity to the ground for quick detection of crude oil spills (see Figure 7).

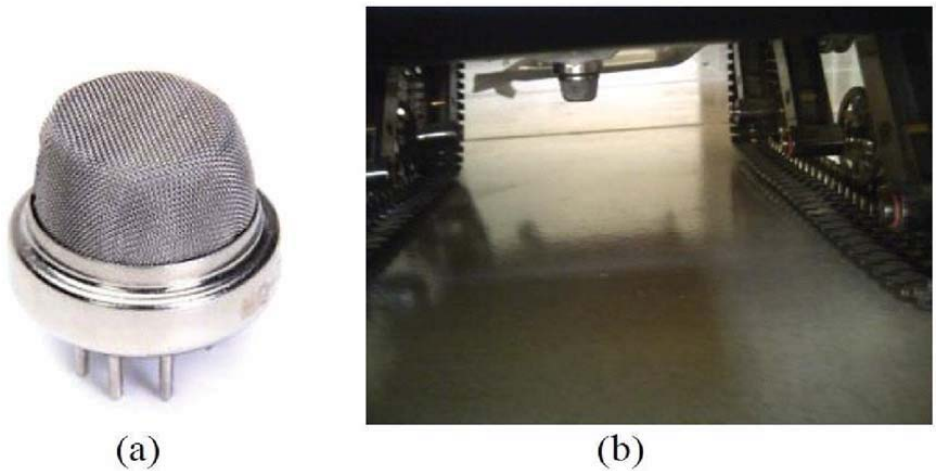


Figure 7. Oil Spill Detector. (a) MQ-4 sensor. (b). Sensor mounted at the bottom of GROSS unit.

- *Camera*

The LS-Y201-Infrared camera captures high resolution pictures using serial port (see Fig 8a). The infrared feature has a built-in sensor to sense the ambient light and will automatically turn on infrared LEDs when light intensity is low. It requires a power supply of 3.3 V or 5 V, has a current consumption of 80-200 mA, and a serial baud rate of 38,400 bps. Image resolution can be set to 160 x 120, 320 x 240 or 640 x 480 pixels. Figure 8b shows the camera mounted on the GROSS unit.
When the GROSS unit detects an oil spill, it stops and takes a picture of the spill site. This picture is transmitted wirelessly along with the GPS latitude and longitude location of the spill site to the remote PC of the surveillance team. This enables the team to have a visual image of the spill site. The higher the resolution of the captured image, the longer the time it takes to wirelessly transmit the captured image to the PC and more errors are introduced into the image. The 320 x 240 image resolution was selected for capturing images of the oil spill site. A unique feature of this camera is its ability to take pictures of oil spill sites during the day and also at night. Figure 8c shows an image captured by a high resolution digital camera. Figure 8d shows the same image captured by the LS-Y201-Infrared camera during daylight conditions at 320 x 240 resolution. Figure 8e shows the same image captured by the LS- Y201-Infrared camera during night-time conditions at 320 x 240 resolution. Visual observation shows virtually no difference between the image captured in daytime conditions and the image captured in pitch-black conditions.

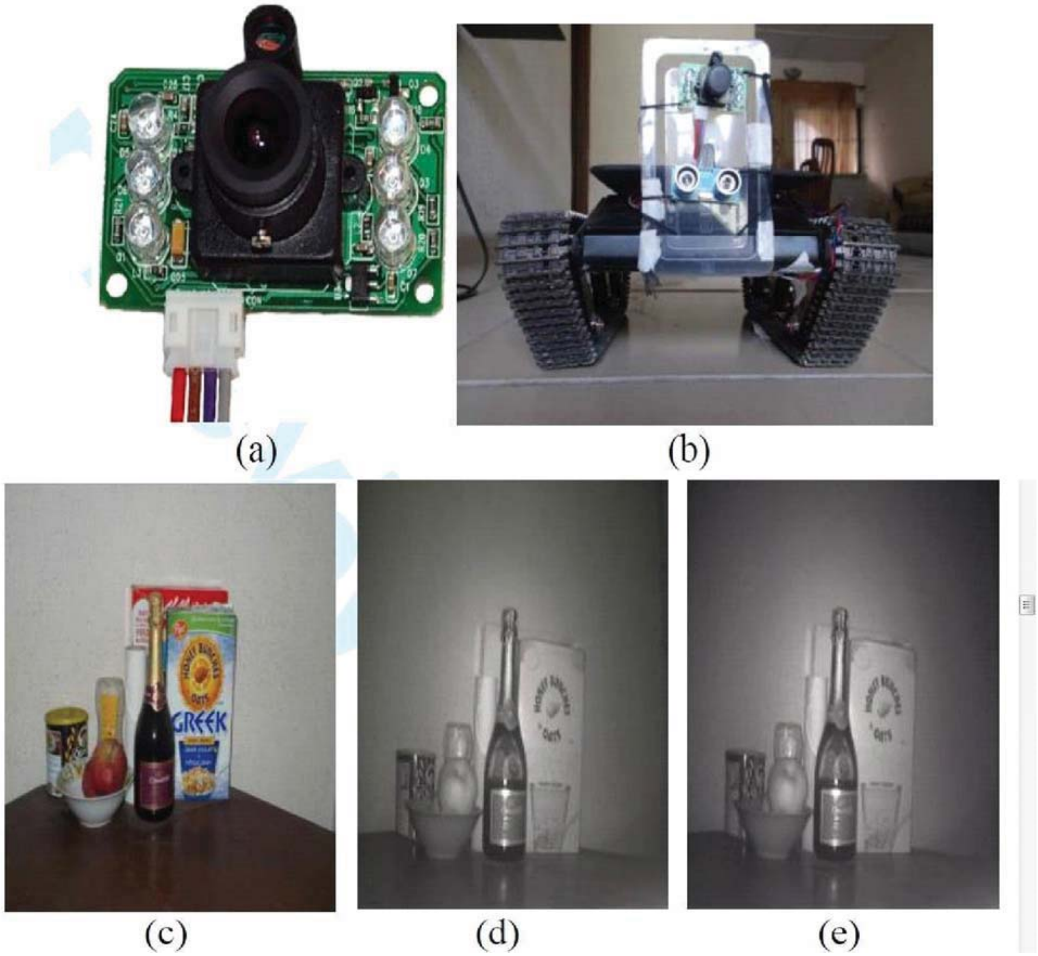


Figure 8. (a) LS-Y201-Infrared camera. (b) Camera mounted on GROSS unit. (c) High Resolution Image captured by digital camera. (d) Image captured by LS-Y201-Infrared camera in daytime conditions with 320 x 240 resolution. (e) Image captured by LS-Y201-Infrared camera in night- time conditions with 320 x 240 resolution.

- *Solar Panel*

The motors of the chassis receive electric power from the 12 V Lead Acid Battery in order to patrol beside the pipeline. If the GROSS unit is mobilized to patrol 100 m of a crude oil pipeline every hour, the 12 V battery will run down before the end of the second day. In order to maintain continuous power supply to the unit, a solar panel was incorporated into the system. The solar panel has an output power of 8 W, an output voltage of over 18 V, and an output current of 450 mA. It is made from polycrystalline cell and keeps batteries charged for top performance.

The positive and negative leads of the solar panel are connected to the positive and negative leads of the 12 V battery. The solar panel is then mounted on the top of the GROSS unit. During time interval between pipeline patrols, the solar panel charges the 12V battery, ensuring the continuous availability of power supply to the GROSS unit.

2.2. Methods

The finished video of the GROSS system can be found here: https://www.youtube.com/watch?v=NMCCZKnUEqQ. The operation of the GROSS system is shown in Figure 9. When the GROSS unit is powered on or initialized, it obtains its current location using GPS. It also obtains the GPS location of the start and end points of the pipeline section it is assigned to, as well as its orientation using the onboard magnetometer. North, south, east and west orientation information is also acquired by magnetometer.

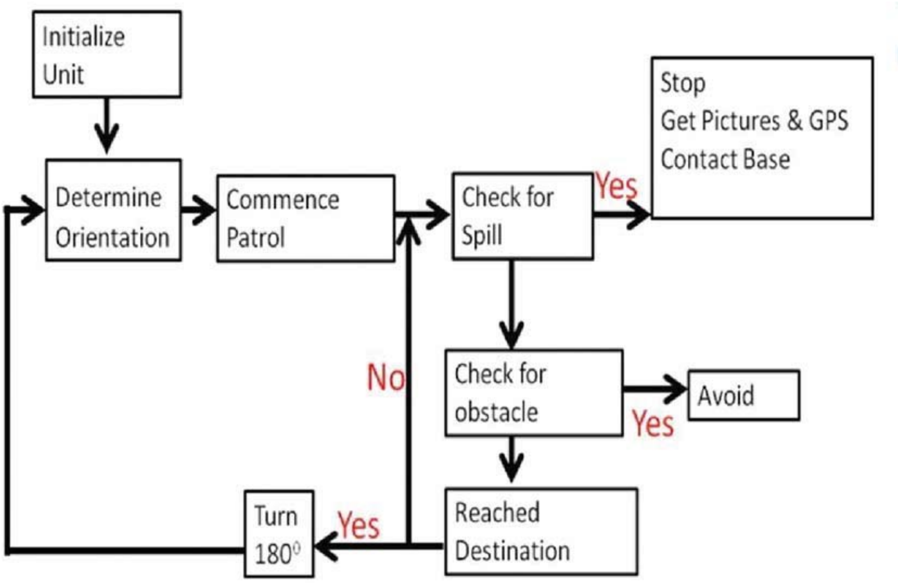


Figure 9. Operation of the GROSS System

The unit starts moving towards the end of the pipeline, while simultaneously checking for crude oil leakage using the MQ-6 sensor. If the unit detects a spill, it stops and takes pictures of the spill site. Images and GPS location of the spill are sent wirelessly to host PC at the base station via the Xbee modules, and spills can be verified from acquired images. During patrol, the unit constantly checks to ensure it is traveling in the correct direction using the onboard magnetometer. If the unit has drifted away from its original direction, a path adjustment algorithm is employed to return it to the correct direction. The GROSS unit is also programmed to autonomously detect and avoid obstacles along its surveillance path, as shown in Figure 9.

While patrolling beside the pipeline, the unit constantly checks for the presence of obstacles in front of it, using the HC-SR04 sensor. If an obstacle is detected less than 35 cm away from the unit, it takes a detour route to go around the obstacle before resuming its patrol. Upon arriving at the End location, the unit turns 180^0, using information provided by the onboard magnetometer. After turning, the unit waits a preset time interval before patrolling the pipeline again. The GPS data for the End and Start Locations are interchanged so the unit can patrol in the opposite direction.

- *Test Procedure*

The GROSS unit was autonomously programmed to provide constant surveillance over a 100 m stretch of a pipeline. The speed of the unit was set to approximately 450 mm/s. A patrol time of approximately 4 minutes was sufficient to ensure a surveillance distance of 100 m. Multiple GROSS units 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 GROSS unit patrolled the 100 m stretch of the pipeline for approximately 4 minutes. The ability of the solar panel to adequately charge the 12V lead acid battery to ensure continuous power supply was also tested. The battery voltage before and after patrol completion was measured. The voltage was also measured in the time interval between patrols when solar recharging was taking place. Approximately 1 litre of crude oil was placed along the surveillance route to determine if the GROSS unit was capable of detecting the simulated crude oil spill during its patrol. Figure 10a shows the GROSS unit patrolling the 100 m stretch of the crude oil pipeline. Figure 10b shows the unit patrolling the 100 m stretch of the crude oil pipeline with a simulated oil spill placed approximately in the middle of the surveillance route. The base station was located approximately 100 m away from the surveillance route. The remote PC with the receiving Xbee module was at the base station (see Figure 10c).

During a few patrols, obstacles were placed along the patrol route to test the system's ability to successfully detect and avoid obstacles along its surveillance route. During and in between a patrol, the unit was physically picked up and carried away from its surveillance route. This was done to test the system's ability to detect and alert the surveillance team if it has been physically tampered with. The key parameters of the system that were evaluated during this testing procedure included the following:

- The ability of the system to continuously patrol the 100 m of crude oil pipeline at designated time intervals without external intervention.
- The ability of the system to detect and avoid obstacles along its assigned surveillance route.
- The ability of the system to detect the presence of simulated oil spills along the 100 m of crude oil pipeline.
- The ability of the system to wirelessly send GPS location and Images of Oil spill sites to the PC at the remote base station, once an oil spill is detected.
- The ability of the system to alert the surveillance team if the system has been physically tampered with.

Figure 10. (a) GROSS unit patrolling 100 m of Crude Oil Pipeline. (b) Simulated Oil Spill placed along surveillance route. (c) Remote Base Station with host PC and receiving Xbee 100 m away from the surveillance route.

3. RESULTS

This section presents the visual and quantitative data obtained from actual field tests carried out on the GROSS unit.

3.1. Patrol

The GROSS unit was programmed to autonomously patrol 100 m of an underground crude oil pipeline (see Figure 11a). Figure 11b shows a picture of the GROSS unit during its 100 m patrol of the pipeline. As stated earlier, it took approximately 4 minutes to complete the 100 m patrol. Once the unit completed its patrol, it stopped and tuned 180^0 to face the opposite direction, as shown in Figure 11c. It then waited for the preset time interval of 1 hour before commencing patrol in the opposite direction. This test verified the GROSS unit's ability to continuously and successfully patrol along or beside crude oil pipelines.

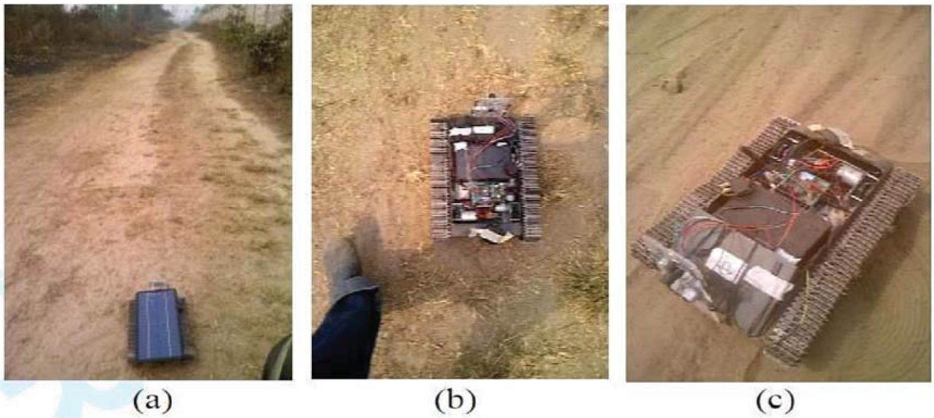


Figure 11. (a) 100 m underground crude oil pipeline (b) GROSS unit during 100 m surveillance patrol (c). GROSS unit completing 180^0 turn after surveillance patrol

3.2. Power Test

The voltage of the GROSS 12 V battery was measured prior to the commencement of the 100 m patrol. The voltage was also measured after the completion of the 100 m patrol. During time interval between pipeline patrols, the solar panel charged the 12 V battery, ensuring the continuous availability of power supply to the GROSS unit (see Figure 12). The voltage of the battery was again measured 15 and 30 minutes after patrol completion and solar charging. Solar charging was performed between 10-11 a.m. on February 11, 2016. During this time, the weather was cloudy and not particularly sunny, as shown in Figure 12b. The data obtained from the 12 V battery testing is shown in Table 2. When the GROSS unit patrols a distance of about 100 m, there is a drop in the voltage of the battery equivalent to 0.27 V. Solar charging of 15 minutes yields a voltage increase equivalent to 0.27V. Therefore, for every 100 m patrolled by the unit, 15 minutes of solar charging is required to restore the battery back to its initial voltage. It is possible that this timeframe could be smaller on bright, sunny days.

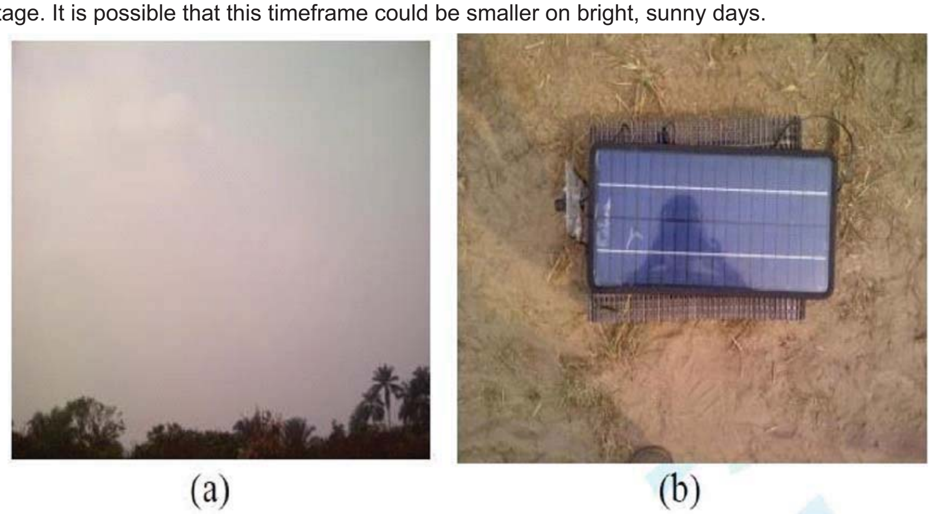


Figure 12 (a) Cloudy weather during solar charging of GROSS unit on February 11, 2016. (b) GROSS unit undergoing solar charging in between patrols.

*Table 2:*Battery Test for GROSS Unit During and In-between Surveillance Patrol

Initial Battery Voltage (V)	Patrol Time (Minutes)	Patrol Distance (m)	Battery Voltage After Patrol (V)	Solar Charging Time (minutes)	Final Battery Voltage (V)
12.92	4	108	12.65	15	12.92
12.92	4	108	12.65	30	12.98

3.3. Obstacle Avoidance

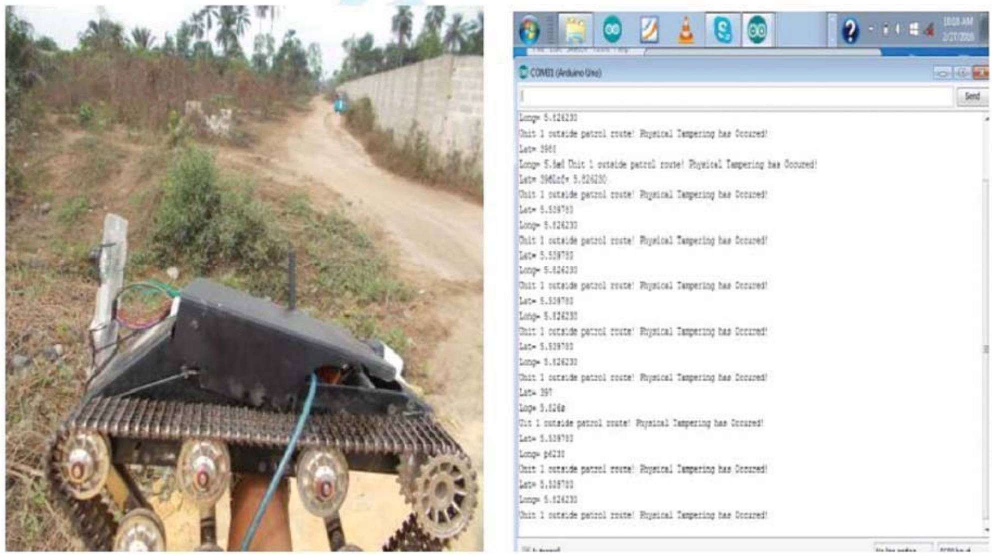
The HC-SRO4 ultrasonic sensor on the GROSS system was programmed to automatically alert the unit if there was an obstacle in front of it. If the sensor detected an obstacle less than 35 cm in front of the unit, the unit was programmed to take a detour route to avoid the obstacle. To test the system's ability to detect and avoid obstacles during patrol, objects were placed along its patrol route (see Figure 13).

(a) (b) (c)

Figure 13. Obstacle avoidance and detection by GROSS unit. (a) Obstacle placed along patrol route of unit. (b) Unit detects obstacle and veers left to avoid it (b). Unit completing detour route after successful obstacle avoidance.

3.4. Tampering Detection

During a patrol, the GROSS unit was physically picked up and carried away from its assigned route. This was also done while the unit was stationary in-between patrols. Figure 14a shows the GROSS unit being physically transported to a location beyond its assigned surveillance route. The GPS latitudes of the surveillance route ranged from 5.539860 - 5.539770. The GPS longitudes of the surveillance route ranged from 5.825970 –5.825250. When the GROSS unit was physically picked up and carried to another location outside its surveillance route, the GPS latitude and longitude of its current location eventually went beyond this range (see Figure 14b). When this occurred, the GROSS unit wirelessly issued warning messages to the host PC at the remote base station, alerting the surveillance team that it had been physically tampered with.



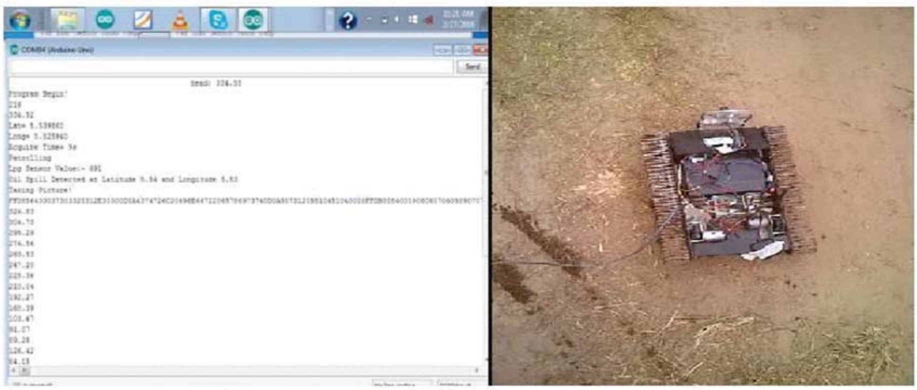
•   (b)

Figure 14. (a). GROSS unit physically picked up and carried to a different location during patrol. (b) Alert Message sent wirelessly to host PC indicating the occurrence of physical tampering.

3.5. Oil Spill Detection

Approximately 1 litre of crude oil was poured generously over a large polythene bag that was placed along the surveillance route of the GROSS unit (see Figure 15a). Figure 15b shows the GROSS unit during patrol approaching and detecting the simulated crude oil spill via the method described in the materials section of this paper. The unit stopped, took a picture of the spill site and wirelessly transmitted this image and the GPS location of the spill to the host PC at the base station. Figure 15c shows the captured spill image sent to the host PC of the surveillance team, while Figure 15d shows the wirelessly transmitted spill GPS location and image data sent to the host PC. After alerting the surveillance team to the presence of the crude oil spill, the GROSS unit resumed its patrol of its assigned surveillance route (see Figure 15e).

(a) (b) (c)



(d) (e)

Figure 15. (a) GROSS unit patrolling surveillance route with simulated crude oil spill. (b) GROSS unit detecting presence of 1 litre crude oil spill. (c) Captured spill image sent to the host PC. (d) Wirelessly transmitted spill GPS location and image data sent to the host PC. (e) GROSS unit resuming patrol after crude oil spill alert.

4. DISCUSSION

Physical surveillance of the right of way to visually identify an oil release is more likely to be successful than any other release detection methods [25]. However, human surveillance, while undoubtedly effective, is extremely time consuming, can only be done at intermittent intervals and may not provide total surveillance for the entire pipeline network. This makes it difficult to detect pipeline vandalism at its onset, as surveillance for the compromised pipeline section may not be available at the time the vandalization is occurring.

The GROSS unit presented in this paper clearly demonstrated the ability to provide this crucial need for Nigeria's crude oil pipelines. Programmed to provide surveillance for 100 m of a crude oil pipeline, the unit was able to complete patrol of this surveillance route in 4 minutes, and then wait for 1 hour before patrolling in the opposite direction. The time between patrols can be reduced so that the unit provides continuous surveillance for that section of the pipeline. While a single GROSS unit can certainly provide surveillance for greater distances than 100 m, there is a trade-off between distance and time. Longer surveillance distances mean longer patrol times; longer patrol time increases the time in which sections of the pipeline are not under surveillance.

Multiple GROSS units can be utilized to provide extensive surveillance coverage for crude oil pipelines with longer lengths. The Xbee modules for each unit can be configured so that multiple units can wirelessly communicate with the host PC at the remote base station. As observed from the power testing of the GROSS unit, autonomous and continuous surveillance is clearly demonstrated. The solar panel provides continuous renewable power to the system. Therefore, once the system is installed along the crude oil pipeline and programmed, it can autonomously provide continuous surveillance without any external intervention.

From the data presented in Table 2, patrolling a distance of 100 m resulted in a battery voltage drop of 0.27 V. During the time interval between patrols, the solar panel charged the battery back to its original voltage in 15 minutes. This means that a GROSS unit set to patrol 100 m of the crude oil pipeline will need only 15 minutes between each patrol to maintain its power supply. Therefore, the time interval between patrols can be reduced to 15 minutes. It should be noted that the solar panel charging was done under cloudy conditions. The charging time will be significantly smaller during sunny weather.

It is expected that the right of way would be properly maintained and that patrolling GROSS units would encounter no obstacles along their assigned surveillance routes. However, with the aid of an ultrasonic sensor mounted on the front of the unit, the system is able to detect obstacles in its front, as shown in the results section. During patrol of its assigned route, if an obstacle is detected less than 35 cm in front of the unit, it takes a detour route around that obstacle. Once GROSS units are installed along Nigeria's crude oil pipelines and the system begins to counteract the activities of vandals, there is a high possibility that attempts will be made to physically remove the units from their surveillance route to avoid detection of oil thefts and sabotage. However, by constantly monitoring its current GPS location, the unit has the ability to determine when it has been moved outside of its surveillance route. In the event that a potential pipeline vandal tries to remove or obstruct the unit during or in-between its patrol, the unit will register its location as being outside its preprogrammed route and will immediately send a warning to the surveillance team at the base location, indicating physical tampering. This ability of the unit will help to alert the appropriate authorities even before pipeline vandalization occurs.

When a spill occurs along its assigned pipeline section, the GROSS unit has the ability to detect these spills. When a spill is successfully detected, a message is sent wirelessly to the surveillance team at the remote base station. This message contains the exact GPS location of the spill site. In addition to the GPS location, the unit also transmits a picture of the spill site taken by its onboard camera module. 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 site. Visual verification of the spill is important, because the surveillance team can remotely see and estimate the size of the spill and immediately initiate the correct containment protocol for that particular spill. The GROSS unit demonstrated the ability to detect spills as little as 1 litre along its surveillance route. This could mean that if this system is installed along Nigeria's network of crude oil pipelines, the surveillance teams can be alerted even before pipeline vandalization occurs via the unit's tampering detection ability. And in the event that a pipeline is compromised and a spill occurs, spills as little as 1 litre can be detected, the surveillance team alerted and containment protocol initiated immediately. It could mean the end of crude oil spills greater than a single litre of crude oil. Spills emanating from pipeline vandalization as well as spills due to corrosion of the pipelines can be detected by the GROSS unit.

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 GROSS system was invented and designed to address this shortcoming and has so far 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 GROSS units beside the nation's pipelines, crude oil spills can be detected promptly as soon as they occur, and pipeline vandalism and sabotage can be eradicated from the nation.

5. CONCLUSION

The Ground Robotic Oil Spill Surveillance (GROSS) system was designed for early crude oil spill detection. The system was able to patrol 100 m of an underground crude oil pipeline in Effurun, Nigeria in 4 minutes. The system demonstrated obstacle detection and avoidance along its patrol route. The GROSS system detected when it was physically tampered with and carried outside its patrol surveillance route with GPS latitudes 5.539860 - 5.539770 and GPS longitudes 5.825970 – 5.825250, and alerted relevant authorities. Solar charging of 15 minutes of the GROSS battery by the on-board 18 V solar panel ensured continuous patrol of the system every hour.

The GROSS system detected crude oil spills as small as 1 litre, captured 320 X 240 pixel images of the spill site and transmitted the spill GPS location and images to a PC at a remote base station 100 m away from the underground crude oil pipeline within 10 seconds. Future work includes utilizing the GROSS system to automatically shut down the pipeline valves within the crude oil pipeline once a spill has been detected, so as to minimize environmental pollution. Installation of multiple GROSS units beside Nigeria's crude oil pipelines will enable prompt detection of spills when they occur and will eradicate pipeline vandalism and sabotage from the nation.

6. REFERENCES

1. Adelana S.O., Adeosun T. A., Adesina O. A., and Ojuroye, M.O., 2011, Environmental Pollution and Remediation: Challenges And Management Of Oil Spillage In The Nigerian Coastal Areas. *American Journal Of Scientific And Industrial Research*, Vol. **6**(2), 834-845.

2. Best Ordinioha, Seiyefa Brisibe, 2013 The human health implications of crude oil spills in the Niger delta, Nigeria: An interpretation of published studies, *Niger Med. J.,* **54**(1), 10–16. doi: 10.4103/0300-1652.108887

3. Osuagwu E. S., Olaifa E., 2018. Effects of oil spills on fish production in the Niger Delta. *PLoS ONE* **13**(10), 1 -14.

4. Frank O., Boisa N., 2018. The effect of crude oil spill on the surface water of the Lower Niger Delta (Sombriero River). *J Ind Environ Chem*. **2**(2),19-24.

5. Agunobi K. N., Obienusi E. A., Onuoha D. C., 2014. An investigation of the pattern and Environmental impact of oil spillage in Etche Local Government Area of Rivers State, Nigeria. *Journal of Natural Resources*. **4**(16),124-37.

6. Blanca Laffon, Eduardo Pásaro, Vanessa Valdiglesias, 2016. Effects of exposure to oil spills on human health: Updated review. *Journal of Toxicology and Environmental Health, Part B,* **19**, 105-128. https://doi.org/10.1080/10937404.2016.1168730

7. Oshienemen N., Albert, Dilanthi Amaratunga, Richard P. Haigh, 2018. Evaluation of the Impacts of Oil Spill Disaster on Communities and Its Influence on Restiveness in Niger Delta, Nigeria. *Procedia Engineering*, **212**, 1054-1061. https://doi.org/10.1016/j.proeng.2018.01.136

8. Kadafa A. A., 2012. Environmental impacts of oil exploration and exploitation in the Niger Delta of Nigeria. *Global Journal of Science Frontier Research Environment & Earth Sciences*, **12** (3), 19-28.

9. S. Pegg, N. Zabbey, 2013. Oil and water: the Bodo spills and the destruction of traditional livelihood structures in the Niger Delta. *Community Development Journal,* **48**(3), 391-405.

10. A. Fentiman, N. Zabbey, 2015. Environmental degradation and cultural erosion in Ogoniland: A case study of the oil spills in Bodo. *The Extractive Industries and Society*, **2**(4), 615-624.

11. Enegide Chinedu, Chukwuma K. Chukwuemeka, 2018. Oil Spillage and Heavy Metals Toxicity Risk in the Niger Delta, Nigeria. *Journal of Health and Pollution,* **8**(19), 1-8. https://doi.org/10.5696/2156-9614-8.19.180905

12. Anna Bruederle, Roland Hodler, 2019. Effect of oil spills on infant mortality in Nigeria. *PNAS*, **116**(12), 5467-5471.

13. Inoni O., Douglason E., Omotor G., and Adun F.N., 2006. The Effect of Oil Spillage on Crop Yield and Farm Income in Delta State, Nigeria. *Journal of Central European Agriculture* Volume **7**, No. 1, 41-48.

14. Oyebamiji M., Adekola Mba, Igwe C., 2014. Effects of Oil Spillage on Community Development in the Niger Delta Region: Implications for the Eradication of Poverty and Hunger (Millennium Development Goal One) in Nigeria. *World Journal of Social Science*, Vol. **1**, No. 1, 27-36.

15. Okoye C.O., Okunrobo L.A., 2014. Impact of Oil Spill on Land and Water and its Health Implications in Odugboro Community, Sagamu, Ogun State, Nigeria. *World Journal of Environmental Sciences & Engineering*, Vol. **1**, No. 1, 1-21.

16. Oyem I. L., 2013. Effects of Crude Oil Spillage on Soil Physico-Chemical Properties in Ugborodo Community. *International Journal of Modern Engineering Research*, **3**(6), 3336-3342.

17. Mogborukor J. O. A., 2014. The Impact of Oil Exploration and Exploitation on Water Quality and Vegetal Resources in a Rain Forest Ecosystem of Nigeria. *Mediterranean Journal of Social Sciences*, **5**(27), 1678-1685.

18. Ajide O. M., Isaac O. O., 2013. An Assessment of the Physical Impact of Oil Spillage Using GIS and Remote Sensing Technologies: Empirical Evidence from Jesse Town, Delta State, Nigeria. *British Journal of Arts and Social Sciences*. **12,** No.II, 235-252.

19. Nwachukwu A. N., Osuagwu J. C., 2014. Effects of Oil Spillage on Groundwater Quality In Nigeria. *American Journal of Engineering Research*, **3**(6), 271-274.

20. Salako A., Oluwafolahan S., and Sunkanmi A., 2012. Oil Spills And Community Health: Implications For Resource Limited Settings. *Journal of Toxicology and Environmental Health Sciences*, **4**(9), 145-150.

21. O'tega Ejofodomi, Godswill Ofualagba, 2016. Development of an Aerial Robotic Oil Spill Surveillance (AROSS) System for Constant Surveillance and Detection of Spills from Crude Oil Pipelines. *IJUSEng*, **4**(2), 19-33. http://dx.doi.org/10.14323/ijuseng.2016.6

22. www.cosid.com.ng

23. O'tega Ejofodomi, Godswill Ofualagba, 2017. Detection and Classification of Land Crude Oil Spills Using Color Segmentation and Texture Analysis. *J. Imaging*, **3**(4), 47; doi:10.3390/jimaging3040047

24. O'tega Ejofodomi, Godswill Ofualagba, 2018. Design of an Underwater Robotic Oil Spill Surveillance (UROSS) System for Spill Surveillance and Detection from Subsea Crude Oil Pipelines, *IJUSENG*, **6**(1), 1-20. http://dx.doi.org/10.14323/ijuseng.2018.1

25. Amnesty International, 2013. Bad Information: Oil Spill Investigations in the Niger Delta. *Amnesty International*.

26. O'tega Ejofodomi, Godswill Ofualagba, 2017. Exploring the Feasibility of Robotic Pipeline Surveillance for Detecting Crude Oil Spills in the Niger Delta. *IJUSEng*, **5**(3), 38-52. http://dx.doi.org/10.14323/ijuseng.2017.7

27. Dmitry Yu. Tyugin, Andrey A. Kurkin, Vitaliy D. Kuzin, Denis V. Zeziulin, Vladimir S. Makarov, Roman V. Shamin, 2018. The Exploration of Autonomous Mobile Robot Movement Characteristics in Difficult Off-road Conditions of a Coastal Zone. *International Journal of Imaging and Robotics*, **18(**1).

28. Yin Mon Myint, 2013. Development of Process Control with Obstacle Avoidance Behavior in Autonomous Mobile Model. I*nternational Journal of Imaging and Robotics*, **10**(2).