



Improvement of Nuclear Track Density Measurements Using Image Processing Techniques

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Abstract: The well known edge detection methods were applied to evaluate accuracy and precision of nuclear track densitometry of polycarbonate detector. All measurements carried out in two cases of before and after improvement of track images. Considering the overlapping phenomenon -including double and triple tracks- experimental and statistical results showed that not only each particular edge detection method affects the accuracy of measurements, there is also a significant difference in accuracies of all techniques before and after image enhancement. However, no noticeable difference observed in precision of each individual edge detection method before and after image enhancement. Results of this study showed that overall, among the several routine edge detection method, Canny is the most accurate technique. Moreover, Laplacian of Gaussian and Canny techniques are more precise than other edge detection techniques in the case of this study.

Keywords: SSNTD, edge detection, image processing, Matlab

INTRODUCTION

Solid state nuclear track detectors (SSNTDs) are frequently used in various research fields^[1]. In all research fields, however, the principle of these detectors is based on their ability to detect and register charged particles as the latent tracks. The required process to enlarge the primary latent tracks is called chemical etching (CE)^[2] or alternatively electrochemical etching (ECE)^[3] by which the latent tracks grow slowly and become visible. Up to now, many researchers have used solid state materials to evaluate the geometrical and morphological characteristics of nuclear tracks^[4, 5, 6]. In these kind evaluations, researches are mainly focused on some developed and fast access methods to find the best relations between geometrical characteristics of tracks and the properties of initial incident particles^[7]. Studies show that nuclear track evaluations using the recent developed methods based on the theoretical and practical aspects of modern optics can be accurate as well as the conventional methods (such as using the optical microscopes) but faster than using the traditional methods^[8]. These recent developed methods include application of Fourier optics^[8] and also applying image processing techniques to improve track

images^[9,10]. In fact, these methods are able to improve applications of SSNTDs, particularly when they are accompanied by image processing techniques.

Methods of image enhancement are divided into two main approaches of Frequency Domain Methods (FDMs) and Spatial Domain Methods (SDMs)^[11]. FDMs are based on convolution theorem and Fourier transformation, while the second approach works based on the directly enhancement of grey level of each pixel of the image. In the present work, we have focused on one of the most informative aspects of the second methods (SDMs) called edge detection by which track boundaries and edges in the image have been identified.

Since the major part of SSNTD evaluations refer to counting and geometrical measurements (diameter, depth, and orientation of tracks) the mentioned description is important for accessing the more accurate estimations. Moreover, the phenomenon of tracks overlapping leads us to apply those image enhancement techniques by which a correct judgment can be carried out to obtain the real track distribution on SSNTDs.

Such techniques help researchers to access more accurate methods for estimating the incident particle characteristics. On the other hand, many image processing techniques such as histogram processing, image smoothing and sharpening (e.g., using derivative

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filters) are available to decrease some technical deficiencies in tracks recognition which can cause less accurate measurements. In order to improve SSNTD measurements, applying the well known derivative filters (edge finders) is one of the most important aspects of image processing.

Edge detection: Edge detection is one of the most important techniques by which the interested components of image are detected. Generally, edge detection methods are based on using gradient matrix operators by which the image pixels with a rapidly change in intensity are detected^[12]. These techniques are commonly performed using the first and second order derivative operators for each pixel of image. The first order derivative operator is used to detect those pixels with a magnitude of intensity larger than the defined threshold in the same region, while the second order derivative is applied to find the zero-crossing points of the interested region. As shown in Fig. 1, gradient of a pixel on an assumed track edge is simply a vertical vector with respect to vector of edge tangent at the same point. Thus, considering $f(x,y)$ as the light intensity function, gradient of the pixel (x,y) is defined as^[11]:

$$\nabla F = \begin{bmatrix} \frac{\partial f}{\partial x} \\ \frac{\partial f}{\partial y} \end{bmatrix} \hat{k} \quad (1)$$

The magnitude of this vector is:

$$|\nabla F| = \left[\left(\frac{\partial f}{\partial x} \right)^2 + \left(\frac{\partial f}{\partial y} \right)^2 \right]^{1/2} \quad (2)$$

$$= \left[(f_x')^2 + (f_y')^2 \right]^{1/2}$$

In discrete state, continuous variables x and y is replaced by discrete quantities m and n indicating the pixel position in the image. Therefore, the gradient method is estimated as follows:

$$\nabla f(m,n) = \sqrt{f_x^2(m,n) + f_y^2(m,n)} \quad (3)$$

where f_x and f_y are gradient estimations along the axes X and Y respectively, and defined as the following:

$$f_x(m,n) = f(m,n) * h_x(m,n) \quad (4)$$

$$f_y(m,n) = f(m,n) * h_y(m,n)$$

where h_x and h_y are two derivative filters along X and Y axes.

The well known edge detection techniques:

- The operators of Sobel, Prewitt and Roberts detect edges using their particular matrices for approximation to the derivative. These operators return edges at those points where the gradients of the original image are maxima^[11,13].
- The operators of Laplacian of Gaussian (LOG) and the Zero-crossing detect edges by looking for zero-crossings after filtering the original image with a Laplacian of Gaussian and a specific filter, respectively^[11,14].
- In 1986 Canny^[15] introduced an operator as an ideal edge detection method^[16]. The operator of Canny detects edges by looking for the local maximums of the gradient of image. In this method the derivative of a Gaussian filter is used for calculation of gradient.

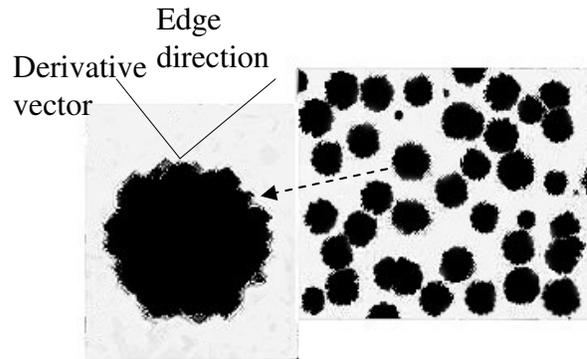


Fig. 1: The edge vector direction in an assumed pixel of a track image

MATERIALS AND METHODS

Detectors Irradiation and etching condition: A set of $n=8$ Lexan polycarbonate (PC) foils with dimensions 2.5×2.5 cm and thicknesses $250 \mu\text{m}$ were separated from a same larger sheet. Then, the cover of each foil on the side which should be irradiated was removed. A 7.5×10^4 APM (α -particles per minute) ^{241}Am as 1.2

MeV alpha-source was used to irradiate the PC foils. Subsequently, an optimized solution of PEW with the composition of 15g KOH+40g C₂H₅OH +45g H₂O was used as the standard etchant for electrochemical etching of the irradiated foils^[17,18,19]. For electrochemical etching with the mentioned etchant, each foil was placed between two cells of chambers to electrically insulation of the cells from each other. Then electrochemical etching process was performed applying the field strength of 32 kV cm⁻¹ and 2 KHz frequency for 3 h. All experiments were carried out at the room temperature (27 °C). The irradiation and etching condition kept constant for all evaluated polycarbonate foils.

In this study, the number of measurements (count per field) was N=10 for each foil. All microscopic fields for counting were chosen around the centre of foil. This process was repeated for all eight etched PC foils and the final average track densities were calculated using the averages over the 8 PC foils. An optical calibrated microscope with a proper magnification power was used to obtain the real track density of all detectors.

Edge detection using Matlab software^[20]: Edge detection techniques applied in this study are defined based on famous derivative operators. The well known Gradient-based operators named Prewitt, Sobel, Canny, Zero-crossing and Gaussian of Laplacian (LOG) applied on the original and enhanced images. In Matlab, edges in an intensity image can be detected using the operator of “edge” (for each method) by which a binary image B&W is formed with a same size with the original image. The pixels detected as edges by the operator are returned to the maximum intensity (1) and other pixels to be given the minimum intensities (0). For edge detection, image Classes supported by Matlab are double, unit8 and unit16. Consequently, each edge detection command in Matlab is in fact an internal function which can transform image grey levels to [0, 1], [0,255], [0,65535] for double, unit8 and unit16 classes, respectively. In each class, zero intensities are considered as dark dotes (0) and the full intensities referred to white (1, 255 and 65535). Consequently, edges are formed as a black and white image contains only boundaries of the image components (see Fig. 2). In order to improvement of track images, we applied the image processing toolbox of Matlab^[20]. This unique software represents a wide range of routine image

enhancement techniques such as smoothing filtration, histogram equalization and gamma adjustment.

RESULTS AND DISCUSSION

Fig. 2 (left column) shows a microscopic field of one of eight etched PC foils in this study. The results of applying edge detection methods on this image also shown in Fig. 2 (left column). Fig. 2 (right column) shows the enhanced image of the same microscopic filed and the comparable results of applying the same edge operators.

The results of SSNTDs densitometry have been shown in Table 1. The relative standard deviation (RSD= σ_{ρ} / ρ) for each measurement has been presented in Table 1. Furthermore, in this study the mean track diameter under the mentioned irradiation and etching conditions was obtained 128.4 ± 46 μm.

The following definition was used to calculate the accuracy of tracks densitometry for each method:

$$Accuracy(\%) = \left| \frac{\rho_R - \rho}{\rho_R} \right| \times 100 \quad (5)$$

where ρ_R is the average real track density of all etched foils $(-2.88 \pm 0.07) \times 10^3$ tracks cm⁻² in this study- and ρ is the average track density after applying each edge detection method. Fig. 3 shows the accuracy of each method calculated by Eq. (5) based on experiment results shown in Table 1.

According to Table 1, there is a noticeable increasing in average track density for all applied techniques due to image enhancement. In order to justifying this phenomenon, we used an accurate calibrated optical microscope with a proper magnification to obtain the real average track density for all detectors as the reference value of our study. This reference value was obtained $(2.88 \pm 0.07) \times 10^3$ tracks cm⁻² which is comparable with the average densities obtained by all edge detection methods “only” after image enhancement. Consequently, it resulted that the phenomenon of increasing of average densities after image enhancement is evidently due to improvement of our tracks recognition system to recognize double and triple tracks.

On the other hand, comparison of accuracies of measurements shown in Fig. 3 demonstrates that for all edge detection methods, measurements after image enhancement are more exact than before enhancement.

As a matter of fact, the standard deviation can be used as a measure of uncertainty in measurements; therefore we used the reported standard deviation of our repeated experiments to evaluate the precision of

measurements. The relative standard deviations (RSD) shown in Table 1 indicate that:

- Regarding image enhancement, each individual method (e.g. Prewitt method) has approximately a same precision before and after image enhancement.
- Regardless any image enhancement, differences in relative standard deviations indicates that precisions of measurements are evidently deferent (Table 1). According to our results (Table 1) two techniques of Gaussian of Laplacian and Canny are more precise than others.

As an interesting and expectable result^[16], our experiments show that among all applied methods, Canny is the most effective technique in the case of this study. According to Fig. 3, Canny is the most accurate technique while according to Table 1, this method - accompanied with Gaussian of Laplacian- is also the most precise method to improve SSNTDs densitometry.

The reason by which the Canny method differs from other methods is applying two different thresholds in this method to detect both strong and weak edges. This technique includes the weak edges in the output “only if” they are connected to strong edges, so that this method is less likely to be confused by noise, and more likely to detect real weak edges. It is also clear from our pictorial results (e.g., Fig. 2) in which particularly compare to Prewitt and Sobel, Canny operator is more able to detect the boundaries between double and triple tracks (overlapping phenomenon). The mentioned fact can evidently be observed in both before and after image enhancement (Fig. 2). Therefore, as an overall result, Canny method showed that this technique can be the most accurate and precise approach to improve densitometry of nuclear tracks.

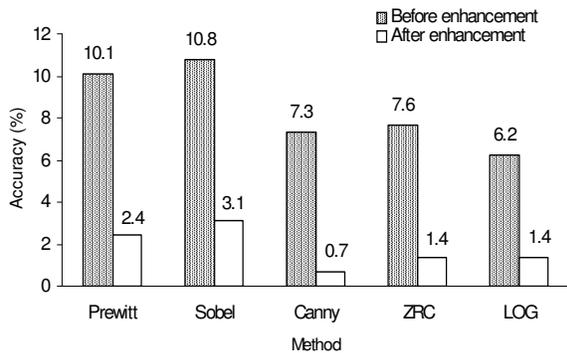


Fig. 3: Accuracy of measurements after applying edge detection methods

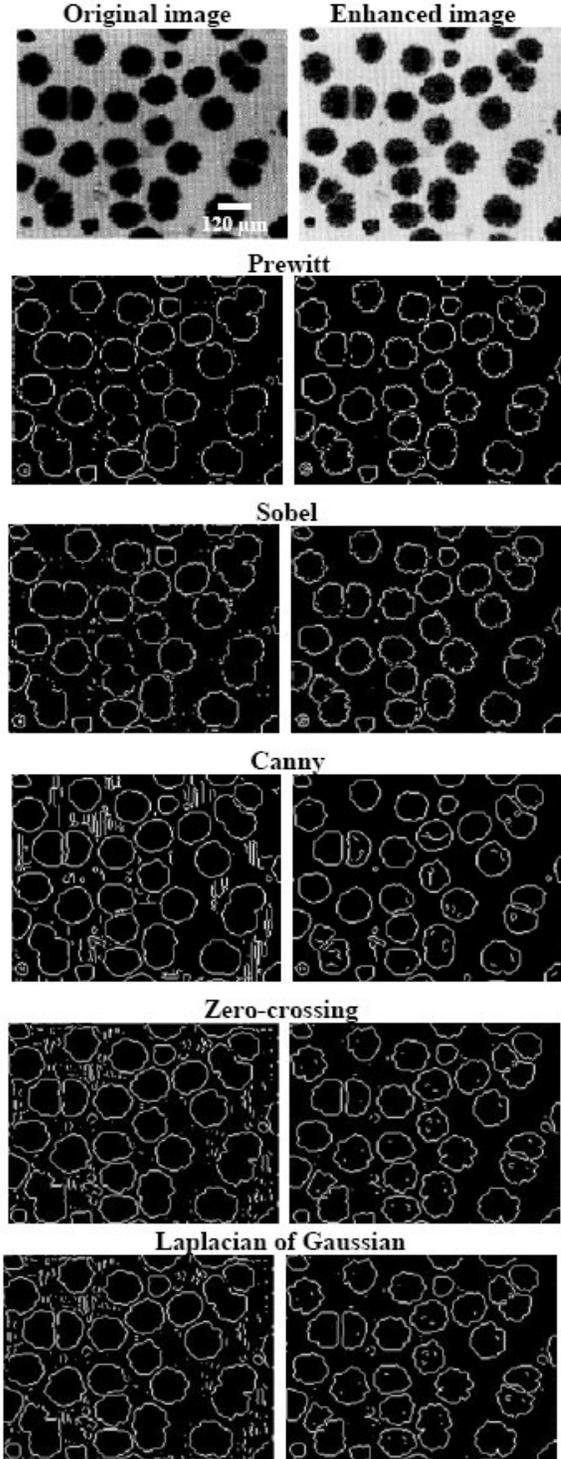


Fig. 2: The results of applying edge detection operators (mean track diameter is $128.4 \pm 46 \mu\text{m}$)

Table 1: Comparison of the measured average track densities (tracks cm⁻²) applying edge detection operators before and after image enhancement

		Methods				
		Prewitt	Sobel	Canny	Zero-crossing	LOG
Average track density (tracks cm ⁻²)	BF	(2.59±0.15)×10 ³	(2.57±0.15)×10 ³	(2.67±0.10)×10 ³	(2.66±0.16)×10 ³	(2.70±0.09)×10 ³
	AF	(2.81±0.16)×10 ³	(2.79±0.18)×10 ³	(2.86±0.12)×10 ³	(2.84±0.17)×10 ³	(2.84±0.11)×10 ³
RSD (%)	BF	5.8	5.8	3.7	6.0	3.3
	AF	5.7	6.4	4.2	5.9	3.9

Note: Real track density: $\rho_R = 2.88 \pm 0.07$ tracks cm⁻²
RSD= Relative Standard deviation (σ_p / ρ)
N_i : The total number of measurements for each method=10 counting fields × 8 foils = 80
BF: Before image enhancement
AF: After image enhancement

CONCLUSION

Due to importance of accurate measurements of nuclear tracks in many fields particularly in radiation protection, we attempted to evaluate the main deficiencies related to track recognition system. In this study we evaluated the well known edge detection methods frequently used by image processing tools such as Matlab image processing toolbox. Although some researchers have previously resulted that some special methods such as Marr-Hildret technique lead to a minimum error in the “case” of their measurements^[16], however we resulted that Canny is the most accurate method in the “case” of our experiments. On the other hand, it should be noticed that some methods such as Marr-Hildret and Morphologic Laplacian techniques are originally based on Laplacian of Gaussian (LOG) method but deferent in methodology^[14,16]. As it can be noticed from our pictorial results (e.g., the image samples shown in Fig. 2), the method based on Laplacian of Gaussian are more sensitive to noise than others, while our statistical results show that the Canny method is more able to find real track edges through the noise^[15,16]. On the other hand as it was resulted by our study, improvement of track images before edge detection has a significant effectiveness to enhance accuracy of measurements (Table 1 and Fig. 3). It is evidently due to decreasing of noise particularly due to applying image smoothing filters and gamma adjustment before densitometry.

As a general suggestion, since nuclear tracks in polymeric detectors are in fact optical phenomena, we propose applying further image processing techniques to access more accuracy in measurements. Further investigations in this filed not only lead researchers to further knowledge about optical aspects of SSNTDs, even can be applied as a fast and accurate alternative method in radiation dosimetry.

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