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EFFICIENT DETECTION OF LANDMINES FROM ACOUSTIC IMAGES

H. Kasban

Engineering Department
Nuclear Research Center
Atomic Energy Authority
Egypt

O. Zahran and M. El-Kordy

Faculty of Electronic Engineering
Menoufia University
Menouf, Egypt

S. M. Elaraby

Engineering Department
Nuclear Research Center
Atomic Energy Authority
Egypt

S. El-Rabie and F. E. Abd El-Samie

Faculty of Electronic Engineering
Menoufia University
Menouf, Egypt

Abstract—The Laser Doppler Vibrometer (LDV)-based Acoustic to Seismic (A/S) landmine detection system is one of the reliable and powerful landmine detection systems. The interpretation of the LDV-based A/S data is performed off-line, manually, depending heavily on the skills, experience, alertness and consistency of a trained operator. This takes a long time. The manually obtained results suffer from errors, particularly when dealing with large volumes of data. This paper proposes some techniques for the automatic detection of objects from the acoustic images which are obtained from the LDV-based A/S landmine detection system. These techniques are based on

Corresponding author: F. E. Abd El-Samie (fathi_sayed@yahoo.com).

color image transformations, morphological image processing and the wavelet transform. The proposed techniques are compared considering the probability of detection, the false alarm rate, the accuracy and the processing speed.

1. INTRODUCTION

Landmines are small explosive objects that are designed to kill, maim, and wound the human such as the Antipersonnel (AP) landmines or designed to destroy or damage vehicles such as the Antitank (AT) landmines. At least 70 countries are affected by landmines, where there are more than 100 million buried landmines covering more than 200,000 square kilometers of the world surface [1]. Many obstacles are faced in removing these buried landmines such as the loss or absence of maps or information about these mines or even the areas where they were laid in, the change of mine locations due to climatic and physical factors, the large variety of types of AP and AT landmines and the high costs needed to remove mines. It is known that the production cost of landmines is very low (may be \$3 per mine) but the detection and removal cost is high (more than \$1000 per mine).

Many techniques have been developed for demining (detecting and clearing) these buried mines. A comparative study among these techniques from the points of view of cost, complexity, speed, false alarm rate and the effect of the environmental conditions is included in [2]. One of the powerful landmine detection techniques is the A/S technique, which performs the detection of landmines by vibrating them with acoustic or seismic waves that are generated and received by acoustic or seismic transducers, respectively [3]. An acoustic or a seismic wave is excited by a source at a known position. It travels through the soil to interact with underground objects. This technique consists of a transmission system which generates the acoustic or the seismic wave into the area under test and a receiving system which senses the changes in the mechanical properties of this area. The LDV-based A/S landmine detection system is considered in this paper. Its transmitting system is composed of acoustic loudspeakers and its receiving system is an LDV [4, 5]. This system has many advantages such as the sensitivity for the detection of both AP and AT landmines and the low false alarm rate. The output data from the LDV based A/S landmine detection system is in the form of 2-D color images.

This paper proposes some automatic detection techniques for objects from acoustic images. These techniques are based on color image transformations, morphological image processing and the wavelet transform. These techniques are applied in this paper to 100 landmine images scanned by the LDV-based A/S landmine detection system.

The paper is organized as follows. Section 2 presents the required color image transformations. Section 3 presents the proposed intensity and statistics based detection techniques. Section 4 presents the proposed morphology based detection technique. Section 5 presents the proposed morphology and wavelet based detection technique. Section 6 gives the experimental results of all detection techniques. Finally, Section 7 gives the concluding remarks.

2. COLOR IMAGE TRANSFORMATIONS

The acquired data using the A/S landmine detection system is in the form of 2-D RGB color images. The RGB color model is the standard model for computer graphics systems but it is not ideal for all color image processing applications because the red, green, and blue color components are highly correlated. Due to the interaction between these color components, it is difficult to discriminate between objects and the background. So, we convert the RGB data into another color space. The HSI space is often a better way to represent color images [6, 7]. The hue component (H) is a measure of the angle that represents the type of the color. The H component of each RGB pixel is obtained as follows [8]:

$$H = \begin{cases} \theta & \text{if} \quad B \leq G \\ 360-\theta & \text{if} \quad B > G \end{cases} \tag{1}$$

where

$$\theta = \cos^{-1}\left(\frac{\frac{1}{2}[(R-G)+(R-B)]}{\sqrt{(R-G)^2+(R-B)(G-B)}}\right) \tag{2}$$

The saturation component (S) represents how much whiteness is mixed with the color and is obtained as follows [8]:

$$S = 1 - \frac{3}{(R+G+B)} \tag{3}$$

The intensity component (I) represents the physical brightness and is obtained as follows [7]:

$$I = \frac{1}{3}(R+G+B) \tag{4}$$

Another model that represents the image is the grayscale model. In this model, the RGB image is transformed into a single grayscale image, in which the value of each pixel is a single sample carrying all the information about the color pixel. This value is obtained using the following equation [8]:

$$G_y = 0.3(R) + 0.59(G) + 0.11(B) \tag{5}$$

Figure 1 shows a sample of an RGB image acquired using the A/S landmine detection system and its corresponding HSI, H, S, I and grayscale images. This image is for an AT VS2.2 mine buried at a depth of 10 cm.

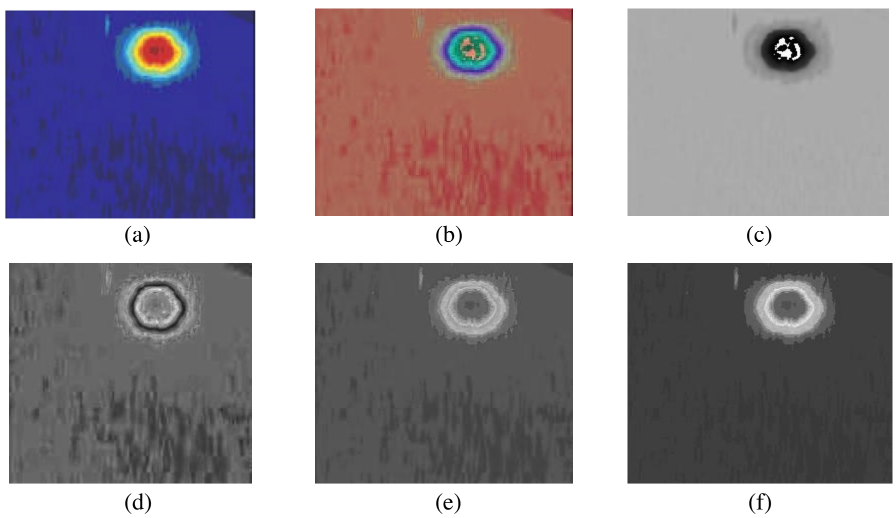


Figure 1. A sample of the acquired data using the A/S landmine detection system and its corresponding transformation components. (a) RGB image. (b) HSI image. (c) H image. (d) S image. (e) I image. (f) Grayscale image

3. INTENSITY AND STATISTICS BASED DETECTION TECHNIQUES

3.1. Intensity Based Detection Technique

The detection of an object from an intensity image is performed by thresholding this image with a certain threshold. Then, clutter is removed by an area thresholding process. After that, a size matrix containing the dimensions of each object blob is obtained. These dimensions are used to generate rectangles to outline the objects. The detection output will be the intensity image with the objects outlined. Figure 2 shows the block diagram of the intensity based object detection technique.

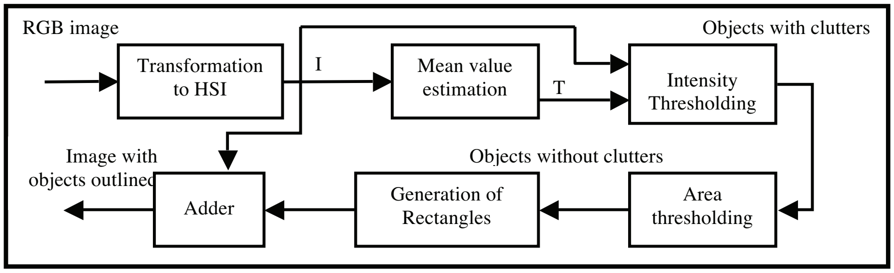


Figure 2. Block diagram of the intensity based detection technique.

From the block diagram shown in Figure 2, it is clear that the image passes through the following steps:

a) Intensity Thresholding: The image is divided into objects and a background using a certain intensity threshold, whose value should be less than the objects intensities and higher than the background intensities. The intensities of the objects and the background are varying from one image to another. Therefore, the value of the threshold is chosen to be the mean of the image.

b) Area Thresholding: As mentioned before, the collected data from the system comprise a mix of mines, blank spots, and clutter. These small blobs are eliminated by an area thresholding process. The value of the area threshold is chosen to be less than the smallest object area in order to obtain the highest probability of detection, and higher than the largest clutter blob area to obtain the lowest false alarm rate.

c) Generation of Rectangles: In this step, rectangles are generated to outline objects in the image.

d) Addition of the Rectangles to the Intensity Image: In this step, the generated rectangles are added to the intensity image to have the objects outlined. Figure 3, shows the resultant images of this technique for the intensity image shown in Figure 1(e).

3.2. Statistics Based Detection Technique

The image statistics such as the variance and the covariance can be used in the detection of an object from an image [9]. In this technique, a variance image with the same size as the intensity image is obtained. The same steps of the intensity based detection technique are repeated

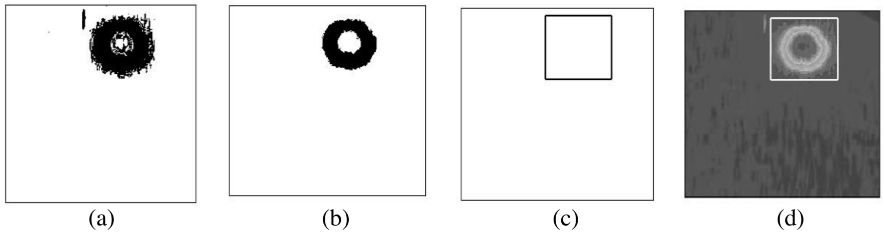


Figure 3. Results of the intensity based detection technique. (a) Intensity thresholding. (b) Area thresholding. (c) Generation of a rectangle. (d) Addition of the rectangle to the intensity image.

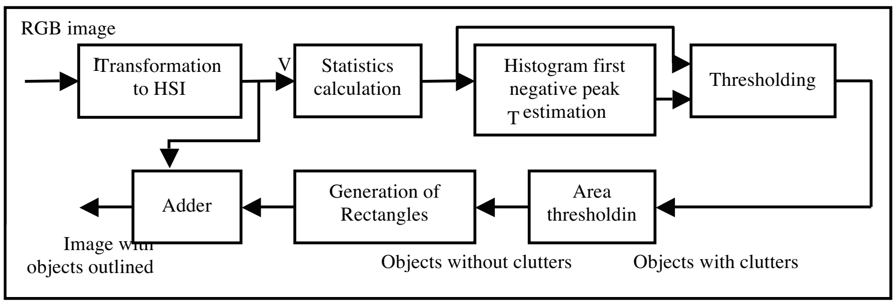


Figure 4. Block diagram of the statistics based detection technique.

on this image. Figure 4 shows the block diagram of the statistics based detection technique.

From the block diagram in Figure 4, we can see that the image passes through the following steps:

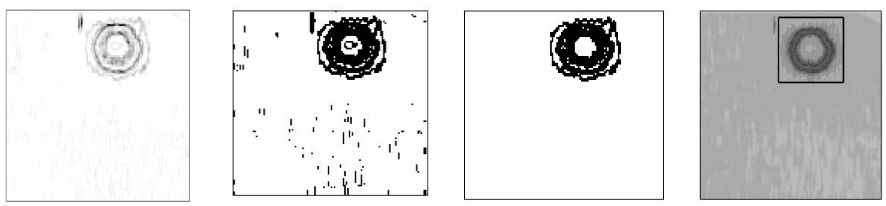
a) Generation of a Variance Image: The first step of this technique is to obtain a local variance image from the intensity image by moving a window of size $(X \times Y)$ across the image. The window size $(X \times Y)$ is chosen so as to span a spatial area sufficient to contain amplitude variations originating from an object, while at the same time being small enough to provide an acceptable spatial resolution. This small window is moving with a 50% adjacent overlap in both X and Y directions to improve the spatial resolution. The optimum values of X and Y are adjusted manually [9].

b) Variance Thresholding: The second step of this technique is a thresholding process of the local variance image using a certain threshold. The value of this threshold is obtained automatically from the occurrence histogram of the variance image which exhibits at least two distinct peaks. The larger one corresponds to the background, while the others correspond to objects in the image. The gray level corresponding to the trough between the first two peaks is considered as the optimal threshold value for discrimination between objects and the background [8, 9]. This value of the threshold ensures that no objects are missed.

c) Area Thresholding: After variance thresholding, a similar area thresholding step to that in the intensity based detection technique is performed on the local variance image.

d) Generation of Rectangles: This step is also similar to that in the intensity based technique.

e) Addition of the Rectangles to the Intensity Image: To show the final output, the generated rectangles are added to the intensity image. The output will be the original image with the objects outlined. Figure 5 shows the resultant images from this technique for the variance image shown in Figure 1(e).



(a) (b) (c) (d)

Figure 5. Results of variance based detection of an AT VS 2.2 buried at a depth of 2.5 cm. (a) Variance image. (b) Variance thresholded image before clutter removal. (c) Variance mask after clutter removal. (d) Intensity image with the object outlined.

4. MORPHOLOGY BASED DETECTION TECHNIQUE

Morphology is a means of structuring and reshaping a binary or a grayscale image. The tool used in reshaping the image is called the morphological structuring element. The structuring element is a simple matrix or a small window that reshapes the image [10]. This element determines the precise details of the effect of the operator on the image. There are many shapes for the structuring element such as the rectangle, the square, the octagon, the periodic line and the flat disk shapes. Morphology has become a popular tool in many image processing applications such as noise removal, image enhancement and image segmentation [11]. Also, this technique can be used for reducing the effect of clutter and enhancing the presence of targets in landmine detection [12].

4.1. Morphological Operations

There are four basic types of morphological operations, which will be described briefly below.

4.1.1. Erosion

In this operation, every object pixel that is touching a background pixel is changed into a background pixel. This operation makes the objects smaller, and can break a single object into multiple objects. Consider an image (F) and a structuring element (S_e), the eroded image of an object F by a structuring element S_e can be obtained using the following equation [11]:

$$F\Theta S_e = \{z|(S_e)_z \subseteq F\} \tag{6}$$

where z is a displacement of the structuring element.

4.1.2. Dilation

In this operation, every background pixel that is touching an object pixel is changed into an object pixel. This operation makes objects larger, and can merge multiple objects into one. The dilated image F by a structuring element S_e can be obtained using the following equation [11]:

$$F \oplus S_e = \left\{z|[(\hat{S}_e)_z \cap F] \subseteq F\right\} \tag{7}$$

4.1.3. Opening

This operation is in fact erosion followed by dilation. Opening removes small islands and thin filaments of object pixels. The opening process is performed using the following equation [11]:

$$F \circ S_e = (F\Theta S_e) \oplus S_e \tag{8}$$

4.1.4. Closing

This operation is dilation followed by erosion. Closing removes islands and thin filaments of background pixels. The closing process is performed using the following equation [11]:

$$F * S_e = (F \oplus S_e)\Theta S_e \tag{9}$$

Figure 6 shows the effect of these operations by using a flat disk structuring element on an ATVS 2.2 landmine image.

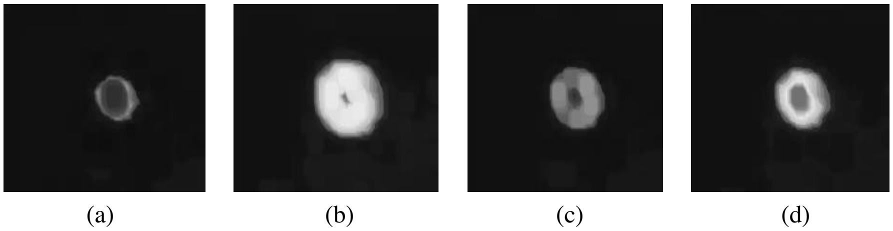


Figure 6. Morphological operations applied on an AT VS 2.2 landmine image buried at a depth of 10 cm. (a) Eroded image. (b) Dilated image. (c) Opened image. (d) Closed image.

5. MORPHOLOGY AND WAVELET BASED DETECTION TECHNIQUE

The wavelet transform is considered as a powerful tool in most image processing applications such as image fusion, denoising, compression and restoration. Wavelet decomposition and reconstruction are used for clutter reduction in ground penetrating radar (GPR) data since 1994 [13]. The wavelet transform is a mathematical operation used to divide a given image into different subbands of different scales to study each subband, separately [9].

The proposed technique for improving the performance of the object detection process from a grayscale image is based on the morphological image processing and the wavelet transform. The block diagram of this technique is shown in Figure 7. The first step in this technique is the transformation of the RGB image into a grayscale image. The second step is applying the closing operation to the grayscale image using a flat disk structuring element. The third step is applying the 2-D Haar discrete wavelet transform (DWT) to the closed image which leads to a decomposition of this image into four components; the approximation component and three detail components. Finally, the intensity based detection technique is applied to the approximation component. The final output will be the approximation component with each object outlined. Figure 8, shows the resultant images from this technique for a grayscale image.

6. EXPERIMENTAL RESULTS

6.1. Intensity and Statistics Detection

In this section, the proposed automatic object detection techniques are applied to 100 images from different types of AT and AP landmines

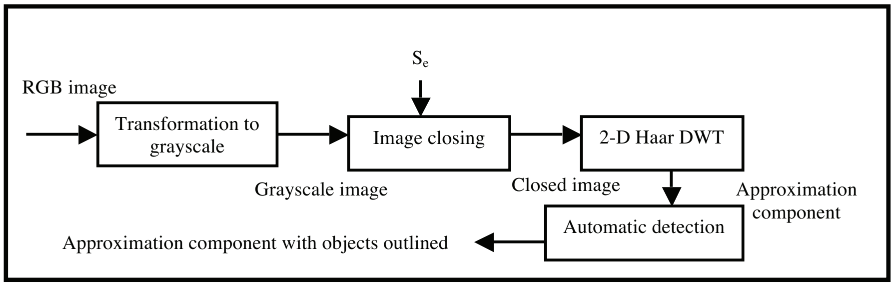


Figure 7. Block diagram of morphology and wavelet based detection technique.

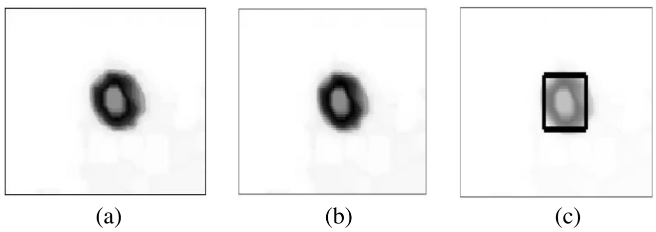


Figure 8. Morphology and wavelet based detection technique steps. (a) Closed image. (b) 2-D DWT approximation coemponent. (c) Approximation component with the object outlined.

Table 1. Specifications of the tested landmines.

Depth (cm)	Type and model	Number of images	Depth (cm)	Type and model	Number of images
15	AT TMA 4	4	2.5	AT VS 2.2	11
10	AT TMA 4	2	5	AT VS 2.2	4
5	AP VS 5.0	25	10	AT VS 2.2	3
2.5	AP VAL 69	3	2.5	AT VS 1.6	3
5	AP VAL 69	8	7.5	AT VS 1.6	3
5	AP PMD6	7	7.5	AT M 15	6
5	AP PMA3	7	5	AT M 19	8
			5	AT EM 12	6

buried at difference depths. These images are scanned by the LDV-based A/S landmine detection system. The collected data comprises 50 AT landmine images and 50 AP landmine images. A summary of the tested images is shown in Table 1. The scanning area for AT images is $100\,\text{cm} \times 100\,\text{cm}$, while for AP images it is $30\,\text{cm} \times 30\,\text{cm}$. These scanning areas are relatively small; therefore every image contains only one object.

The two main factors which are of interest in applying these techniques are the high probability of detection and the low false alarm rate. The probability of detection means the rate of correct detection, so that it should be as high as possible. The false alarm means that the system introduces some clutters as landmines in the automatic detection process. Since the removal of a landmine is very expensive, the false alarm rate should be as low as possible. The probability of detection (P_d) and false alarm rate (F_a) are calculated for the developed techniques as follow [8, 9, 13, 14]:

$$P_d = \frac{\text{Number of detected objects}}{\text{Total number of existing objects}} \tag{10}$$

$$F_a = \frac{\text{Number of detected clutter}}{\text{Total number of existing objects}} \tag{11}$$

The processing time of the detection process is few seconds for each image using a 2.4 GHz PC running with Matlab$^{\text{TM}}$. The processing time for a single image for each technique is tabulated in Table 2.

Table 2. Comparison between the intensity and statistics based detection techniques.

Detection technique	P_d	F_a	Processing time/image
Intensity image	92%	6%	1.26 sec
Intensity variance image	87%	15%	3.66 sec
Intensity covariance image	87%	15%	4.05 sec
Grayscale image	94%	4%	1.35 sec
Grayscale variance image	90%	16%	5.12 sec
Grayscale covariance image	90%	16%	5.60 sec

The results in Table 2 show that the grayscale based detection technique gives the highest probability of detection and the lowest false alarm rate for all considered landmine images.

6.2. The Effect of Morphological Operations

The basic four morphological operations are tested for improving the performance of the grayscale detection technique. These operations

Table 3. Effect of morphological operations on the grayscale detection technique.

Morphology operations	Detected objects	Detected clutters	P_d	F_a	Processing time/image
Erosion	53	0	52%	0%	1.76 sec
Dilation	100	22	100%	22%	1.8 sec
Opening	84	6	84%	6%	1.88 sec
Closing	96	6	96%	6%	1.83 sec

Table 4. Results of the grayscale based detection techniques.

Detection technique	P_d	F_a	Processing time/image
Grayscale	94%	4%	1.35 sec
Grayscale + Closed	96%	6%	1.83 sec
Grayscale + Closed + Wavelet	97%	2%	1.9 sec

are applied to the 100 images described in Table 1. The statistical results are shown in Table 3.

Based on the results shown in the above table, it is noticed that the erosion process breaks the object into multiple small objects. Many of these objects will be removed in the clutter removal process resulting in a very low probability of detection. Furthermore, all clutters will be removed and the erosion process introduces zero false alarm rates. On the other hand, the dilation process merges multiple objects into one large object resulting in no objects missed, 100% probability of detection and very high false alarm rates. The erosion or dilation processes cannot be used alone for improving the detection process. From Table 3, we can see that the closing process is more suitable for this purpose. The execution time of the detection process based on a grayscale image is 1.35 sec while the execution time of the detection based on a grayscale image with a closing operation is 1.83 sec. The execution time difference is very small.

6.3. The Effect of the Wavelet Transform

The morphology and wavelet based object detection technique is applied in this section on the 100 landmine images given in Table

1. The obtained probability of detection is 97% and the obtained false alarm rate is 2%. The execution time of this detection process is 1.9 sec per image. It is very close to the execution time of the detection process based on morphology only. A comparison between all the proposed object detection techniques based on a grayscale image is shown in Table 4.

7. CONCLUSIONS

This paper proposes several techniques for the automatic detection of landmines from an image. These techniques are based on the grayscale and the intensity component of HSI images and their calculated statistics. The results show that; the grayscale based detection technique is found to be more accurate with a higher probability of detection and a lower false alarm rate compared to the other techniques for all considered landmine images. To improve the performance of the automatic object detection techniques, the closing operation and the wavelet transform can be used. This gives a higher probability of detection and a lower false alarm rate for all the tested cases. This is attributed to the ability of the wavelet transform to reduce the size of objects and clutters, as well. The reduction of clutters size leads to their removal in the area thresholding process while the objects still exist. The effect of the morphological operations is to smooth objects prior to the application of the wavelet transform.

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