Integrated detection of landmines using neutron backscattering and magnetic gradient techniques

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ABSTRACT

The main problem in demining process is to locate and characterize the landmines in the ground, as their different types and sizes make them difficult to be detected using a single technique. In this paper we present results of an experimental study of integration between Neutron Backscattering and magnetic gradiometer techniques. The experiment was established in a test site located in Cairo using different types of landmines buried at different depths. The Neutron Backscattering technique provided information about the hydrogen content for the buried object and was successful to detect almost 85% of the used objects. The magnetic gradiometer detected most of the objects with ferro-metallic contents. Integration of both techniques increases the detectability to reach 100%. Such integration is very effective in decreasing the high false alarm rate resulting from the magnetometers sensitivity to any metal debris and detects landmines of relatively deeper depths which are not sensed by Neutron Backscattering sensor. The results suggest multi-sensors detection approach of landmines would help greatly in the demining process.

Key words: Neutron Backscattering, Vertical magnetic gradient, analytic signal, landmines.

INTRODUCTION

Millions of landmines have been buried and laid around the world. In Egypt, for example, nearly 20 million of landmines buried in very vast areas in the northern cost of Western Desert, North and West of Sinai, Suez Gulf, and the Western Cost of Red Sea. Detection and precise location of these objects and estimation of their types and contents are becoming increasingly important in environmental investigations worldwide (Salem et al., 2002).

Several techniques are currently used for the detection of landmines. Most of the techniques are based on conventional methods deploying prodders, metal detectors and sniffing dogs. Some of these methods are very effective for locating metal objects, but they suffer from high false alarm rates because they cannot recognize a landmine from other scattered debris.

A nuclear technique based on the measurement of thermal neutrons produced from the moderation of fast neutrons by elastic scattering with hydrogen nuclei is effective for distinguishing explosive material, i.e., a landmine from other non hydrogenous materials. This approach can be considered as an effective way to discriminate between a landmine and other objects (stones and metals). However, this technique has a limited depth resolution and, as a result, cannot stand alone for detecting of all landmines buried at different depths.

A solution to this problem may be found in developing a multi-sensors system to detect and discriminate between the different landmines. Toward building such system for the detection of land mines in Egypt, we present results of an experimental study of integrating Neutron Backscattering and gradient magnetic techniques. The experiment was made at test site in Cairo using different landmines buried at different depths.

BACKGROUND OF THE MAGNETIC GRADIENT TECHNIQUE

Magnetic method is one of the best geophysical methods for locating and mapping the distribution of ferro-metallic materials, especially when the signal-to-noise ratio of the magnetic anomalies is high. Measurement of perturbations in the direction and/or strength of the Earth's magnetic field are used to locate underground ferro-magnetic objects. Gradient of the perturbations were also used for the detection. Advantage of the gradient measurements is that it removes to some extent the undesirable influence of disturbing fields, compensates for the influence of the regional field and does not depend on diurnal variations in the Earth´s magnetic field. Recent development of magnetic survey systems has made it possible to rapidly detect much smaller objects using magnetic surveys than it was possible before (Salem et al., 2002).

BACKGROUND OF THE NEUTRON BACKSCATTERING TECHNIQUE

Neutron Backscattering (NBS) technique is a well established method to detect the explosive chemical within the landmines. It is based on the high concentration of hydrogen in landmines, which is present in the explosive chemicals (Datema et. al, 2001). NBS detector operates by irradiating neutrons with high energy into the soil. These neutrons lose energy by scattering from atoms in the soil and become thermal after a number of collisions. A thermal neutron detector monitors the low-energy neutron flux coming back from the soil (Datema et. al, 2002). An advantage of the NBS based devices over the metal detectors are the insensitivities for rocks, stones, metal objects, and underground holes such as burrows. The main limitation of NBS method lies in the sensitivity to soil moisture (Obhodas et al, 2004). The hydrogen content of a landmine is comparable to that of sand with 10 % moisture content resulting in a loss of contrast between the mine and its surroundings, thus NBS method can be used advantageously in arid countries.

THE EXPERIMENT

A test lane was conducted at Anshas area, East Cairo. The layout of the test lane is illustrated in Figure 1. The sand in this site was very dry to depths of over 30 cm with silt and flint stones. The moisture content of the soil was very low. In this test, seven objects were used (Figure 2). A separation distance of 2 meters is made between each object and the other. Table 1 lists the description and burial depth of the objects. As it could be seen, both antipersonnel and antitank landmines with both metal and plastic casing used in the test, with a piece of wood that works as a "Clutter, i.e. Hydrogen Content Object" in the NBS images. Also a steel cylinder is used. For the plastic casing landmines, a small piece of metal was added to each one of them, representing the "detonator" of the landmine.

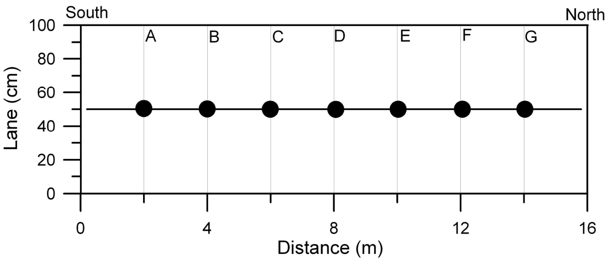

Figure 1. Layout of the conducted Test Lane. Circles indicate the locations of the objects

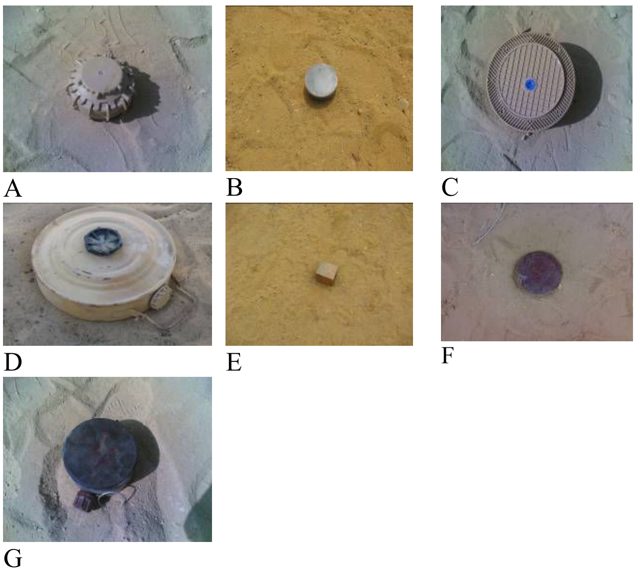

Figure 2. The used objects in the Experiment- their description in Table 1

The magnetic instrument used in this experiment is a proton gradiometer with a resolution of 0.01 nT. This device uses two sensors to measure either vertical or horizontal gradient of the magnetic field. In this test, the instrument was used to measure the vertical gradient and the distance between the two sensors was 60 cm. The distance between the lower sensor and the ground level was 60 cm making the measurement level from the ground to be 90 cm. The measurements were made at a sampling interval of 30 cm.

Table 1 : Description of the buried objects

Object	Type	Size cm	Casing material	Explosive Content G	Buried Depth cm
A	VS50 APM	9 x 4.5	Plastic	50 RDX	10
B	Dummy APM	9 X 4	Bakelite	100 TNT Simulant	15
C	T-80 ATM	20.4 x 10.8	Plastic	2400 compB	20
D	T-71 ATM	31.5 X 10	Metal	6000 TNT	30
E	Cube of wood	10 X 10 X 10	wood	No Explosive Content	on surface
F	Steel Cylinder	10 X 3	Steel	No Explosive Content	30
G	PMN APM	11.2 x 5.6	Plastic	240 TNT	15

In this experiment, we use a scanning NBS device called the Egyptian Scanning Landmine Detector "ESCALAD' (Figure 3). This device has been developed at the laboratories for detection of landmines and Illicit Materials, Nuclear Research Centre, Egyptian Atomic Energy Authority, with the help of Delft University of Technology and supported by the IAEA (Bom et. al, 2008).The detector is based on the Delft DUNBID landmine system which was tested in Egypt (Bom et. al, 2005). ESCALAD consists of 8 ^{3}He proportional counter tubes with resistive wires, mounted parallel in a flat incasing of 142 x 60 x 10 cm^{3}, perpendicular to the direction of scanning. ^{3}He tubes are sensitive mainly to thermal neutrons. The specification of each tube is: length 100 cm, diameter 2.5 cm, and ^{3}He pressure 10 bars. The neutron detection efficiency varies from 1 for thermal energy down to 10^{-4} for neutrons in the MeV energy range. The tubes are mounted in two banks of 4 tubes with sensitive detector area of about 100 x 22.5 cm^{2}. The bank separation is 70 mm between the adjacent tube axes. This separation allows for the placement of radioactive neutron source/sources in the center of the detector. Two Pu-α-Be neutron sources each of strength = 5 x 106 n/s were used for the real field measurements. Pu-α-Be neutron sources were chosen because neutrons emitted from these sources posses higher mean energy than neutrons from 252Cf and these of mono-energetic from DD-neutron generator. Two steel scatterers with special geometrical shape of 6 cm thick were placed under the sources to flatten to some extent the distribution of fast neutron flux impinging the ground. Also specially designed and constructed steel reflector of 1 cm thick was used above the neutron sources to enhance the number of fast neutrons incident on the ground. The detectors tray was dragged directly on the ground by electric motor driven trolley as shown in Figure 3. The speed of the trolley can be varied between 6 mm/s and 300 mm/s.

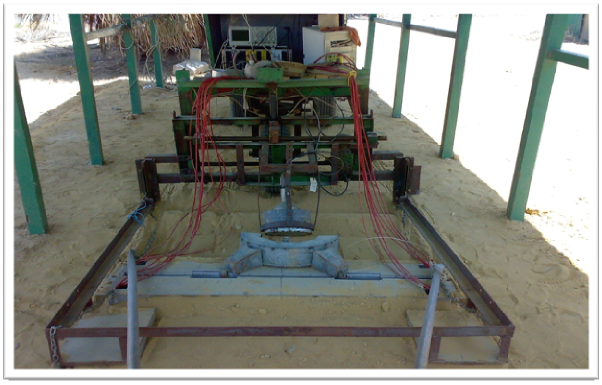

Figure 3. Photograph of Egyptian Scanning Landmine Detector, ESCALAD.

DATA ANALYSIS

Magnetic gradient

Figure 4 shows the recorded vertical magnetic gradient over the buried objects. Many anomalies were recorded but not correlated directly to the landmines. Generally, the magnetic signature of hazardous objects is related to the physical properties of the ferromagnetic materials that are used as a casing or as the detonator of many landmines. The magnetic signature is usually controlled by the contribution result of remnant and induced magnetization. If both magnetization directions are vertical, then the anomaly will be symmetrical and has a peak located directly above the source. In Egypt, the direction of the Earth's magnetic field is inclined and produces asymmetrical anomalies that are very difficult to interpret. Correction of the direction of the Earth's magnetic field is usually made using a technique known as reduction to the pole. However, this reduction is correct if there is no remnant magnetization.

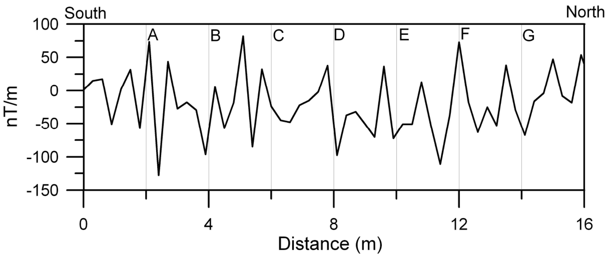

Figure 4. Vertical magnetic gradient magnetic profile over the buried objects.

Alternative to the reduction to the pole, analytic signal approach is used to enhance the shape of the magnetic anomaly over their sources. The approach of the analytic signal of magnetic anomalies, which was initially used in its complex function form and makes use of the properties of Hilbert transform (Blakely, 1995). The amplitude of the analytic signal is defined as the square root of the squared sum of the vertical and two orthogonal horizontal derivatives of the magnetic field. This transformation produce positive anomaly with peak located nearly above shallow object. The appeal of the method is that analytic signal anomalies can be easily computed. Another reason for the appeal of the method is that the locations and depths of the sources are found with only a few assumptions about the nature of the source bodies.

Figure 5 shows the analytic signal of the vertical gradient profile. The analytic signal transformation enhanced the position of the anomalies with respect to the actual location of the objects. The locations of the peaks over some objects were found slightly shifted. But most of the objects were detected. Only C and E were not sensed by the magnetometer. It is not surprise as these objects are made of plastic and wood. However some anomalies not related to the objects were also detected. See, for examples, the anomaly between B and C and the anomaly between D and E. These anomalies are most probably related to scattered debris and would represent stumbling block in enhancing the detectability using magnetic systems.

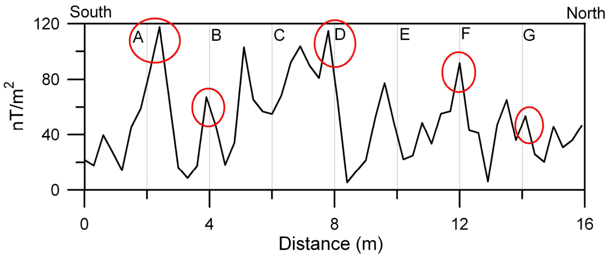

Figure 5. Analytic signal of the vertical gradient magnetic profile.

Neutron Backscattering

For ESCALAD NBS device, the image of the intensity distribution of the back-scattered thermal neutrons over the soil surface is formed while scanning. Figure 6 shows the scanned NBS over the buried objects. The area of hot spot depends on mine burial depth, mine size and detector standoff distance. Generally the raw data consists of three components: 1) signal from the mine (if present), 2) a contribution caused by neutrons scattered from the soil, and 3) a contribution from fast neutrons, which hit the detector without having entered the soil. The latter two components constitute to the background in the image. A row of image pixels perpendicular to the scan direction will be called "pixel raw", while a row of image pixels along the scan direction will be called "pixel line".

The first step in the processing of the raw image is the application of a "fast neutron background" correction. The fast neutron background is an intrinsic system property. It has been measured by placing the detector about 1.5 m above the soil and registering the count rate distribution along each tube. The correction is done by summing the fast neutron measurement along the scan direction and subtracting the result from the pixel rows in the raw image after normalization to the measurement time. The effect of this correction is to remove the central high intensity band and to increase relatively the intensity at the edges of the detector. The next step in the image analysis concerned with the using of a proper filter to enhance the mine signal over the background fluctuation. The process consists simply of moving the center of the filter mask of size 3 x 3 pixel from point to point in an image. At each point (X, Y), the response of the filter at that point is the sum of products of the filter coefficients and the corresponding neighborhood pixels in the area spanned by the filter mask.

Figure 7 shows the filtered image for scanning of lane test. The obtained image shows clearly the effectiveness of ESCALAD system for detecting of landmine with different amount of explosives encased in plastic or steel casing. The only object that has not been detected is a piece of steel was buried at a depth of 30 cm, while it was detected by the magnetic gradiometer. This result concludes to the potential advantage of using an integrated system containing the two nuclear technique represented on ESCALAD system and conventional technique that depend on the detection of metal parts only represented in magnetic gradiometer.

CONCLUSION

This paper presents results of experimental study of investigating the integration of Neutron Backscattering and magnetometer techniques to detect landmines buried at a test site in Egypt. Landmines of different types and buried at different depths were used in this test. The Neutron Backscattering technique was successful to detect almost 85% of the used objects, where it fails in detecting steel cylinder at a relatively deeper depth (30 cm). The magnetic gradiometer could able to detect this steel cylinder and also detected most of landmines with ferro-metallic content. In conclusion integration of both techniques increases the detectability of the landmines to reach 100%. However, utilization of sensors that are able to detect landmines of non-conductive materials is also required. Such integration is very effective in decreasing the false alarm rate resulting from the magnetometers sensitivity to any metal debris and detects landmines of relatively deeper depths, which are difficult to be sensed by Neutron Backscattering approach. The results suggest multi-sensors detection of the landmines would help greatly in the demining process and reduce the risk of hazardous objects.

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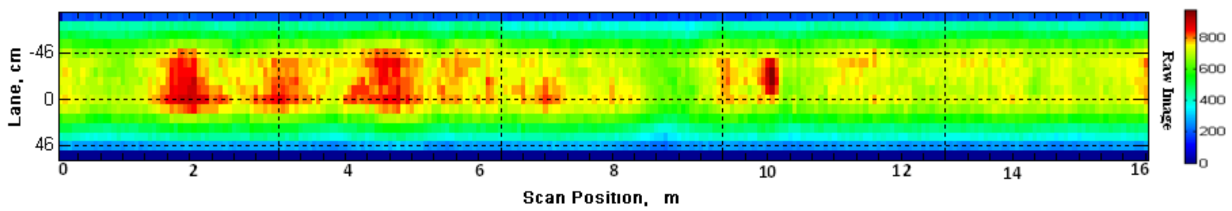

Figure 6. Measured signals of the lane with the tested objects by ESCALAD system

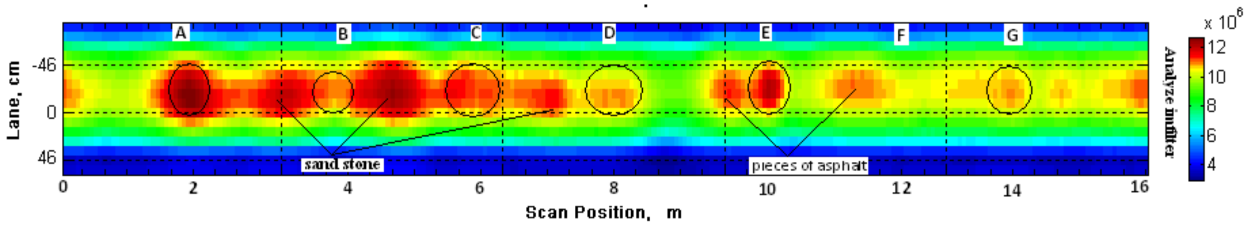

Figure 7. Filtered image of the lane with the tested objects by ESCALAD system