Upgrading the Egyptian Scanning Landmine Detectors

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ABSTRACT

This article presents and discusses the upgrading processes which were performed to increase the detection capability of the Egyptian SCAnning LANDmine Detectors, ESCALAD system. The upgrading processes include different designs which were made to mount the detectors tray. These arrangements aim to overcome the effect of the soil surface roughness and stand off distance on the scanning capability. Also a more stable and reliable PCI data acquisition board with fast Digital I/O up to 125 M/s was used. Moreover, data acquisition software which uses different algorithms for background subtraction and 2D-image filtration was build and developed. The software was build using Qt-cross-platform application and other Linux based packages. Examples of images constructed from experimental measurements using the upgraded and modified software are given and discussed. The obtained displayed images show more developed improvements and reliability.

Keywords: Upgrading, Surface Roughness, Qt-Cross-Platform and ESCALAD.

INTRODUCTION

Demining or mine clearance is a process based on detection and a landmine, or UXO from contaminated area, while minesweeping describes the act of detecting of mines. Humanitarian demining is still largely done by conventional methods such as prodding in combination with metal detectors. Although metal detectors are very efficient in finding mines that contain metal parts, they are much less efficient in finding almost metal-free mines. Several landmine detection methods based on nuclear techniques have been suggested in recent years (1). One of the proposed techniques to detect non-metallic landmines that have shown great potential is using neutron backscattering. This method is based on the moderation of fast neutrons by hydrogen atoms in the mine and soil and was first demonstrated for landmine detection by Brooks et al. (2). As the amount of hydrogen in a landmine in most cases is higher than for the soil, the amount of thermalized neutrons scattering back to the detector can indicate the presence of a mine.

ESCALAD is a scanning landmine detection system based on neutron backscattering (NBS). It was consist of 16 $^3$He detector tubes, fast neutron sources and measuring electronic module all mounted on an electrically driven trolley. The performance of the system was checked through an international field tests held in Nov. 2007 in a landmine test field area located at the Nuclear Research Center, Cairo Egypt. The tests revealed that the workability of ESCALAD suffer from the variation of the standoff distance during scanning and with the amount of data input into the computer system (3-7).

Accordingly, many trials were performed to modify the trolley and detectors arrangement (detectors tray) and carrier to ensure minimum effect of soil surface roughness and stand-off distance.
Further the usefulness of ESCALAD depends also on the achieved scanning width, which was only 35 cm when one central source is used. A wider scanning width is achieved by the use of two neutron sources placed 50 cm apart in combination with iron scatter blocks fixed underneath the sources and an iron reflector above the sources. With such arrangement an almost homogeneous neutron field was achieved and used to probe ground.

This work demonstrates the upgrading process of the ESCALAD system. The effectiveness and reliability of each upgrading stage was investigated experimentally using real defused landmines of different types under various conditions. More details for these process and its related results are given below.

2. UPGRADING THE ESCALAD:

The ESCALAD main construction elements were modified to avoid false signal arise from the effect of surface roughness and time out occurs due to the use of data acquisition board of limited capacity. Also, the image pixel area was increased to 6.2 x 6.2 cm$^2$ instead of 3.1 x 3.1 cm$^2$ to reduce the statistical errors in the number of counts in the reconstructed image. A short description of the performed changes is given below.

2.1 Reduction of the Number of $^3$He-Tubes:

Initially designed ESCALAD system was based on using 16 $^3$He proportional counter tubes each of 1 m length and 2.54 cm diameter. The new upgraded one uses only 8 tubes instead of 16 tubes. This provides a great reduction in the overall cost and less detector tray width. The latter factor tends to give a great reduction in effects due to change in surface roughness and stand-off distances. The $^3$He output signals are fed to the input of position sensitive read out electronics (changed division) as shown in Fig. 1. The tubes are mounted in an aluminum tray in a horizontal plane, next to each other with 2.4 mm space in between. The tubes lengths are perpendicular to the scanning direction, thus forming a 2D sensitive detector. The coordinates of a detected neutrons are determined from the position of the tube hit and the position of the neutron along that tube.

The 8 tubes were first placed in one bank that gives detectors tray width 22.5 cm$^2$. In such a case the source/sources of neutrons were placed above the tray with the steel scatterer underneath the source/sources. This arrangement has disadvantages due to the fact that the source/sources are far from the ground and in turn the flux of fast neutrons incident into the ground in 37000 c/s. to overcome such a problem, the 8 tubes are divided into two groups each of 4 tubes placed in two banks with a space in between with a width = 8 cm, where the neutron source/sources are fixed. With such arrangement, the neutron flux was measured to ~ 45000 c/s. Two Pu-α-Be neutron sources each of strength = 5 x 10$^6$ n/s were used for real field measurements. Pu-α-Be neutron sources were chosen because neutrons emitted from these sources posses higher mean energy than neutrons emitted from $^{252}$Cf or from D,D- reaction. Two steel scatters 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 Fig. 1. The speed of the trolley can be varied between 6 mm/s and 300 mm/s.

Results obtained during measurements performed to check the effectiveness of the modified ESCALAD system are given below.
2.2 Using new Digital I/O Board:

Initially designed ESCALAD was using a data acquisition board, DIO type power DAQ. The old PCI data board has a max possible count rate of $\sim2 \times 5^{10}$. This tends to repeated time-outs during the scanning. This results of bands in the measured images with reduced number of counts and makes the recognition of a landmine in the displayed image nearly impossible. The old DIO board was replaced by a new one type: Spectrum M2i.70xx with a maximum possible count rate $\sim 10^{9}$ c/s which corresponds to a source of maximum neutron emission of about $6 \times 10^{7}$. Further, using a DIO board of high capacity tends to modify the software for data acquisition, analysis and image reconstruction. Fig. 1. shows the count rate profiles for both old and new board. This figure illustrates that there is no dead time in the new broad profile. This fact tends to reduced the time out signals. This makes the possibility of mine detection using neutron source/sources of higher intensity quite effective specially in case of mine with small quantities of explosive.

![Count Rate Profiles](image)

Fig. 1. Schematic diagram show the count rate stability for the old DIO board and the new DIO board.

2.3 Changing Image Spatial Resolution:

The statistical error in the number of counts in an image pixel is determined by the square root of this number of counts. A mine signal can not be separated from the background if the statistical error in the background becomes of the same order as the mine signal itself. The pixel counts should therefore be large enough. This can be achieved with stronger sources or slower scan speed that both have disadvantages. Therefore the pixel size was increase to $6.2 \times 6.2 \text{ cm}^2$, still small enough to recognize a small anti personnel mine in an image. This modification again took time consuming software changes (see Fig. 2).

The image of the intensity distribution of the back-scattered thermal neutrons over the soil surface is formed while scanning. A pixel area of $6.2 \times 6.2 \text{ cm}^2$ was chosen which is sufficient for proper depict a landmine hot spot which has a diameter of several tens of cm. The area of hot spot depends on mine burial depth, mine size and detector standoff distance. During the scanning, each tube spends a time of $6.2/v$ s above a row of pixels, with $v$ (cm/s) the scan speed. The total measuring
The time for all detector tubes to completely measure a row of pixels is therefore, $8 \times 6.2/v = 49.6/v$ s. The time for the detector to pass over a pixel row i.e., the pass-over-time, is $(8 \times 6.2 + 8)/v = 57.6/v$. The detectors must pass completely over a position to measure the neutron flux at that position. The real length over which the detector has to move is larger than the effective length of the scan by the detector size, ≈ 58 cm.

3. SCANNING PROCEDURE

The upgraded ESCALAD was tested by performing some scanning to determine the ESCALAD workability and effectiveness for detecting landmines with different amount of explosive material and buried at different depths. The performed measurements consisted of burying the mines, resetting the scan position electronics on the trolley, measure the distance on the ground between the buried mine and the trolley, start the trolley movement and start the data acquisition. The measurement was stopped when the neutron detector had a sufficient distance passed over the mine. The trolley was then moved backwards approximately to the starting position. A number of scans were usually made over the same mine, including resetting the position but without re-measuring the mine distance. The accuracy of the position of the mine with respect to the scan start position is therefore only about 20 cm, which is sufficient to identify the mine in the images. The measurements were carried out on very flat terrain to realize a smooth horizontal movement of the detector and to keep the standoff distance as constant as possible.

4. RESULTS AND DISCUSSIONS

The thermal neutrons back-scattered from a mine in the displayed raw data is shown as a hot spot called a “mine signal”. The following remarks can be made regarding the raw images:

- The signals from the $^3$He tubes for neutron hits near the tube ends are too small for the electronics to sense a good position. These ends are effectively 'dead', and therefore the figure shows a scan lane of only ~ 85 cm as shown in Fig. 1.
- The band of high intensity appears through the center of the image due to those positions being closest to the source.
- The mine signal is very strong for an antitank mine, but for deeper lying and/or smaller mines and/or at greater scan speeds the mine will give a weaker signal. The mine signal will disappear in the statistical counting noise for conditions near the limit of detection and will no longer be perceivable by eye although data analysis may still reveal the mine.

The measured raw data is composed of the following components:

i. The signal from the mine, if present,

ii. A contribution caused by neutrons scattering from the soil,

iii. A contribution from fast neutrons, which hit the detector without having entered the soil.

The latter two components constitute a background in the image, which is present irrespective of the mine, and which may vary over the image due to the instance variations in moisture level or in standoff distance. These sources of background must be considered and taken as a first step in the image analysis.
A row of image pixels perpendicular to the scan direction is called ‘a pixel-row’, while a row of image pixels along the scan direction will be called ‘a pixel-line’. The background at a certain pixel is estimated by the determination of the average of the lowest data along the pixel-line within a window around the pixel. The corrected pixel content is stored in the background-corrected image. This procedure is done for every pixel of the pixel-row. When the pixel-row is finished the window is shifted in the scan direction and the process is repeated for the next pixel-row. The width of the window should be taken larger than the size of mine image to ensure a proper background subtraction around the hot-spots. The background estimation procedure can in principle be carried out during the scanning because it only relies on pixel data which has already obtained, and thus allows for scans of indefinite length \(^{(8)}\).

The filter type has proven to be the most crucial step in the image analysis to recognize the hot spots and to distinguish them from background statistics. The method of ‘Linear filter’ was used for smoothing and filtering the obtained images. In this method, the filtration 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 spanning by the filter mask \(^{(9, 10)}\).

Figure 3 shows the spatial distribution of backscattered thermal neutrons and the reconstructed 2-D images from backscattered thermal neutrons using 16 and 8 tube detectors. Measurements were performed with two neutron sources placed at 60 cm apart distance. The effectiveness of using a DIO power DAQ was checked by checking the thermal neutron count rate stability as shown in Figure 1. This figure indicates that the new DIO board show more stability at even higher count rates.

Figures 4a and b show the 2D-images reconstructed from the displayed thermal neutron backscattered from an APM type PMN with 150 g explosive material buried at 0 and 10 cm depths respectively. Also a reconstructed images for ATM type T-80 with 2.5 kg buried at 0 and 30 cm depths are shown in Figures 5a and b. The reconstructed images show clearly the dependence of both the intensity and size of the measured signals on the mine burial depth. In addition, these images show the reliability and effectiveness of the upgrading process that has been done in the ESCALAD main construction elements. As well as, these figures clearly show that ESCALAD can be easily detected APM with 150 g and ATM with 2500 g explosive material buried at depth down to 10 cm and 30 cm respectively.

Fig. 2. Schematic diagrams has shown the reconstructed 2D images with different pixel size.
Fig. 3. Spatial distribution and reconstructed 2D-images of backscattered thermal neutron fluxes from sources placed at 60 cm apart measured with 8 and 16 tubes.

Fig. 4. APM type- PMN with 150 g explosive buried at the surface and 10 cm depth respectively.
Fig. 5. ATM type- T-80 with 2.5 kg buried at the surface and 30 cm depth respectively.

CONCLUSIONS AND RECOMMENDATIONS

The displayed thermal neutron count rate and constructed images from measured backscattered thermal neutrons show that,

- Reduction of number of $^3$He tubes from 16 to 8 tubes to reduce the width of detector tray from 75 cm to 35 cm. This of course tends to reduce the number of false signal as the tray is moving more smoothly on the ground surface.
- Moreover, using 8 tubes instead of 18 makes a big reduction in the cost of mine detection.
- However, reducing the number of tubes tends to make observable reduction in the number of measured thermal neutrons. This reduction does not cause any appreciable effect during landmine detection.
- Efforts were done to reincrease number of measured thermal neutrons by using fast neutron reflectors of special geometry and shape. Moreover image pixel area of 6.2 x 6.2 cm$^2$ was used during data analysis to increase the number of count rate per pixel area.
- Using the data acquisition board of larger capacity tends to deduct the time out signals. This makes the possibility of mine detection using neutron sources of higher intensity quite effective specially in case of mine of small quantities of explosive.

REFERENCES

(2) F. D. Brooks, A. Buffler, M. S. Allie; Proceedings of the Sixth International Conference on Applications of Neutron Science, Crete, June (1999).
(3) K. Maki Habib; J. of Biosensors and Bioelectronics; Volume 23, Issue 1, 30 August 2007, Pages 1-18.


