Construction of a developed software for nuclear forensics of micro particles

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ABSTRACT

Nuclear forensics has capabilities to implement the national nuclear security infrastructures as well as the usage in the illicit trafficking of radioactive and nuclear materials. One of the forensic analysis methods that is widely spread is scanning electron microscope (SEM), which provides images of a sample by scanning its surface with an optimized electron. In this study, a large number of images that represent all steps of magnifications that range from x30 to x300000 were used in addition to the SEM data of uranyl nitrate hexahydrate samples and two uranium ores to develop an SEM image manipulation software. The constructed software aims at image processing of micro particles to matlab that supplies a comprehensive collection of reference-standard algorithms for processing images, analyzing, visualizing and algorithm development. The developed software (SEMMICRO001) can produce a wide range of image treatments such as enhancing image, noise removal or reduction, geometry transformations, image statistics and displaying image. It can also help us to obtain more information for small particles in micro scale especially particles size in the analyzed samples.

Research highlights

- SEM MICRO001 software helps to obtain information on micro particles.
- SEM MICRO001 measures the distance between two points in micro scale depending on only one image information
- SEM MICRO 001 process and analyze SEM images JSM6510LV.

1. Introduction

Nuclear forensics is a rising science, resulting from objectives of national security, together with those of both law enforcement and intelligence authorities. Nuclear forensics is one input into nuclear contribution, in which responsibilities are assigned, in addition with different information sources, such as law enforcement and intelligence. It is used to create conclusions by application of validated signatures to analytical outcomes from the interdicted material (Moody, Grant, & Hutcheon, 2014). These validated signatures contain both signatures comparison, in which the interdicted material is subject to similarity check with results from material of known origins and predictive signatures, in which conclusions are generated in absence of reference to other samples (Jamie et al., 2016). Validating analytical methods, sampling properly, and a quality control/assurance program lead to good analytical results. Nuclear forensic analysis uses elements, isotopes, physical and chemical signatures to get a clear technical insight into the nuclear materials source and history of an unknown origin (Schwerdt et al., 2018).

The microscope role is to produce a sample image at certain magnification that allow to observe features which cannot be realized by the human eye (roughly 50–100 μm) due to lack of resolution (Goldstein et al., 1981). An essential starting point of most forensic investigations is its ability for identifying and characterizing samples of diverse suites rapidly and with no compromise to the integrity of the sample. Various microscopy techniques are applied in nuclear forensics, utilizing photons, electrons, and X-rays to screen the physical and chemical properties and structural features of samples at spatial scales ranging from nanometers to centimeters (Pestana, Sarkis, Marín, & Elita, 2013).

Radiological and nuclear materials morphologic properties may introduce information and serves as a signature for the former sample history (Olsen et al., 2017, Tamasi et al., 2016 & Shaban, Ibrahim, El-Mongy, & Elshereafy, 2013). In scanning electron microscope (SEM), a finely optimized electron beam produced from an electron gun is passed over a sample and interacts with it, this interaction leads to production of various signals: back-scattered electrons (BSE), secondary electrons (SE), Auger electrons, X-rays, and photons. An image of a sample is formed by measuring the intensity (in terms of counts) of one or more of the emitted particles as a function of raster position. Each kind of these
particles contains different information concerning the sample and by selecting the suitable mode of detection, either compositional or topographic contrast is revealed in the image. Inelastic collisions between incident electron beam and atomic electrons lie in the outer few nanometers of the sample surface resulted in production of secondary electrons reveal information about sample topology. In contrast, information about the mean atomic number can be obtained from back-scattered electrons. Also, it can be used in constructing maps of the distribution of phases with distinct chemical composition. With thermionic, W filament sources, the resolution of the image is restricted to ~10 nm, with a maximum corresponding magnification of 100,000. With field-emission electron sources, the resolution exceeds 1 nm with a maximum corresponding magnification of 1,000,000 (Pidduck, Houlton, Williams, & Donohue, 2006).

2. Materials and methods

SEM images at different magnifications (X 30 – X 300,000) were obtained in the work of Sameh E. Shaban, Sayed, and Walid (2016) and Shaban et al. (2016). These images along with the images of uranyl nitrate hexahydrate sample-UNH (Egyptian Nuclear and radiological Regulatory Authority) and two ore samples (Egyptian Nuclear Material Authority) were scanned at all magnifications using JSM 6510 LV. These images were enhanced to increase its quality and analysis using a commercial validated image software (IMAGEJ) which is used for examination of microscopy images (Chaichi, Sharif, & Mazinani, 2018) then correlation between the size in pixels using IMAGEJ and the SEM image manipulation software (Smile view software). Finally, the SEM MICRO 001 was validated using IMAGEJ software (Ferreira & Rasband, 2012). Table 1 represents image properties estimated by the two softwares. SEM MICRO 001 is represented in Figure 1. As evident in the figure, the software design consists of two parts: the first part is located on the left side concerned with image processing system in which certain functions were used such as load image, gray image, black and white, image details, histogram, histogram equalization, contrast tool, imcontour, crop tool, resize, entropy, mean, standard deviation, divide image, and noise removal. The second part is located on the right side and was used as a size estimator tool. To sum up, our (SEM MICRO 001) software makes benefits from functions in image processing tool box in matlab. The software depends on the correlation between pixel value and micro size. This correlation is the result of experimental data obtained from imaging a large number of samples at different magnifications. This software is valid for image processing and analysis of micro particles images resulting from SEM (JSM6510lv) for the

![Figure 1](image1.png)

**Figure 1.** SEM MICRO 001 software design. The left side contains a display screen. The buttons beneath are concerned with a specific image characteristic. The reset button is concerned with removing an image to get another one. The clear button is for removing the upper three buttons. The pop-up menu is for selecting the desired magnification. The image tool is for measuring the size in pixel to write where “Enter Pixel Value” is written. Finally, the distance button is for calculating the size in micro.
magnification values ranging from X30–X300000. The method is only valid for elements ranging from Be-4 to U-92 and the detection limits are typically about 0.1 wt% (Shaban et al., 2016).

3. Results and discussions

The results contain the SEM images of different samples that were scanned at different magnifications. The images in Figure 2 represent the uranyl nitrate sample scanned at x30 and the other two are ore samples that exist in the powder form scanned at x100 and x500, respectively.

It is clear that the histogram of SEM uranyl nitrate sample image in Figure 3 obtained by IMAGEJ and SEM MICRO 001 were identical hence the validity of SEM MICRO 001 is remarkable. Finally, the process of histogram equalization in Figure 4 was done using SEM MICRO 001 to enhance image contrast.

The validation of the image processing partition of SEM MICRO 001 was completed by doing measurements to these three images. The properties that were measured were mean, standard deviation, and image details. It is obvious the results were also identical and the image details were the same for all samples because they are measured at the same scan rate.

The second part of results were concerned with the validation of software. In this part, a correlation was done between the value of size measured by smile view software and that obtained by IMAGEJ software. All magnifications of SEM image processing system were correlated using both software. The resulting data were plotted and represented in Figure 5, where the correlation value was directly proportional to SEM magnification value.

The image size estimation system of SEM MICRO 001 was validated using IMAGEJ software and the results were obtained in pixel and in micro and the results were identical.

The results in Table 2 are the same as in SEM MICRO001 and IMAGEJ software as they depend on measuring the size based on pixel values and the error results is due to the human error and pixel values. The overall error is approximately less than one pixel and this percent lies within the acceptable uncertainty.

4. Conclusions

SEM MICRO 001 software can overcome problems that face smile view software which is only combatable with SEM of JSM 6510 LV model and it can be used to measure the distance between two any points in micro scale depending on only the value of magnification. This software uses an available and widely used program and does not need any specialized, complicated or expensive software. With this technique, we can compete and exceed smile view in accuracy by making a benefit from the algorithm that is used to determine edges and boundaries of the images in matlab. By using this algorithm, we can get more accurate results and we can also overcome the human error in determining the edges of any image. This advantage can be used in any sample image especially, in the case of swipes that contain very small particles that become more bright at high magnifications and it becomes difficult for the eye to determine its diameter. In addition, these particles can be enhanced using matlab.

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Figure 2. SEM images of different samples at various magnifications. The left image is an image of a uranyl nitrate hexahydrate sample scanned with JEOL SEM 6510 LV at optimal conditions and spot size value of 50. The two other images are two uranium ores (powder) scanned at electron beam conditions with the same instrument.
Figure 3. Histogram of SEM images by IMAGEJ on the left and SEM MICRO 001 on the right. The two histograms give information concerning the distribution of pixel values in the whole image.

Figure 4. Histogram equalization of SEM image by SEM MICRO001. Histogram equalization figure in the right side makes a wide distribution of all pixel values to cover the scale from 0 to 255 to as fair as possible and the outcome is on the left side which is image of adjusted contrast.

Figure 5. The relation between magnification and correlation value. This relation is a result of more than 90 SEM images that represent all steps of magnification in the instrument software. These images micro bar studied accurately to obtain an accurate and precise correlation for each magnification value.
Disclosure statement

No potential conflict of interest was reported by the authors.

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| Table 2. Size estimation by SEM MICRO 001 and IMAGEJ. |
|-----------------------------------------------|
| **Image** | **Size (pixel)** | **Size (micro)** |
|-----------|-----------------|-----------------|
| Image 1   | SEM MICRO001    | 45              | 300             |
| (UNH)     | IMAGEJ          | 45              | 300             |
| Image 2   | SEM MICRO001    | 15.50           | 31              |
| (ore powder) | IMAGEJ     | 15.50           | 31              |
| Image 3   | SEM MICRO001    | 88.75           | 35.5            |
| (ore powder) | IMAGEJ    | 88.75           | 35.5            |