

Enhancement of Photon and Neutron Images by Denoising Using Stationary Wavelet Transform

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Abstract: The noises introduced during the experimental procedure greatly affect the detection capability of measuring system. In this paper, a new approach to deal with the noise inherent with neutron back scattering, NBS and transmission imaging process is presented. The image noises are eliminated using the Stationary Wavelet Transform, SWT with time invariant characteristic which is particularly useful in image denoising. The test results of SWT on images obtained by NBS and transmission techniques have shown an enhanced images quality. The results also show that SWT has a superior performance than the widely used adaptive Matched Filter Method, MFT.

Key words: Illicit trafficking • Landmines • Stationary Wavelet Transform • Matched Filter and Image Denoise

INTRODUCTION

Radiation imaging techniques provide a very efficient tool during the investigation of nuclear and advanced materials as well as for applications in science and engineering research. A radiation beam of neutrons or photons of X-rays or γ -rays on penetrating the examined object is attenuated through different interaction process with the elements of the examined object material. The penetrating radiation is detected by a two dimensional imaging device. The constructed image contains information depend on material type and internal structure of the examined object. These radiation techniques have been effectively applied to art-facts of archaeological significance. In addition, neutron imaging technique, rather than being in competition with photon imaging with X-rays or γ -rays, is entirely and ideally complimentary to it. Whereas photons are scattered and absorbed by the atomic electrons, neutrons on other hand interact with the atomic nuclei. Furthermore, there is no real periodic regularity dictating the degree of this interaction and even isotopes of the same element may differ markedly in their attenuation ability. Of particular practical significance is the high contrast between hydrogen (which interacts very strongly with neutrons)

and most metals, which offer effective transmission of neutrons. This is directly opposed to photon imaging and offers a mean for effective visualization of the dynamics of organic hydrogen-containing substances in metal containers and provides the ability to visualize fuel within engines. It can also equally be used to view plastic seals or lubricants embedded within metal structures.

The studies reported in this article explore the scientific and technological issues associated with the applications of radiation imaging techniques to humanitarian demining and to illicit material trafficking systems in particular. Nowadays the security problem in the whole world is concerned with the huge numbers of landmines which are buried in vast areas of lands of about 70 countries in the whole world and the smuggling of explosives and illicit materials through the border of the intended countries.

Most established X-ray and γ -ray methods for explosives detection depend critically on shape recognition and therefore on human operator skill. Furthermore, photon radiography only permits very limited differentiation among elements in the low-Z range. The latter can be rendered quasi undetectable by high-Z element materials. In contrast, Fast-Neutron Radiography (FNR) is one of the most promising methods for fully

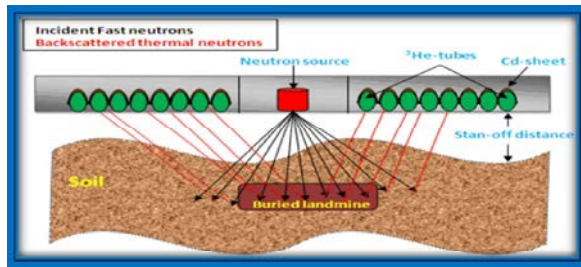


Fig. 1: Schematic diagram for NBS detector array while scanning over a landmine.



Fig. 2: The ESCALAD trolley: to the right the neutron detectors are seen, mounted on a positioning system. To the left is the driver seat where the speed control, steering and data inspection are located.

automatic detection and identification of explosives concealed in luggage and cargo containers. Neutrons probe the nuclear properties of the absorber and exhibit highly characteristic structure in their various interaction cross sections with different isotopes and at diverse neutron energies. These features were exploited in developing various interrogation techniques for automatic luggage and cargo containers inspection, using thermal and fast neutron-induced, gamma emission, or energy dependent characteristic of neutron transmission, FNTS. [1].

A general description of the current research activities concerned with the development and adaptation of nuclear techniques for detection of landmine and illicit materials is given below:

Neutron Backscattering Imaging Technique: The Neutron Backscattering Imaging NBSI is a nuclear sensor based on using a source of fast neutrons and subsequently detecting the thermalized neutrons which return back from the interrogated object [2-7]. In this work, the NBSI detectors consist of 16 ^3He proportional counter tubes of 1 m length and 2.54 cm diameter, with position sensitive readout electronics (charge division) as shown

in Fig.1. The tubes are mounted in an aluminum casing 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 neutron are determined from the position of the tube hit and the position of the neutron along that tube. The 16 tubes are grouped into two banks each of 8 tubes separated by 160 mm with a total sensitive detectable area of $100 \times 40 \text{ cm}^2$. A ^{252}Cf neutron source of strength 10^5 n/s was used.

The detector array is mounted at the front of a trolley propelled by electric motor as shown in Fig. 2. The speed of the trolley can be varied between 6 mm/s and 300 mm/s. The trolley has a suspension for smooth movement and can be steered from a driver seat. Provisions have been made to vary the standoff distance, i.e. the distance between the detector and ground. The stand-off distance can be varied from 7 to 22 cm.

The image of the intensity distribution of the back-scattered thermal neutrons over the soil surface is formed while scanning. A pixel area of $3.1 \times 3.1 \text{ cm}^2$ was chosen which is sufficient to properly 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 $3.1/v$ s above a row of pixels, with v (cm/s) the scan speed. The total measuring time for all detector tubes to completely measure a row of pixels is therefore, $16 \times 3.1/v = 49.6/v$ s. The time for the detector to pass over a pixel row i.e. the pass-over-time, is $(16 \times 3.1 + 16)/v = 65.6/v$. The detector 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, $\approx 66 \text{ cm}$.

Noise Processes Associated with Imaging by NBS:

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 ^3He 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 $\sim 30 \text{ cm}$ wide,
- The band of raised intensity running 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:

- The signal from the mine, if present,
- A contribution caused by neutrons scattering from the soil,
- A contribution from fast neutrons, which hit the detector without having entered the soil,
- A background from gamma rays emitted by the source.

The latter three 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 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 [7].

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 two types of filters which have been tested in this work are given and discussed below:

Image Denoising Using Stationary Wavelet Transform, SWT: In the present work, a new approach based on wavelet theory to provide an enhanced approach for

eliminating such noise sources and ensure better signal to noise ratio is proposed. It is well known that wavelet transform is a signal processing technique which can display the signals on both time and frequency domain. Wavelet transform is superior approach to other time-frequency analysis tools because its time scale width of the window can be stretched to match the original signal, especially in image processing studies. This makes it of particular useful for non-stationary signal analysis, such as noises and transients. For a discrete signal, a fast algorithm of Discrete Wavelet Transform, DWT is multi-resolution analysis, which is a non-redundant decomposition. The drawback of non-redundant transform is their non-invariance in time/space, i.e. the coefficients of a delayed signal is not a time-shifted version of the original signal. The stationary wavelet transform overcomes this problem and makes the wavelet decomposition time invariant. This improves the power of wavelet in signal de-noising.

In this paper, the SWT method [8] is proposed to preprocess the NBS images for removing the noises. A comparative analysis of this method with Matched filter is presented to validate the obtained results. Also, a comparison was made with the Matched filter, to validate the enhanced characteristics of this method to NBS image processing.

The wavelet denoising is achieved via thresholding or shrinkage. The wavelet thresholding procedure removes noise by thresholding only the wavelet coefficient of the detail sub-bands, while keeping the low resolution coefficients unaltered. The general denoising procedure involves three steps, which are, Decompose, Threshold detail coefficients and Reconstruct. In these steps, a signal is first decomposed by the wavelet transform and the decomposition coefficients are controlled by the threshold rule. After threshold processes, a new coefficient is obtained. This new coefficient is then used to reconstruct a new signal. This is the filtered signal by wavelet transform. Also, the Coiflets Wavelets (caoif5) procedure was applied to decompose the image using MATLAB. Through the threshold process, the noise source in images was eliminated at each level to have detailed images. After denoising processes, the obtained detailed and approximated images are reconstructed. These images are displayed in Figs. 3 and 4. Figure 3 shows the measured and denoised images for three dummies of ATM with PVC casing filled with two kg of melamine. The first is for an ATM buried at 15 cm depth and the other two are for ones buried at 10 cm depth. The scanning process was performed with a scan speed of 10 mm/s and stand-off

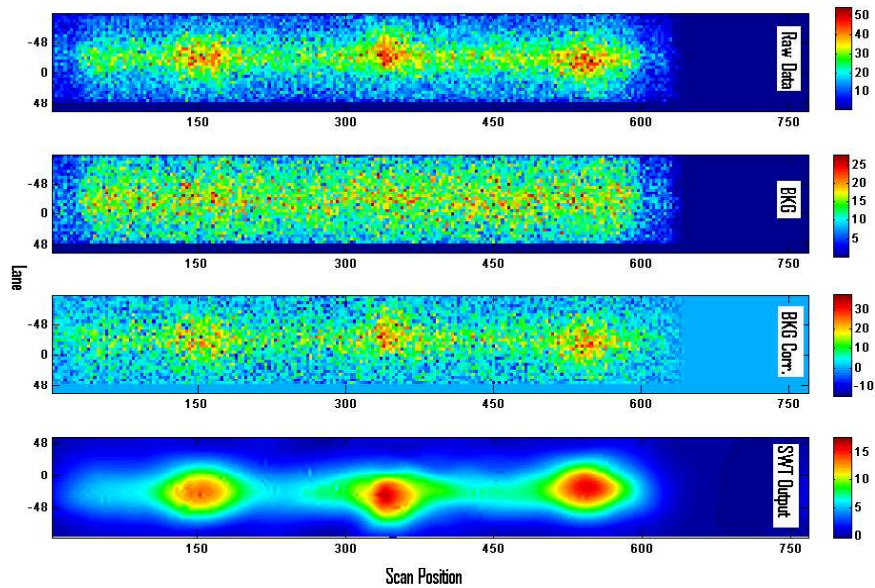


Fig. 3: The origin and denoised images for three ATMs.

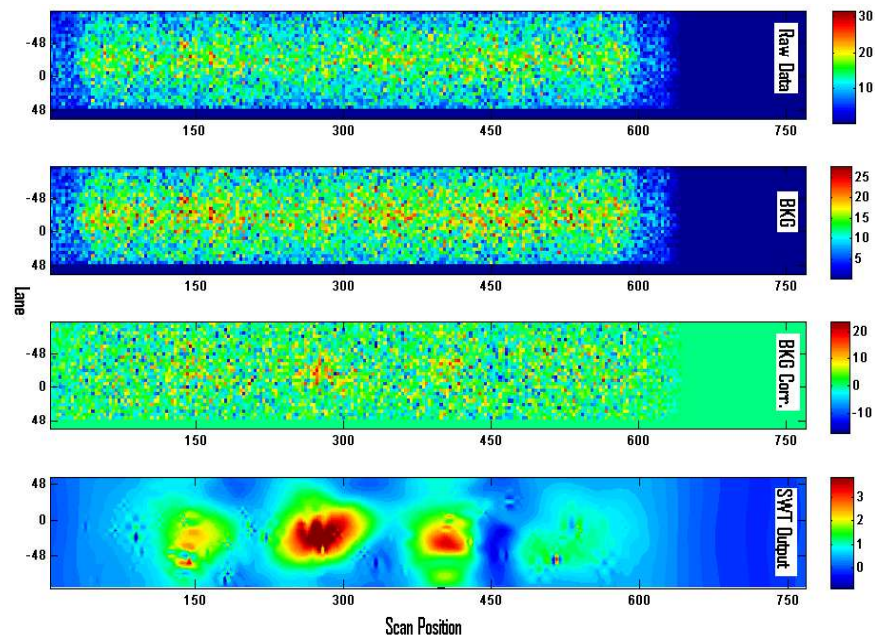


Fig. 4: The origin and denoised images for three APMs.

distance = 10 cm. The denoised images for three dummies of APM, type DLM2 (buried at the surface and two massive polyethylene buried at 5 and 10 cm depths) measured with a scan speed of 10 mm/s and stand-off distance of 10 cm, are shown in Fig.4.

Matched Filter: The method of ‘matched filter’ entails a convolution of the image with a reversed template of the sought mine signal. The template was obtained from the mine signal of an ATM at small depth. After removal of

the background, it was smoothed by Gaussian filtering and the content was normalized to one. The output of the convolution is high when the image does contain the sought signal. A mine signal is detected at a position if the matched filter output at that position is above a certain threshold value. To make a comparative analysis, the previous measured mine signals were filtered using the matched filter technique and the obtained images are displayed in Figs. 5 and 6. These two images clearly indicate that the SWT denoising method achieves a better

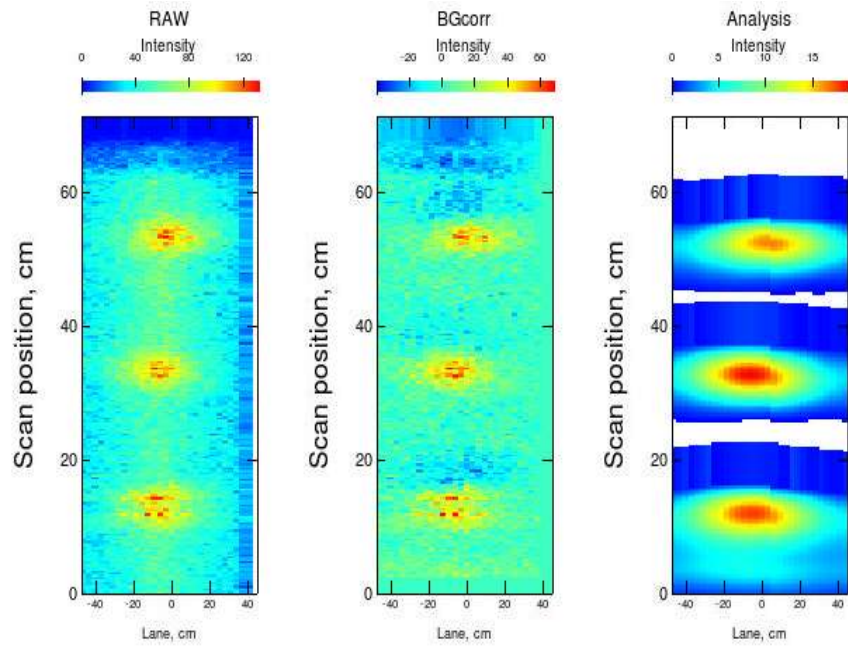


Fig. 5: The origin and filtered images for three ATMs.

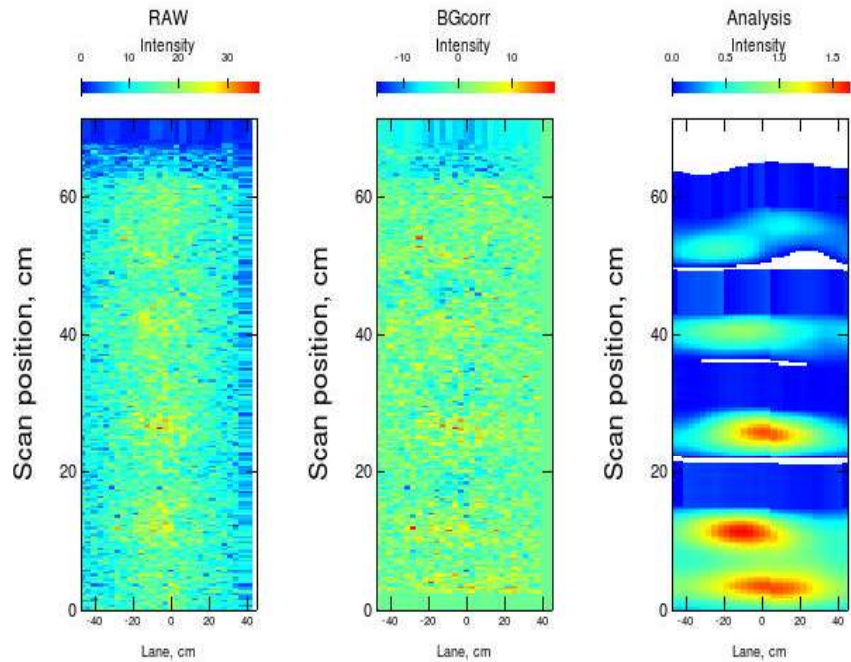


Fig. 6: The origin and filtered images for three APMs.

image quality than the ones treated by Matched filter method. In addition, the signal to noise ratio is much better incase of SWT than MF technique (for SWT S/N=75% and for MF S/N= 66%).

Transmission Imaging Techniques: The developed, adapted and implemented nuclear techniques based on

measuring the transmitted photons or neutrons emitted from small radioisotope sources were used to locate and identify contraband materials hidden in cargo containers [9-10]. The objective of these techniques was achieved by gamma-ray radiography methods to locate the position of hidden object and by a gamma spectrometer to identify suspected object by neutron -gamma elemental analysis.

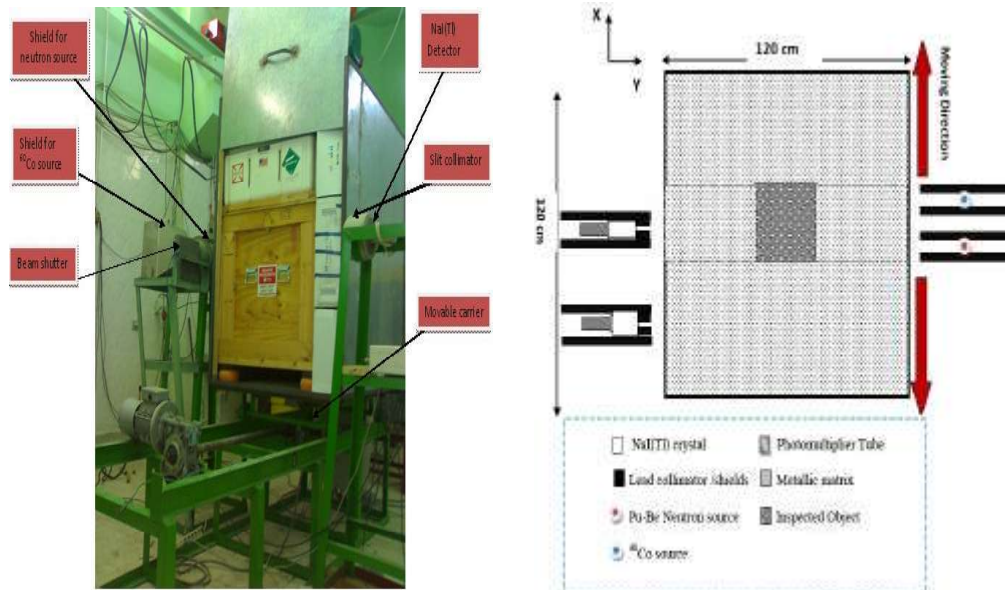


Fig. 7: Photograph and schematic diagram for the installed combined systems

The designed and installed mechanical system for manipulating the inspected container is shown in Fig. 7. The system consists of a transfer table moves on steel frame by step motor. The inspected container is fixed on the transfer table and is moved between radiation source and detector in step increment varies from 0.05 mm to 100 mm. The system works as well in continuous mode in the backward and forward directions. The movement increment and time of measurements are changed and adjusted by a control unit.

The position of hidden object within container payload is located by a gamma-ray scanner. A brief description of the installed gamma-ray radiography systems is given below:

Gamma-Ray Scanner: A gamma scanner based on using slit beam of gamma-rays emitted from ^{60}Co source of activity ~ 0.5 Ci was used. The source was fixed in a lead shield with horizontal channel where gamma-ray collimators of different geometries can be inserted to have gamma-ray beams of different geometries. The gamma-rays transmitted through the inspected container are measured by a NaI(Tl) detector housed in lead collimator with central slit to enhance the spatial resolution of the 2D image constructed from the transmitted gamma beam. The output signals of NaI(Tl) detector were amplified and fed to the input of a radiation analyzer to only count signals of gamma-rays of energy ranges from 1.1 to 1.4 MeV. The output of scan is fed to a counter/timer NIM module type, ORTEC 776 and its output is fed to the input of a PC for signal processing and image reconstruction.

Image Reconstruction from Fan-beam Projected Data: Assuming a narrow beam geometry in which the scattered radiation dose not reach the detector, the transmission of photons through an object of density ρ (g/cm^3) and thickness X can be calculated using the attenuation relation:

$$\frac{I_n}{I_o} = e^{(-\mu\rho X)} \quad (1)$$

Where:

- I_n is the measured photons intensity through the object across X and Y- directions and the subscript n are refer to the pixel number, where $n = 1, 2, 3$
- I_o is the incident measured photons intensity (the container removes).
- μ is the gamma mass attenuation coefficient.

The measured photons transmitted through the inspected object carry most of the information about shape and density of the suspected object. For each pixel the quantities $R = -\ln\left(\frac{I_n}{I_o}\right)$ is calculated to construct a two dimensional image with different color zones using MATLAB program. A hot zone indicated a high density materials or hidden (shielded) organic materials.

Figs. 8 and 9 show the constructed images and its projections for steel screened ATM hidden inside a container filled with papers scanned with ^{60}Co source. Fig. 8 shows the original and denoised images accomplished with its profiles using SWT as discussed in section 1.2.1.1. The original and filtered images using median filter

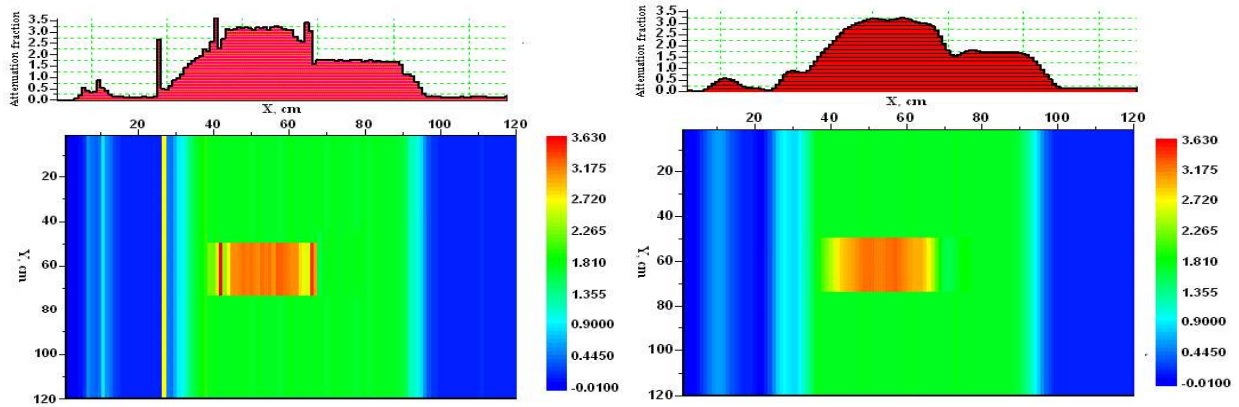


Fig. 8: Origin and denoised 2D-images constructed from gamma ray scanning of ATM hidden inside cargo container filled with papers.

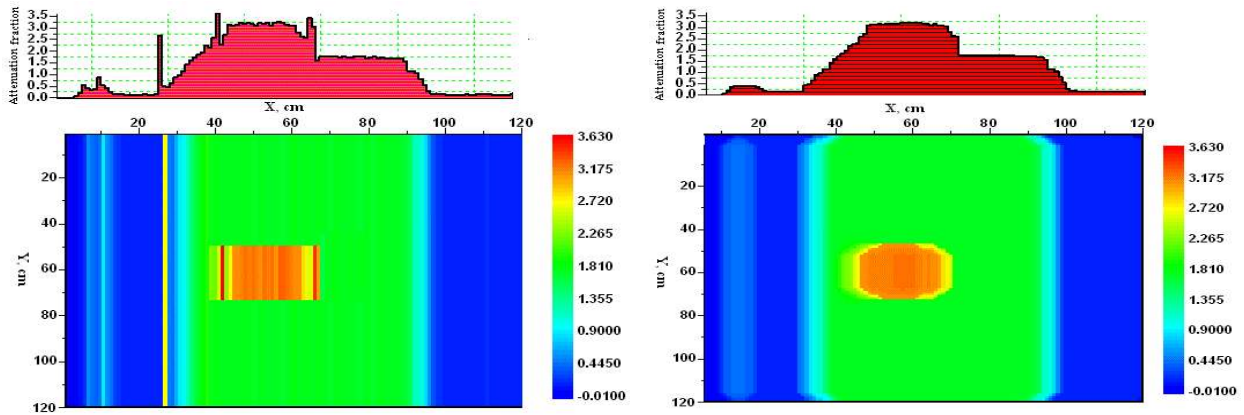


Fig. 9: Origin and filtered 2D-images constructed from gamma ray scanning of ATM hidden inside cargo container filled with papers.

is displayed in Fig. 9. The displayed images give a good indication for the position of the hidden object inside the container. In addition, the displayed images indicate that, the using of SWT preserve the fine details of the obtained images.

CONCLUSIONS

The main conclusions that can be drawn from the presented results and constructed images are:

- The use of penetrating nuclear radiations, photons and neutrons shows a great potential for application to detect buried landmines in the arid countries and illicit materials hidden inside cargo containers.
- The new approach based on the denoising by SWT via MATLAB wavelet tool box provides a good, fast and accurate performance in denoising NBS image. The results show that, the stationary wavelet SWT denoising has a 30% better performance than

Matched filter which is commonly used to remove white and randomly noises in radar signals.

- The application of this method would improve the detection accuracy by decreasing the number of false positive signals which are associated with the matched filter technique.
- The Matched filter technique can not be used incase of detection of explosives and illicit materials because there is no reference signal.
- Software developments for image reconstruction and filtration have to be performed to make it more reliable and accurate for real field application.

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