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Development of A Computational Model for Monitoring Pipeline Network Using Unmanned Aerial Vehicle

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Abstract

The study identified and acquired relevant data for pipeline monitoring model, formulated a mathematical model, simulated the model and evaluated it. This is with a view to developing an intelligent information gathering for pipeline monitoring and security. Data was acquired by taking different aerial images of vandalisation tools and probable vandals using Unmanned Aerial Vehicle (UAV). Surfer 10 application was used to digitize the Nigerian pipeline grid and distribution network to obtain the pipeline coordinates. The itinerary of the UAV for monitoring pipeline was formulated while Sobel edge detection algorithm was engaged with template matching algorithm for vandal detection. Stored image templates of digging equipment around the vicinity of the pipeline were used in a template matching model to detect the presence or absence of digging activities. The different template matching algorithms method such as sum of absolute difference (SAD), sum of squared differences (SDD) and maximum absolute differences (MAD) were used on random images, where best fit results which produced optimal correlation and peak signal to noise ratio (PSNR) values were adopted for object detection and classification. The designed model was simulated using Simulink in MATLAB and evaluation was done by comparing the efficiency of the model. The simulation results showed SSD technique as having the best accuracy with an average value of 5.7065 x E^{+04} while SAD and MAD techniques have average values of 4.1835 x E^{+04} and 1.635 x E^{+04}, respectively.

Keywords: Unmanned Aerial Vehicle, Pipeline, SAD, SDD, MAD, PSNR, Sobel

1. INTRODUCTION

Pipeline networks consist of many branches that are built in sections of varying length possibly reaching up to hundreds (or even thousands) of kilometers. Pipelines are built in any of these three ways: above ground, buried underground or buried under seabed (Ramalli *et al.*,2016). The safety and the protection of all pipelines are important both for the people and the surrounding environment. Despite continuous and effective maintenance, the possibility of a leak cannot be eliminated, since not all causes of leakage can be *detected* in advance. Leaks from the pipeline can occur due to various causes, such as earthquakes or slippage of the soil (Gómez and Green, 2015), but also due to accidental hot taps or external actions by Vandals. Unmanned aerial Vehicles (UAV), also called Drone, was engaged in this work.

Drone is necessary to relay immediate and real time happenings at any of the pipeline location. Drone unlike other mechanism, is mobile and therefore allows for a wide range of visual coverage at a single surveillance inspection, without processing of the data collected, since the camera mounted on the drone transmits images directly to a video terminal, where a technician checks the state of the pipelines being analysed. The mobility and altitude advantage of drones make it difficult for easy reach of vandals for destruction unlike other mechanisms that can easily be destroyed because of their location and static nature. The ability of drone to efficiently and timely detect unscrupulous action of vandals gives it an edge over other mechanism.

Hence, in this work, attempt was made to develop a security model for Unmanned Aerial Vehicle (UAV), also called drone, with a view to eliminate oil pipeline vandalism which has been bringing a great loss to the nation and affecting her economy negatively.

Problem Statement

Oil pipeline vandalization in Nigeria has led to shortage of petroleum product for end users, loss of life as a result of accompanied fire outbreak, pollution of aquatic life and food crises in the nation (Ondracek *et al.*, 2014). The Nigerian government loses about 20 billions of dollars yearly as a result of the activities of pipeline vandals (Okoli and Orinya, 2013). This is asides the monetary cost of loss lives, property and the environment. In previous years, the main measure taken by the government to guard against pipeline vandalization was the deployment of security personnel to some of the areas that are prone to attack by vandals. However, this effort has failed to ameliorate the problem. There are also allegations of security personnel aiding and abetting the vandals. (Vidal, 2011)

Vandalism has been a major setback to the growth and development of the nation. In spite of the huge amount yearly spent on securing critical infrastructures, our oil pipelines are still not secured.

Existing measures deployed in providing security for the oil pipelines seems ineffective and inefficient because of low sensitivity, inaccuracy in vandal detection which make them non-preventive and immobility which subject them to easy destruction by the vandals.

An effective and efficient mobile measure is therefore needed to tackle the menace of vandalism that has eaten deep into the fabric of our nation; hence this study.

2. METHODOLOGY

This aspect outlines the steps taken in this research, design adopted methods, sample selections, data collection and analysis. The integrity of oil pipelines and similar critical infrastructures are highly dependent on the level of security existing thereof. The adoption of real time remote monitoring technology based on unmanned aerial vehicles (drones) is expected to mitigate the issue of vandalism.

Extensive literature review was done to gather knowledge, identify techniques and to obtain relevant data needed for the model for effective monitoring. The pipelines coordinates were obtained by designing the Nigerian pipeline grid and distribution network through digitization using Surfer 10 application software. These coordinates were used by the drones to navigate the pipeline network during surveillance. Sobel edge detection algorithm was engaged with template matching algorithm for vandal detection. Stored image templates of digging equipments around the vicinity of the pipeline were used in a template matching model to detect the presence or absence of digging activities. The designed model was simulated using Simulink in MATLAB. Different template matching methods such as sum of absolute difference (SAD), sum of squared differences (SDD) and maximum absolute differences (MAD) were engaged and used on random images where best fit results which produced optimal correlation and peak signal to noise ratio (PSNR) values were adopted for object detection and characterization. Evaluation was done by comparing the efficiency of the model, in terms accuracy and response time, with an existing model.

2.1 Formulation of the Model

The flight dynamics of the Quad coper, to ensure effective monitoring of the pipelines, was formulated. In the same vein, image recognition and classification model using template matching technique with sobel edge technique was also formulated.

$$(x, y, z) \quad (3.1)$$

Where x, y and z represent the 3-D axis of horizontal, vertical and depth coordinates respectively. To have knowledge about the characteristics of the entire structure and their dynamics based on the center of gravity (CG) of the quad copter, there is a need to define an additional three coordinates, which are

$$(\emptyset, \theta, \psi) \quad (3.2)$$

$$\begin{pmatrix} b1 \\ b2 \\ b3 \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} x \\ y \\ z \end{pmatrix} \quad (3.3)$$

Where for heading (Ψ), the body and reference frame is defined as

$$\begin{pmatrix} b1 \\ b2 \\ b3 \end{pmatrix} = \begin{pmatrix} \cos\psi & \sin\psi & 0 \\ -\sin\psi & \cos\psi & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} x \\ y \\ z \end{pmatrix} \quad (3.4)$$

The pitch (θ) is defined with respect to the body and reference frame as

$$\begin{pmatrix} b1 \\ b2 \\ b3 \end{pmatrix} = \begin{pmatrix} \cos\theta & 0 & -\sin\theta \\ 0 & 1 & 0 \\ \sin\theta & 0 & \cos\theta \end{pmatrix} \begin{pmatrix} x \\ y \\ z \end{pmatrix} \quad (3.5)$$

and the bank angle (Φ) is defined with respect to the body and inertia reference frame as

$$\begin{pmatrix} b1 \\ b2 \\ b3 \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\Phi & \sin\Phi \\ 0 & -\sin\Phi & \cos\Phi \end{pmatrix} \begin{pmatrix} x \\ y \\ z \end{pmatrix} \quad (3.6)$$

The template matching block is capable of implementing all the various template matching techniques such as the sum of absolute differences (SAD) otherwise known as the taxicab technique expressed by

$$d_1(I_j, T) = \sum_{i=1}^{n} (I_{i*j} - T_i) \quad (3.7)$$

The Sum of Squared Difference (SSD) which is also known as Euclidean distance metric, expressed by

$$d_2(I_j, T) = \sum_{i=1}^{n} (I_{i*j} - T_i)^2 \quad (3.8)$$

And the maximum absolute differences (MAD) technique, which is also referred to as the uniform distance metric, expressed by

$$d_\infty(I_j, T) = \lim_{x\to\infty} \sum_{i=1}^{n} (I_{i*j} - T_i)^p \quad (3.9)$$

Where, $\boldsymbol{d_1(I_j, T)}$, $\boldsymbol{d_2(I_j, T)}$, and $\boldsymbol{d_\infty(I_j, T)}$ estimates the best match position of a template within an input image.

Template matching technique is an edge detection technique of which sobel among others (Canny, Prewitt, Roberts, and fuzzy logic methods) is an algorithm under it.

The template images are by default in "RGB" format, which is in 3-D as shown in Plate 4.1. The sobel edge detector as well as the template matching block operates in 2-D as shown in Plate 4.2, thus the image must be converted to 2-D. This was accomplished using the color space conversion block in Simulink. Its parameter setting was such that the conversion was set to convert from "RGB to Intensity". Image input was set at "one dimensional input", where;

intensity is 2-D gray scale image rendering. The output from this block was fed as input to the edge detection block.

In the Edge Detection Block: The "sobel" method was selected as and output type was set to "binary image". Rounding mode was set to "floor" and overflow mode to "wrap" for fixed point operational parameters.

2.2 The coordinates of the pipeline network

The coordinates of the pipeline network were obtained by digitizing the Nigerian map with a software called surfer 10. The coordinates for each pipeline axis were programmed into the drones' Ground Control Point (GCP) CSV template file which contains **GCP labels, latitude, longitude,** and **elevation** columns. Figure 4.1 shows the Nigeria digitized map with the generated coordinates.

2.3 Simulink Model for Object Detection using Template Matching

Figure 4.2 shows the main simulation for the work which generated all the results discussed and analyzed within. It contains the Simulink blocks that prepare the images before it can be fed into the template matching block for image recognition.

3. RESULTS AND DISCUSSION

In Table 4.1, the template matching of the sobel edge detected images of the input and the template takes place in the template matching block in Simulink. Three possible methods were used namely, sum of absolute differences (SAD), sum of squared differences (SSD) and maximum absolute differences (MAD). Thus for each run of the model, at each instance of input image as template, a single method was selected to measure the SAD, SSD and MAD

metric accordingly. Therefore the higher the PSNR value, the higher the degree of similarity between reference and edge detected image.

Thus the Simulink model was generally able to detect a similarity between the template images and the input images representing the objects of interest. The MAD algorithm was known to be the fastest as corroborated in several studies such as (Foudaa, 2018) , however, it is usually ignored because of its inability to generate a valid metric value.

The average PSNR for the Simulink model based on all templates is 12.1755, while for the SAD is 4.1835 x E^{+04}, the SSD is 5.7065 x E^{+04} and MAD is 1.635 x E^{+04}. These average values is a clear indication earlier depicted in Figure 4.6 and 4.17, where the lower values of SAD and

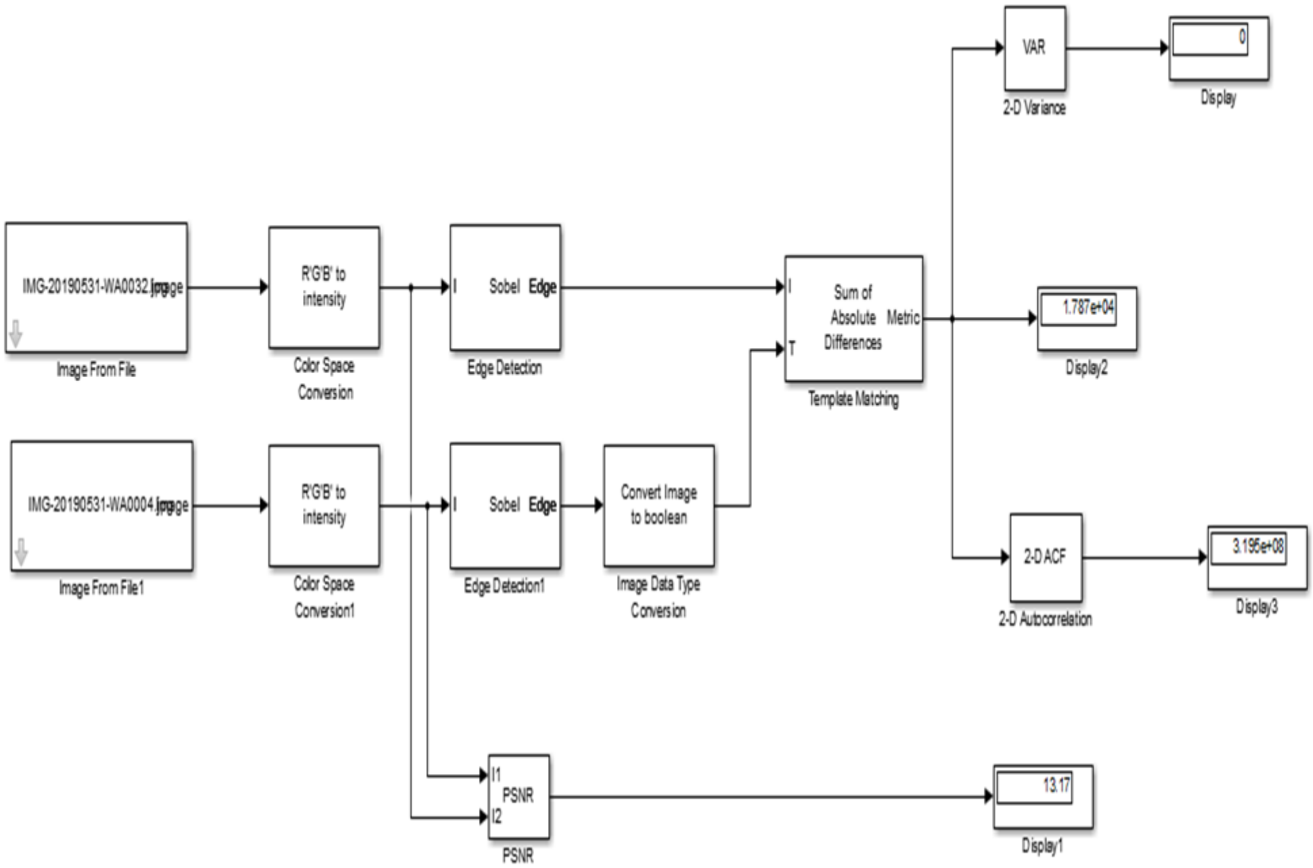

Figure 4.2: Overall Simulink Model for Object Detection using Template Matching

Plate 4.1: A 3-D image of a shovel

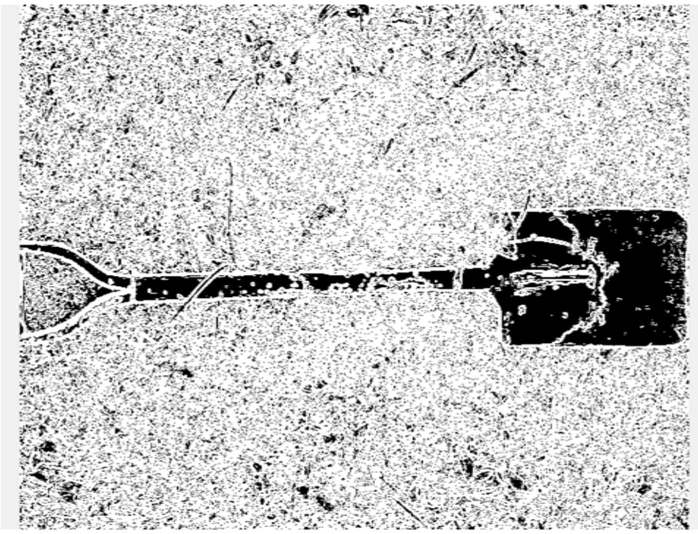

Plate 4.2: A 2-D shovel generated image used by vandals

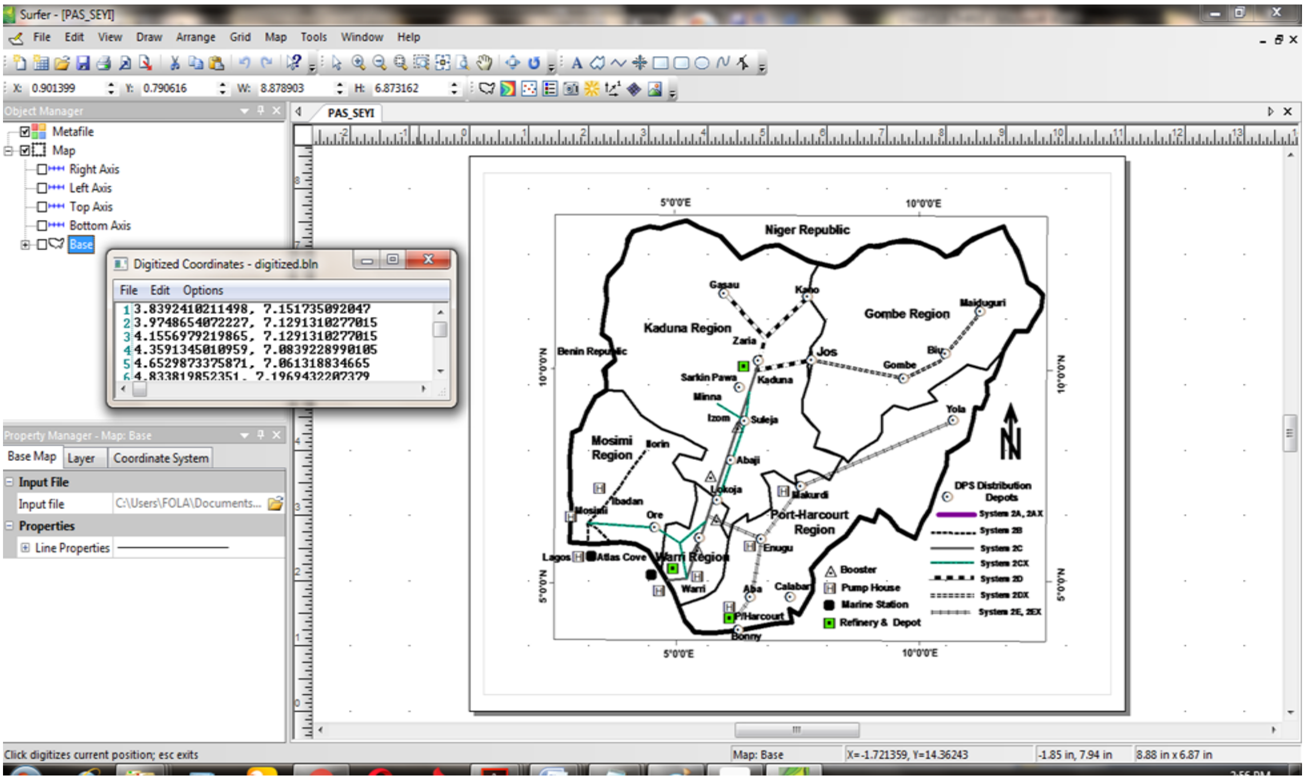

Figure 4.1: Nigeria digitized map with generated pipelines coordinates.

Table 4.1: Simulink Results for Digger Template and Digger Image Input Different Orientation

S/N	Image Description	PSNR	Correlation Index	Variance	Sum of Absolute Difference (SAD) Metric	Sum of Squared Differences (SSD) Metric	Maximum Absolute Differences (MAD) Metric
1	Digger Template + Digger image 1	14.83	3.195 x E^{+09}	0	8.62 x E^{+04}	8.62 x E^{+04}	1
2	Digger Template + Digger image 2	14.27	3.374 x E^{+09}	0	1.09 x E^{+04}	8.69 x E^{+04}	8.62 x E^{+04}
3	Digger Template + Digger image 3	11.33	2.694 x E^{+09}	0	5.19 x E^{+04}	5.19 x E^{+04}	1

Table 4.2: Average Values of Model Performance Metrics

Template	Average PSNR	Average SAD Metric	Average SSD Metric	Average MAD Metric
Digger Template	13.47	4.97 x E^{+04}	7.5 x E^{+04}	3.54 x E^{+04}
Standing Human Template	10.92	1 x E^{+04}	3.76 x E^{+04}	1 x E^{+04}
Digging Human Template	14.18	5.168 x E^{+04}	5.97 x E^{+04}	1 x E^{+04}
Shovel Template	10.132	5.596 x E^{+04}	5.596 x E^{+04}	1 x E^{+04}
Average Total	**12.1755**	**4.1835 x E^{+04}**	**5.7065 x E^{+04}**	**1.635 x E^{+04}**

MAD were later ignored and the SSD template method was adopted as the optimal template matching method that is adopted in the quadcopter for object recognition during flight.

4. CONCLUSION

The model was simulated using Simulink in MATLAB and the result showed that Sobel edge detection algorithm and SSD template matching technique were effective in vandal detection and accurate in classifying pipeline intrusion images.

The model was evaluated against an existing model in the light of PSNR and correlative index which are measures of accuracy and response time as performance metrics. The developed model showed more accuracy with a PSNR of 12.1755 as against the existing model with a PSNR of 10.183. The developed model also showed a better response time of 182 seconds than 241 seconds for the existing model.

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