Monitoring of Oil and Gas Pipelines by Use of VTOL-Type Unmanned Aerial Vehicles

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Summary

The vast and diverse spread of the oil and gas pipeline infrastructure makes real-time monitoring of the entire network a very costly task. This topology has provided vandals and crude-oil thieves with the opportunity of tapping the pipelines and successfully stealing crude oil from them unhindered. Nigeria lost more than USD 11 billion to crude-oil theft and pipeline vandalization over a 4-year period (2007 to 2011). The increase in vandalization has led to the divestment of assets by some of these oil companies because it is no longer economical to continue operating the assets. Strategies used by the government and oil companies to tackle these challenges include the deployment of military personnel to these assets and also along their pipeline right of way (ROW). In spite of these attempts, the results show that the deployment of these personnel and the attendant cost have not reduced the quantity and frequency of oil theft because the deployment time to some of these locations also contributes to delay in the response of the security personnel.

The deployment of dynamic pipeline-pressure profiles enables the determination of the onset of a leak or a loss of crude oil. This paper presents the deployment plan and communication architecture of the vertical take-off and landing (VTOL) type of unmanned air vehicles (UAVs) for pipeline monitoring. The pipeline network of the company is divided into wide area cells, and each cell is controlled from a facility. Low-power UAVs with directional antennas and long-range zoom cameras are deployed to provide real-time visual monitoring of the pipeline section whenever a pressure drop or any significant third-party activity is detected on a section of the pipeline. Security personnel can then be deployed to the pipeline section if vandal activity is detected. This solution has the capability of reducing crude-oil theft by providing accurate location data in a timely manner to the company with respect to the bunkering activity along its pipeline ROW and also enabling the timely deployment of personnel to contain the situation.

Introduction

Pipelines play a critical role in the oil and gas production process because they are used to provide a less-expensive and faster means of transporting either the crude oil or the refined products. Nigerian National Petroleum Corporation (NNPC) uses pipelines to transport crude oil to the refineries and to transport the refined products to depots across the nation. Most of the pipeline systems in Nigeria are jointly owned by NNPC and oil majors, while the export terminals are operated by Shell (Forcados and Bonny terminals), ExxonMobil (Qua Iboe terminal), Chevron (Escravos and Pennington terminals), and Eni (Brass terminal). The visibility and the fact that the locations of these pipelines are known and easily accessible make them targets for vandals and oil thieves. From 2007 to 2011, Nigeria lost more than USD 11 billion to crude-oil theft and pipeline vandalization (NEITI 2013). The total amount being lost by Nigeria annually has been estimated at approximately USD 6 billion. Oil and gas companies have had to deploy military personnel in addition to private security forces. Funds have also been spent (and are currently being spent) on the development of technologies to help with the identification of these acts of vandalism, with oil companies spending in excess of USD 600 million. In spite of these attempts, the spate of vandalism has not abated (NEITI 2013; Okoli and Orinya 2013).

The deployment of supervisory control and data-acquisition (SCADA) systems has also made it possible to monitor in real time the flow rate, pressure, and temperature of crude oil as it moves from one facility to another. Whenever a drop in pressure is detected, the system can be configured to notify the operators and automatically send a request for inspection (RFI) to the operator in the flow station covering the pipeline section where the drop is detected (Mohammad 2013). The operator then launches the UAV and guides it to that location using the flight controller, and the UAV provides a video feedback of the pipeline ROW as it moves to the suspected point of activity.

This paper proposes the deployment of VTOL-type UAVs for the purpose of providing real-time images and videos of the vandalization or crude-oil theft as it is being carried out. The pipeline networks are to be broken into wide area cells controlled by the processing facility, such as a flow station, with the size of the cells determined by the transmit range of the VTOL UAVs located at these flow stations. This system will provide accurate information on the type of activity causing the pressure drop and enable the rapid deployment of military personnel in the event of the detection of criminal activity or the oil-spill-response team in the event of a leak.

Pipeline Network

The typical pipeline network is shown in **Fig. 1.** The dimensions of the pipelines are shown to increase from the well location, with the flowlines taking the crude oil from the well to the flow station. The flow-station output is directly fed either to a small manifold using a delivery line or to the main manifold using the pipelines. The crude oil is then sent to the export terminal or the refinery through the trunk line. From the diagram in Fig. 1, it can be seen that the most critical of these lines is the trunk line because any attack on these lines will lead to a shut-in of the production from all the wells feeding into it. They are also the costliest to build and the most lucrative for major crude-oil thieves because the volume taken out per time is very large (Okoli and Orinya 2013).

The diagram in **Fig. 2** shows the architectural diagram of the pipeline network, illustrating the layout of the wells and the different sections of the pipeline and the processing facilities. Multiple wells feed to a single flow station from several flowlines. Small-scale vandals can tap into these flowlines or the delivery lines from where the crude oil is transferred into tankers or barges.

Fig. 3 shows a typical crude-oil pipeline network in Rivers State, Nigeria (Kakulu 2007). From the diagram, the main trunk lines are linearly installed, with the delivery lines feeding into them through the manifolds.

The pipeline network in Fig. 3 can be broken up into wide area cells, as shown in **Fig. 4.** The UAVs are located at the nearest manned station or the processing facility closest to the intersection of the cells. The same UAV can be used to provide coverage for the

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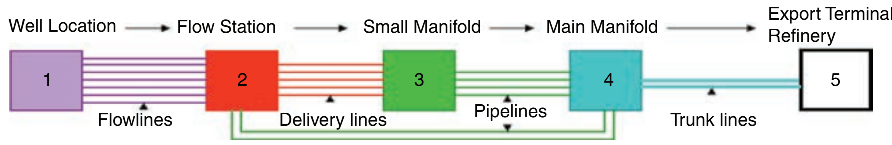

Fig. 1—Typical pipeline network.

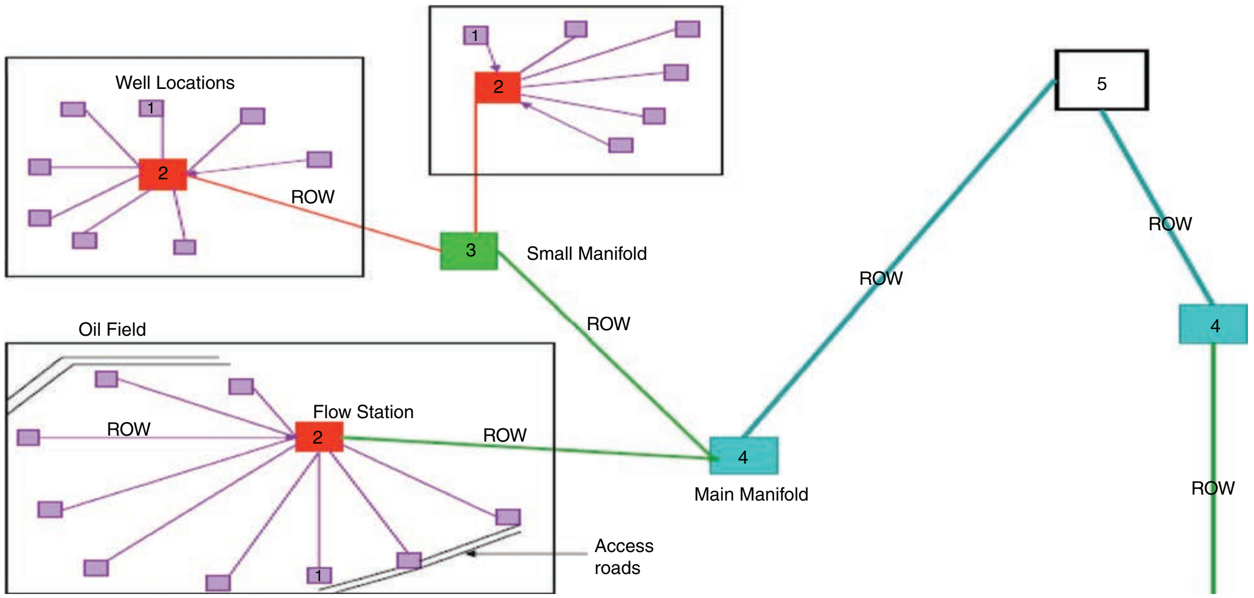

Fig. 2—Pipeline architectural network.

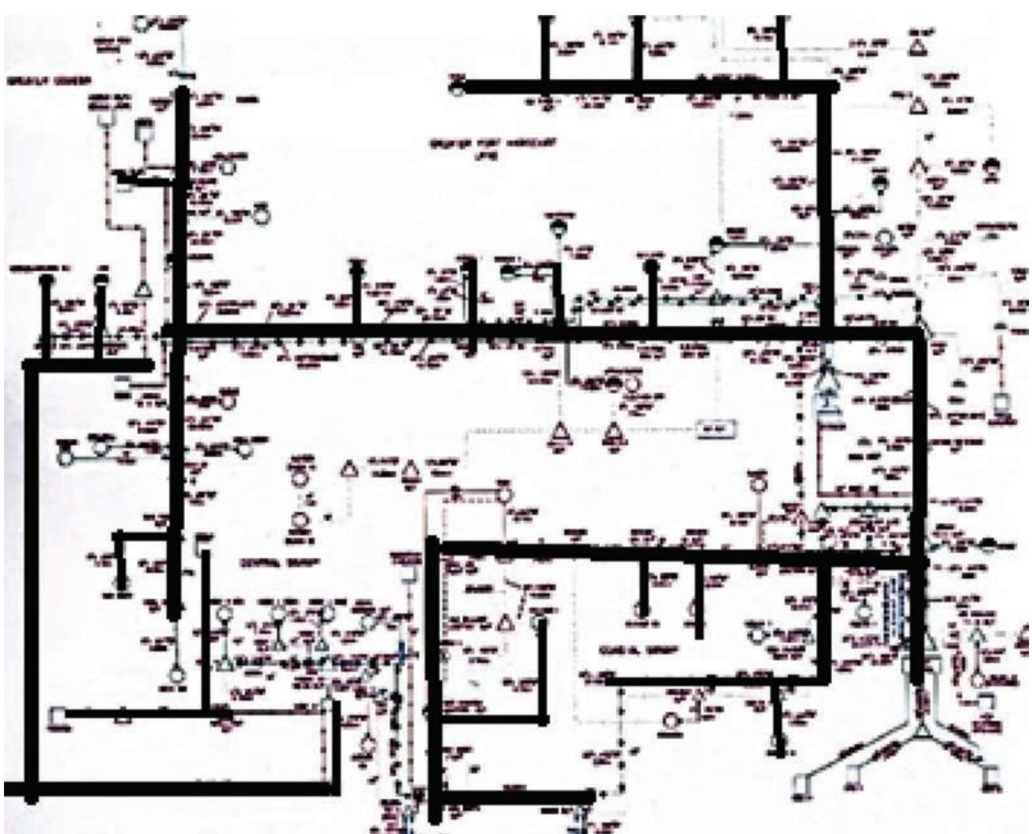

Fig. 3—Typical crude-oil-pipeline network.

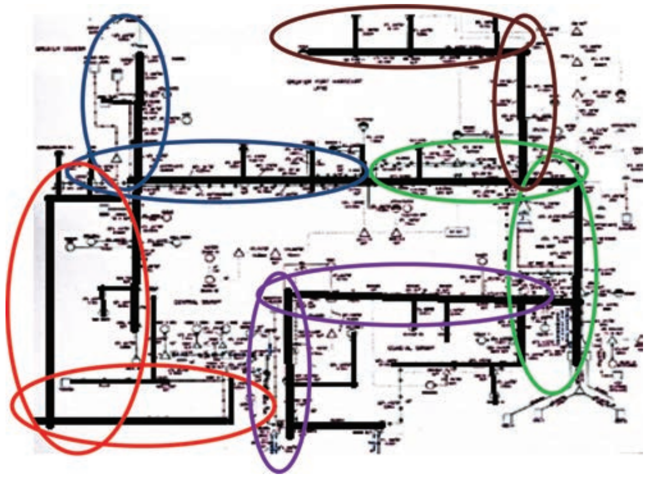

Fig. 4—Pipeline network broken into wide area cells.

cells with the same colors. The cells can be designed and arranged such that the number of UAVs required to provide coverage is kept at a minimal number. This will ensure that multiple alerts and suspected attacks on the pipelines can be inspected simultaneously.

Unmanned Aerial Vehicles (UAVs)

UAVs are aircraft deployed with or without the control of human operators, and they are used to provide video information over a location (da Silva et al. 2007; Kontogiannis and Ekaterinaris 2013). The component systems that make up the UAV include the air vehicle, the ground-control station, payloads, data link, and support equipment. The UAVs have been used more by the military for reconnaissance missions but are currently finding more and more applications in civilian and urban applications.

The most-popular applications of UAVs include

1. Aerial reconnaissance: UAVs are often used to obtain aerial video of remote locations, especially where there would be unacceptable risk to the pilot of a manned aircraft. UAVs can be equipped with high-resolution still, video, and even infrared cameras. The information obtained by the UAV can be streamed back to the control center in real time.
2. Scientific research: Scientific research often necessitates obtaining data from remote and sometimes hazardous locations where a manned aircraft would pose a risk to the pilot. A UAV can be used to obtain data from such locations with no risk to a human pilot.
3. Logistics and transportation: Helicopter-type UAVs can be used to carry and deliver a variety of payloads. The suspension of the payloads at the bottom of the helicopter makes it immune to any aerodynamic drag.

The cost of UAVs varies from less than USD 100 to more than USD 1 million depending on the type and the application. Depending on the budget of the operator, UAVs costing between USD 1,000 and 5,000 can be modified for long range and fitted with the required cameras and transmission equipment suitable for the pipeline-inspection applications. The Unmanned Vehicle University also provides a drone/UAV pilot training certification costing USD 3,500 (Unmanned Vehicle University 2015). Thus, with less than USD 10,000, operators can maintain and manage an effective pipeline-surveillance system. This, compared with the deployment of human personnel with security teams and the associated logistics and security costs and also the time required for repeated visits to these sites, is a much more cost-effective approach to pipeline monitoring.

Types of UAVs. There are different types of UAVs, and their designs are determined by the application and purpose for which they will be deployed. The US Air Force classification of UAVs is determined by the size, the flight altitude, and the duration. These classifications are:

- Micro-UAVs: small, extremely portable units
- Low-altitude, long-endurance UAVs
- Medium-altitude, long-endurance UAVs
- High-altitude, long-endurance UAVs

For the purpose of this work, the micro-UAV (small portable unit) will be used. These portable units do not require a runway and can be easily transported, deployed, or stored. Another key feature is the fact that they are powered by electric motors and are designed to take off and land vertically. The most-common classification for this type is the VTOL UAV (Austin 2010). The range and altitude classifications for the different UAVs are shown in **Tables 1 and 2.**

VTOL. VTOL UAVs are those that are able to generate downward thrust and take off within a very limited space. They are used in locations where runway facilities are inaccessible such as operations in forest or bush areas. The VTOL UAVs are identified in the Micro and Mini categories in Table 2. They can be fitted with cameras for either still-picture acquisition or fitted with video cameras for recording of motion pctures. The can also be fitted with specialized infrared cameras or sensors for atmospheric-monitoring purposes.

Designation	Maximum Altitude (ft)	Radius (km)	Speed (knots)	Endurance (hours)
Interim medium-altitude endurance	Up to 15,000	Up to 250	60 to 100	5 to 24
Medium-altitude endurance	3,000 to 25,000	900	70, cruise	> 24
High-altitude endurance	65,000 maximum	Up to 5000	350	Up to 42
Low observable high-altitude endurance	45,000 to 65,000	800	300, cruise	Up to 12

Table 1—Range and altitude classification of high-capacity UAVs (Wong 1997).

Category Name	Mass (kg)	Range (km)	Flight Altitude (m)	Endurance (hours)
Micro	< 5	< 10	250	1
Mini	< 25/30/150	< 10	150/250/300	< 2
Close range	25–150	10–30	3000	2–4
Medium range	50–250	30–70	3000	3–6
High-altitude long range	> 250	> 70	> 3000	> 6

Table 2—Classification of UAVs.

They are capable of a flight range of less than 10 km at an altitude of up to 250 m with flight-duration capacity of 1 hour.

VTOL Configurations. The different configurations of the VTOL UAVs are shown in **Fig. 5.** The most-popular architecture for urban surveillance is the quad-rotor type. With this type, flight control is achieved by changing the speed of each rotor with each rotor individually driven by an electric motor mounted at the rotor head.

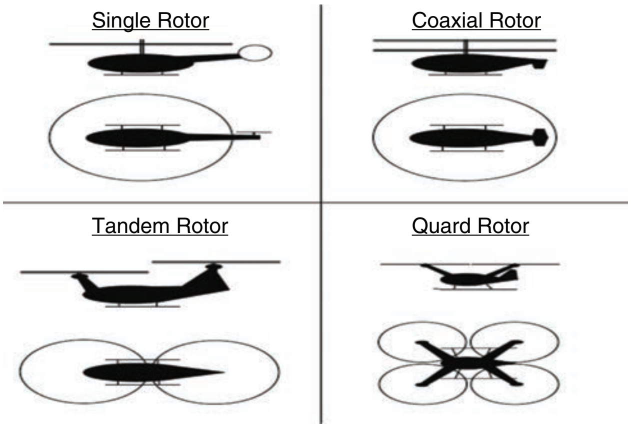

Fig. 5—VTOL UAV configurations (Austin 2010).

UAV Deployment for Pipeline Monitoring

The block diagram of the UAV pipeline-monitoring network is shown in **Fig. 6.** The selection of the UAVs and the cell size is made such that the cell sizes are small enough to shorten the required flight time for the UAV to arrive at the location of interest. Other leak-detection and dynamic pipeline-pressure monitoring algorithms are used to localize suspicious leak sites, and the UAVs are deployed to provide video feedback of the locations. In the event of multiple attacks or diversions, nearby UAVs from other cells can be deployed to the different locations. This is made possible by the small sizes of the cells and the proximity of the cells to each other. For operators who have already installed fiber-optic-based intruder and leak-detection systems, the fiber-optic-based system identifies and classifies any activity around the pipeline ROW, and it is able to send an alert whenever there is any intruder activity before the pipelines are breached. The UAV can be deployed to check these activities and detect if it is an actual attack or a diversion. The UAV to be deployed is the VTOL-type because of its deployment ease, portability, and lack of the requirement of a runway. The flight range of remote-controlled UAVs is usually limited by the range of the control signals from the remote controllers and the available fuel on the UAV. Typical flight ranges for commercial UAVs extend up to 40 km, with newer UAVs having capabilities for longer distances. Autonomously controlled UAVs (UAVs with onboard controllers) can fly for longer ranges spanning up to 12 hours of continuous flight, but the onboard cameras of those UAVs cannot be manipulated while the UAV is on its flight. A hybrid approach, which enables a longer flight compared with the remote-controlled UAVs while still retaining the camera and flight-control capability from the ground-control center, is presented in this paper. It uses a highly directional antenna mounted on a steerable axis on the telecommunication tower located at the respective flow station. These highly directional antennas are mounted such that the high-capacity long-range-communication link is guaranteed whenever the UAV is scanning any pipeline. The use of highly directional antennas increases the range of the UAVs. The clarity of the images of the pipeline ROW and the pipelines depends on the type of cameras mounted on the UAV. The pictures taken by the cameras or the video recording is relayed to the ground-control center in real time to enable the operators to determine the state of the pipeline and deploy the appropriate response in the event of any incidents on the pipeline. The desired video- and picture-recording cameras should have pan, tilt, and zoom functionalities that are controllable from the ground-control center. The cameras can also have thermal-imaging capabilities and night-vision capabilities for data capture at night. The UAVs can also be programmed to undertake routine monitoring, with the flight plan and route programmed into the onboard controller. The route of the UAV can be programmed such that the UAV controller manipulates the rotors from its base to

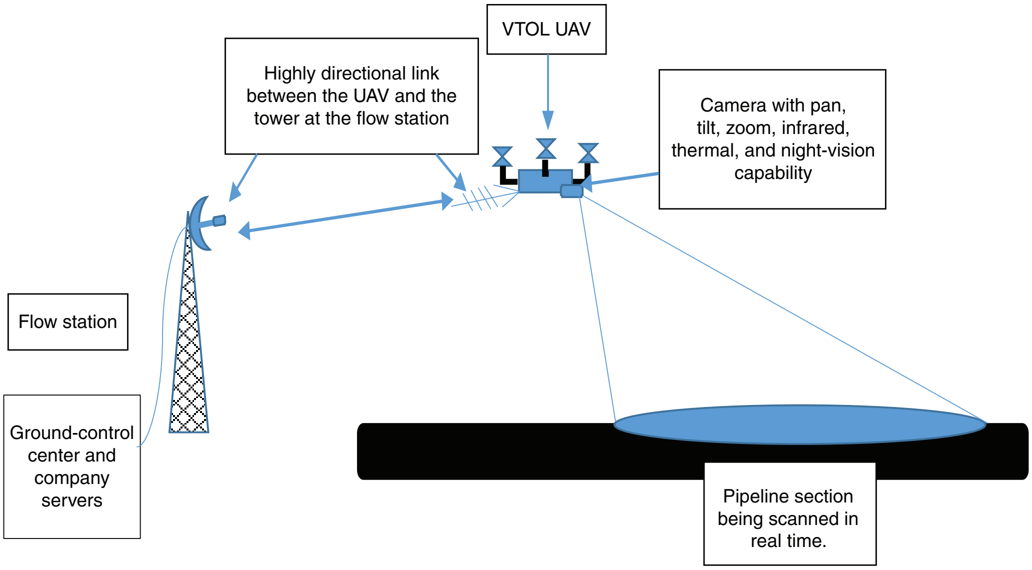

Fig. 6—UAV deployment for pipeline monitoring.

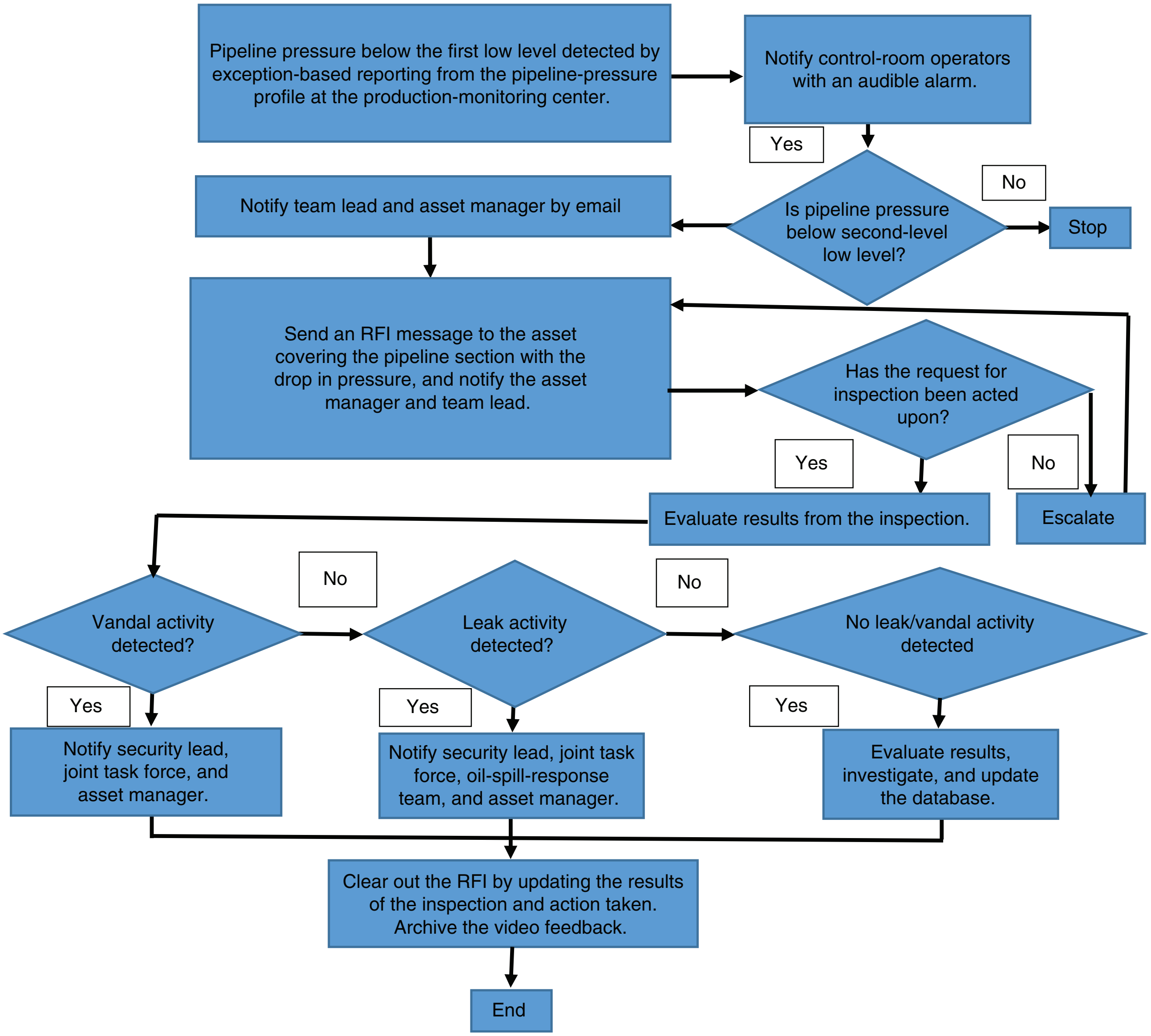

Fig. 7—System flow chart.

go through a specific route capturing the video signals along that route. In this mode, the real-time transmission may or may not be activated because this is for routine inspection. The UAVs are also designed to carry embedded—global-positioning system (GPS) and global system for mobile communications (GSM)—tracking systems. The GPS monitors the location of the UAV in real time, and, if at any point during the flight the UAV experiences any failure or a sudden drop in altitude, these flight data can be sent to the ground-control center through the relay link. If, however the UAV crashes, the last set of GPS coordinates are sent through the GSM to a registered mobile phone to enable the tracking and recovery of the system. It can also be designed with a beacon that sends out radio-frequency signals to enable trackers to pinpoint it in the event of it landing in forested areas.

Ground-Control Station. The ground-control station can be implemented with minimal infrastructure. Compact configurations include the backpack models deployed for military operations. The control station for small UAVs can be manned by one operator by use of one or more screens to serve as the control and navigation interface and the video-feedback interface. The screens can be switched to view the desired screen or multiple screens to display each interface.

Operation Work Flow and Flow Chart. The work flow guiding the operation of the system is described in **Fig. 7.**

System Advantages. The key advantages of this deployment include

1. Real-time video feedback of activity on the pipeline.
2. Reduced cost of deployment by eliminating unnecessary deployments.
3. Reduced volume of crude-oil theft because the rapid operation of UAVs leads to a quicker deployment of military personnel to the vandalization site.
4. The VTOL UAV is a cost-effective UAV deployment requiring no runway or expensive control-station costs.

Conclusion

UAVs are capable of providing a rapid, real-time view of remote locations. The pipeline network is broken down into wide area networks for the different pipe sections, and the deployment of UAVs for these sections provides real-time video feedback of the pipeline whenever an exception-based pressure reduction is detected. The VTOL UAV does not require a runway and is capable of carrying video cameras for real-time capture. The use of highly directional antennas on the UAVs and at the flow station increases the range of the UAV. This deployment is capable of enhancing military response to vandalization/theft activity by providing accurate and timely data of the vandalization/theft activity, thereby reducing false alarms and ultimately reducing the volume of crude-oil theft in Nigeria.

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