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An Agent Based Surveillance System for Oil Pipeline Vandals Detection in the Niger Delta Area of Nigeria

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ABSTRACT

Oil sector account for over 90% of foreign exchange earning to Nigeria Government and the bulk of the oil comes from the Niger Delta Region. Over the years, crude oil theft and spillage through pipeline vandalism is considered one of the major problems of the region, as it affects the economy of not just the region but also the government. Several approaches including deployment of military personnel's, drones etc have been used to tackle the issue of vandalism but none has yielded any good result. This research work addressed the issue of pipeline vandalism through synchronization of wireless agents' activities for optimum power utilization and intelligent reporting of vandal's activities from the location of pipeline deployment to the central control station using satellite and data communication tools. A simulation of the environment shows that false positive alert was greatly reduced as every captured data is highly analyzed at the pipeline site before information can be transmitted to the central control station for further actions, and by so doing the battery life of the network is preserved due to high reduction in the processor and storage utilization. While this work ensures proactive intervention of events before any harm can be exerted to the pipelines, it equally takes a decision that will help in preserving the network so that the network nodes can exist for a prolonged period of time without any disruption.

Keywords: Surveillance System, Pipeline Vandalism, Wireless Agents, Vandals Detection, Kalman Filter

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1. INTRODUCTION

The Niger Delta region is one of the richest oil producing areas in Nigeria and the largest wetland in Africa. The region is estimated to have 37 billion barrels (bb) of oil reserves and 168 trillion cubic feet of gas deposits (Omotola, 2010). The oil sector account to over 90% of foreign exchange earnings for Nigeria and the bulk of the oil comes from the Niger Delta region of Nigeria. Crude oil is of great economic importance, as it is used for the production of essential materials like plastic (electronic/automobile cases, automobile parts, etc), electronic systems (telephone materials, sound system covers, etc), textile materials, furniture and kitchen utensils (Watts, 2004).

Over the years' crude oil theft and spillage through pipeline vandalism is considered one of the major problems of Niger Delta region. Rising cases of pipeline vandalism by militant groups and other uncategorized vandal groups have significantly affected oil production and the revenue base of the government and oil companies operating in the region. In spite of all the efforts made by the research communities and Nigerian government to curb these activities, it continues unabated. Several methods have been proposed to combat these problems, some of which are the use of internet of things (IOT) technologies, Unmanned Area Vehicles (UAV), law enforcement agents and community vigilante groups.

However, none of these yielded the desired solution due to the disparity between the time an event occurs and the time a report is made for an action to be taken. The aim of this paper is to build an intelligent agent-based system that will keep surveillance of the oil fields in the region with optimum power utilization and a reduced false positive alarm. The paper continues with extensive review of related literatures in the field. Next is a detailed explanation of the methodology adopted for the research, the results and discussion and finally the conclusion.

2. RELATED WORKS

Several literatures have addressed different approaches used in petroleum vandal detection. Some of the approaches use surveillance based, oil spillage detection approach, pipeline pressure detection, etc. Ogujor et al. (2013) proposed a system based on microcontroller that is capable of retrieving and reporting security and location information from the oil field to the operator at the control center. The system reports information through Liquid Crystal Display (LCD) and it is kept within the pipeline environment as it is based on physical cable connection. Franklin et al. (2016) on a similar note took an oil spillage detection approach for vandal detection in Niger Delta region of Nigeria.

Eluwande et al. (2016) proposed the development of Unmanned Aerial Vehicle (UAV) for real-time monitoring and surveillance of vandals in oil pipelines. The system uses a live stream video for gathering information about vandals in the oil pipeline. The major drawback with this approach is the high energy and implementation cost involved. Ezeh et al. (2014) used obstruction detection in the normal flow of electrical signals to detect and send SMS and alarm to the control room as an indication that a vandal has been detected. Igbajar et al. (2015) proposed a microcontroller based system that monitors and reports vandalism through irregular inflow and outflow of oil pressure in the pipeline. The system was not very sensitive to small reduction in the oil pressure, so any small damage to the pipeline may not be noticed by the system.

Obodoeze et al. (2014) developed video camera based pipeline surveillance and SMS alert system for oil pipeline intrusion detection. Ajao et al. (2018) extended the work of (Obodoeze, Asogwa, & Ozioko, 2014) by incorporating ATmega 328, GSM and GPS to report the position, geographical locations and distance of the intruder to the pipeline. Their approach lacks the intelligence needed to optimize detection so as to avoid false positive reporting and resource (memory and processor) wastage. This paper tends to optimize the use of the system resources by making intelligent intrusion detection that will reduce false positive detection.

3. METHODOLOGY

The two important concepts in this research work are, object recognition and geo-location identification. Based on the two concepts there are two important datasets required to actualize the intension. The first dataset is Google image dataset for object recognition training and the second is a simulation of the GPS readings for tracking of the suspected vandals using Kaman Filter Algorithm.

3.1. System Architecture

This paper uses hybrid (Star – Mesh) network topology for transmission of messages across the network. The network nodes are made up of sensing, processing, transceiver and power units. It also has a location finding system and a mobilizer. The sensing units are made up of the ADC and sensors. The ADC helps to convert the sensing signals from analog to digital after which it is transmitted to the processing unit. The processing unit also consists of machine learning application that helps to understand if an object is to be transmitted for further processing at the sink node. Once an object in the network is detected to be a vandal his/her information (position, picture, coordinates and movement) is transmitted on real time through the internet to all the designated users for tracking and follow up. The network architecture is show in figure 1.

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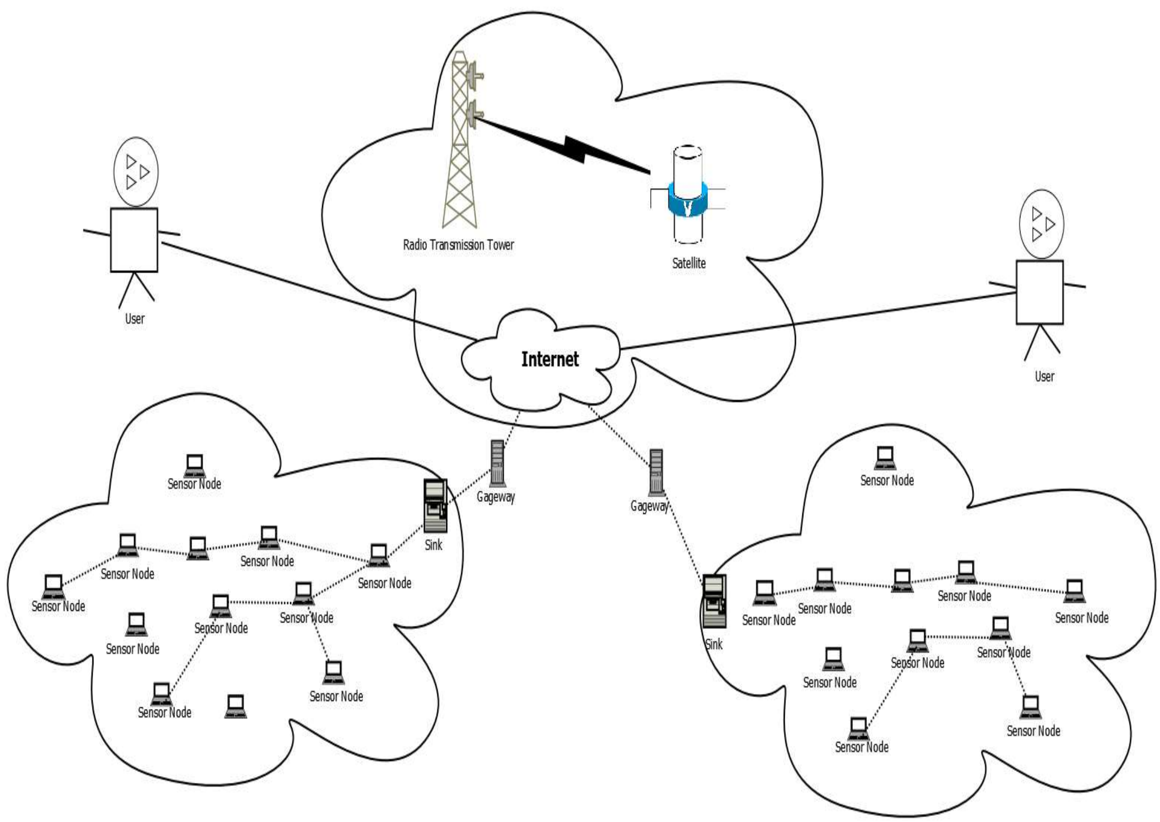

Figure 1: The Wireless Sensor Network Architecture

3.2. Algorithm Development

This paper uses Kalman Filter Algorithm for the estimation of the location and the direction of a detected vandal. The data used for this algorithm is a simulation of the GPS readings and it consists of three important variables: the position of the object under consideration (S_t), the object direction of movement (u_t) and the observed error in the movement and the actual sensor or GPS readings (z_t). The relationship between the three variables can be realized using the following Bayesian Filter.

$$P(s_t|z_t, u_t) = \eta P(z_t|s_{t-1})P(s_{t-1}|u_t) \tag{1}$$

In this equation η denote the normalization factor, z_t denote the system observation, u_t denotes the transition modification parameter for the state, and s_t denote the current state vector.

3.3 Outline of the Kalman Filter

The main goal of Kalman Filter as a Bayesian filter is to solve equation 1 using the following assumptions.

a. There is a linear state transition, which is in the following form.

$$s_{t+1} = As_t + Bu_t + w_k \quad (2)$$

Where s_t is the state, u_t is the control, and w_k is added Gaussian noise.

b. There is a linear measurement which is in the form

$$z_t = Hs_t + v_k \quad (3)$$

Where z_t is the observation and v_k is added Gaussian noise.

c. The system is continuous.

The assumption is the main reason for the optimality of the algorithm. The algorithm development comes in two phases: the update and measurement phase.

3.4 The Time Update Phase

This phase foresees the forward projection of the state using equation 2 and because of the forward projection of the state the uncertainty must also be projected forward too. Equation 4 can be used to update the covariance of the state since it follows a Gaussian distribution with fully parameterized value of mean S_t and covariance P_t

$$P_{t+1} = AP_tA^T + Q \quad (4)$$

Where A is the matrix used to propagate the state mean and Q is the random Gaussian noise. After this phase S_t and P_t becomes the new Gaussian characterized by S_{t+1} and P_{t+1}.

3.5 The Measurement Phase

This is the phase responsible for estimating and correcting the error in the values obtained using the calculated value and the actual value. In this phase a measurement is made to obtain the Kalman Gain as can be seen in equation 5 using the linear model of equation 3.

$$K = PH^T(HPH^T + Q)^{-1} \quad (5)$$

The next step will be to obtain the innovation (see Equation 6) which is the difference between the expected observation and the actual observation.

$$\hat{z} = (z_t - H_t s_t) \quad (6)$$

Now we combine equations 5 and 6 to get the posterior distribution as shown in equation 7 (correcting the mean) and equation 8 (correcting the covariance)

$$s_t^- = s_t + K\hat{z} \quad (7)$$

$$P_t^- = (I - K_t H_t)P_t \quad (8)$$

Here, the posterio distribution are full parameterized by S_t^- and P_t^- The steps used all along show a single iteration of Kalman filter which output are used as input, and new control for subsequent observations.

$Algorithm: Kalman\_Filter$
$Input: s_{t-1}, P_{t-1}, u_t, z_t$
$Output: s_t^-, P_t^-$

1. $s_t = As_{t-1} + Bu_t + w_t$
2. $P_t = AP_{t-1}A^T + Q$
3. $K = PH^T(HPH^T + Q)^{-1}$
4. $\hat{z} = (z_t - H_t s_t)$
5. $s_t^- = s_t + K\hat{z}$
6. $P_t^- = (I - K_t H_t)P_t$
7. $return\ s_t^-, P_t^-$

Figure 2: The full Kalman Filter algorithm in pseudocode.

4. RESULTS AND DISCUSSION

The result is shown in figure 3, 4 and 5. When an object appears at the remote station that is the pipeline field the system captures the object, process it and make interpretation based on the result of the processing. The object might just be an ordinary farmer, a herdsman, cattle, etc. so in that case the system will not alert sleeping sensor nodes or will not continue processing and storing images about the object. But if the object happens to be a suspect with some harmful instrument like harmer, chisel, gun, etc the system will alert all other neighboring sensors so they will be at alert in other to start sending information regarding the position, coordinates, and images of the object. As the sensors are sending messages their activities are displayed at the base station as shown in the log section of figure 3.

The Graphical User Interface (GUI) at the base station consists of a map view showing the position and movement of the vandal, a video footage of the vandal with an inscription to identify the vandal as extremely harmful, relatively or not harmful. For every message that enters, the system generates a log to aid decision making regarding the intruder. As the vandal is navigating the region the system keeps track of the movement using Kalman filter algorithm as shown in figure 4 and 5. Figure 4 shows how far the vandal has moved from the time he/she was first reported, while figure 5 shows the rate at which he/she is moving. The result shows an overall false alert detection of less than 5%.

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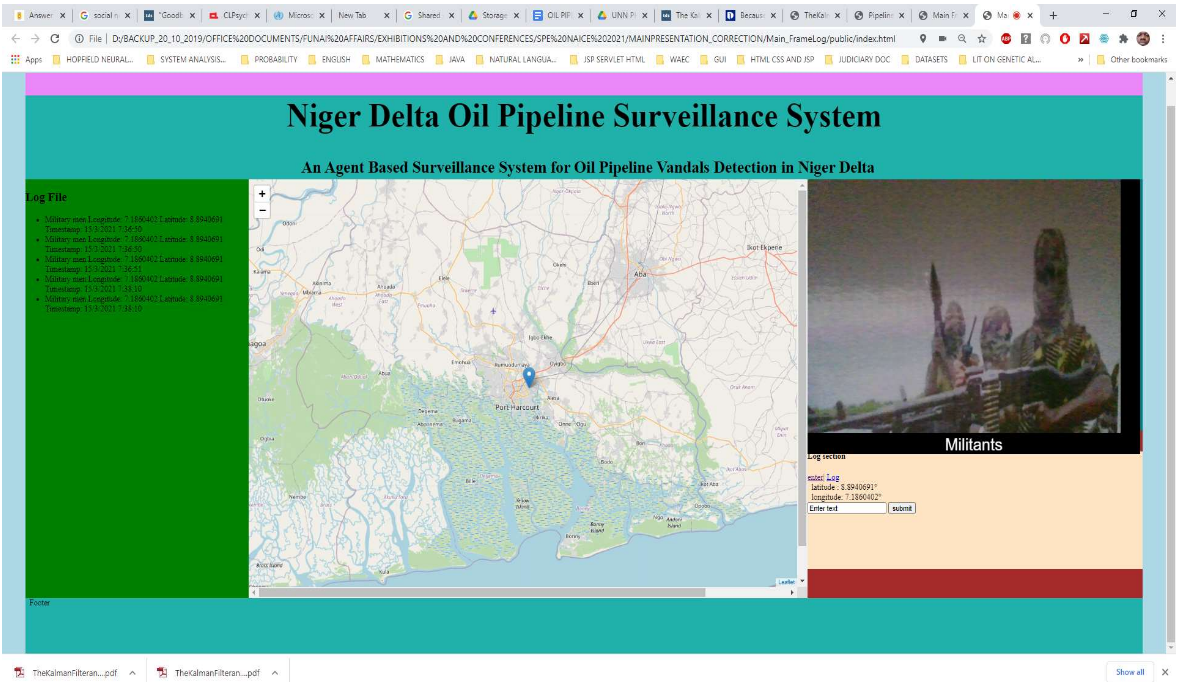

Figure 3: Central System Interface for monitoring pipeline vandals

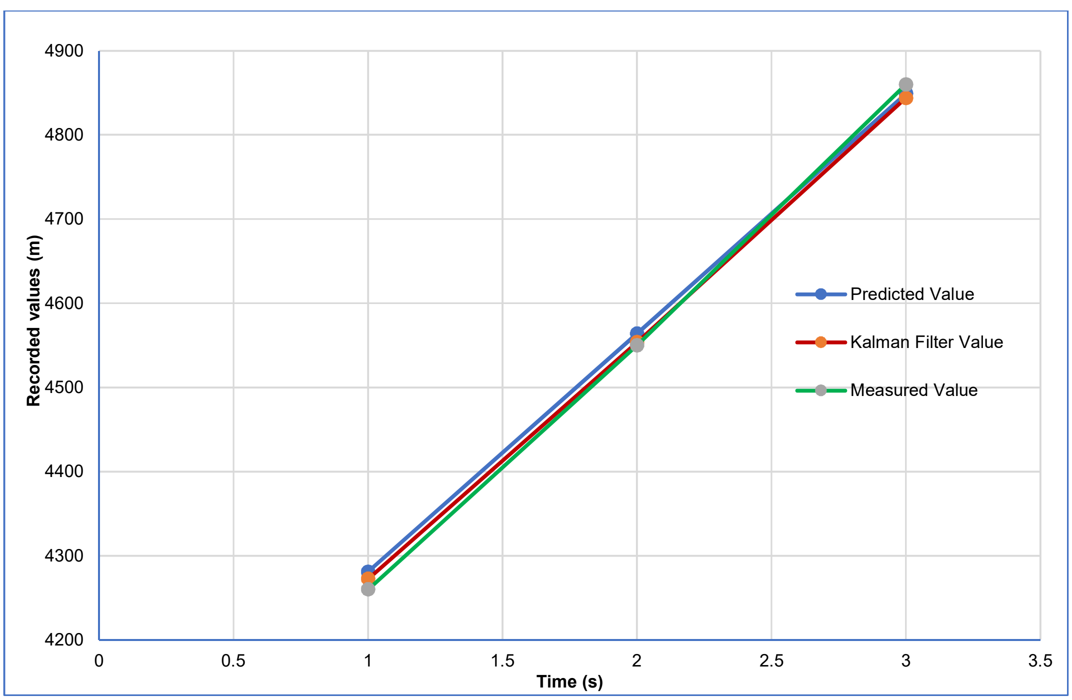

Figure 4: Kalman Filter prediction of vandals distance

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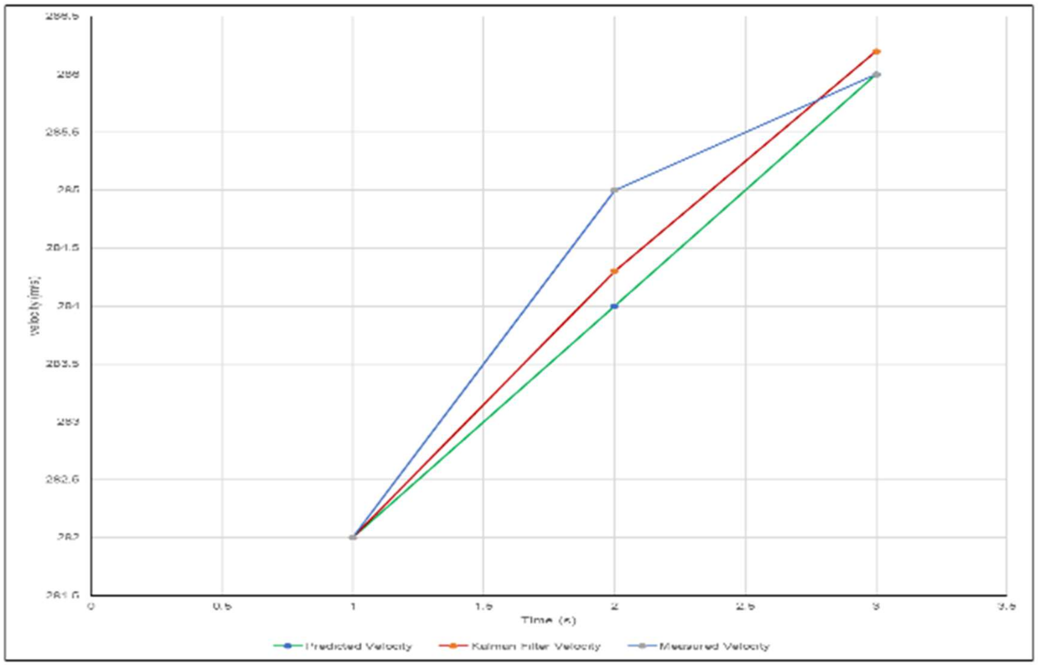

Figure 5: Kalman Filter prediction of vandal's velocity with respect to time

5. CONCLUSION

The effectiveness of an agent-based surveillance system can be evaluated based on the life span of individual nodes in the network and the percentage of true positive detections. Based on these criteria, this research work has critically addressed the issue of power optimization, true positive detection and prediction of vandal location even when they are partially out of the network range.

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