Automated Method for Solid State Nuclear Track Measurements

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Abstract. Solid state nuclear track detection technology is an important nuclear technology based on the measurement of track density and geometric parameters, but manual measurement is difficult to ensure the accuracy and efficiency. Aiming at the uneven brightness, low contrast and noise pollution of nuclear track images, this paper proposes a method of acquisition, brightness correction, de-noising filter, target segmentation, boundary extraction, recognition of solid nuclear track image, and finally obtaining the geometric characteristic parameters of nuclear track, which improves the accuracy and efficiency of nuclear track parameter measurement.

Keywords: Solid state nuclear track, image acquisition, brightness correction, morphological filtering, parameter measurement.

1. Introduction

When the heavy charged particles with certain kinetic energy incident on the insulating solid material, they will cause radiation damage in their path, leaving tiny traces. The trace can be seen under the optical microscope after proper chemical etching. Somogyi, Fews and Nikeziec all studied the etching principle and track formation process of CR-39 in detail, and proposed different theoretical models and calculation methods [1-3]. Under the same etching conditions, the same kind of particles with different energies or different particles with the same energy has different track forms. The same kind of particles with different energy or different particles with the same energy can be distinguished according to the shape and diameter of the track [4].

Li estimated the energy and incident angle of proton based on the nuclear track morphology on CR-39 [5]. With the increase of incident proton energy, the nuclear track becomes smaller and shallower; in the case of normal incidence, the track form is close to a circle; With the increase of incident angle, the track gradually changes into an ellipse, as shown in Fig. 1. Both the diameter of circular track and the minor axis or equivalent diameter of elliptical track has a significant exponential decay relationship with the energy of the incident proton. Meanwhile, the incident angle of particle has a relatively fixed quantitative relationship with the ratio of major and minor axis of elliptical track.

In laboratory research, using high power optical microscope to identify and measure nuclear track needs more manual intervention. Researchers’ different understanding of interpretation rules is prone to measurement errors, and the work is heavy, tedious and inefficient, especially in the observation of large quantities of samples, it is difficult to ensure the accuracy and efficiency of measurement work. The method designed in this paper can automatically obtain the track area, axis length, eccentricity...
and other parameters after the track image is obtained by optical microscope, which is helpful to improve the measuring efficiency.

![Image of track contour change](image1.png)

**Figure 1.** Change of track contour with different particle incident angle.

2. Acquisition of nuclear track image

The diameter of the radiation damage region formed by charged particles incident on the solid state track detector is about a few nanometers, which can be observed by electron microscope. Chemical etching is used to etch the damaged area to produce corrosion pits and show the track. When the track is enlarged to micron dimension, it can be observed by optical microscope. After adjusting the focal length, the computer can obtain the nuclear track image through the CCD camera installed on the eyepiece, image processing and transmission module, as shown in Fig. 2(a).

The degradation of nuclear track image will seriously affect the accuracy of automatic measurement. The track images obtained by high power objective lens generally have uneven brightness. This is because the distance and angle between each point on the nuclear track film and the light source are different, resulting in different surface illumination. The image obtained by CCD is formed by the reflection of light through the track target, which makes the image brightness uneven, and the details in the dark are not clear, resulting in measurement error. In addition, inaccurate focusing of the optical imaging system, impurities, bubbles and scratches formed during the production, storage and etching of the nuclear track film can lead to image degradation, as shown in Fig. 2(b).

![Image of nuclear track image](image2.png)

(a) Image acquisition platform. (b) Nuclear track image. (c) The histogram of (b).

**Figure 2.** Nuclear track image acquisition platform.

3. Preprocessing of nuclear track image

3.1. Uneven brightness correction

Fig. 2(b) shows that the brightness on the left and right sides of the track image is uneven, and according to its histogram in Fig. 2(c), it can be seen that the overall dynamic range of the image is small, the gray level distribution is concentrated, and the contrast is low, which increases the difficulty of recognition. Histogram equalization is a common method for uneven brightness correction and image contrast enhancement. The output pixel value of histogram equalization transformation
conforms to the rule of equation (1), where \( k \) is the gray level, \( n_k \) is the number of pixels whose gray level are \( k \), \( MN \) is the total number of pixels, and \( L \) is the gray levels of the image:

\[
s_k = \frac{L-1}{MN} \sum_{j=0}^{k} n_j , \quad k = 0,1,...,L-1
\]

Fig. 3(a) shows the results of global equalization. Global equalization enhances the details on the right side of the image, but the pixels with a few gray levels on the left side cannot be enhanced, and the contrast drops instead, failing to achieve the desired effect.

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(a) Global equalization. (b) Results of CLAHE. (c) The histogram of (b).

**Figure 3.** Uneven brightness correction for nuclear track image.

The Contrast-Limited Adaptive Histogram Equalization (CLAHE) achieves better results. The image is divided into 8×8 small areas. After the histogram specification method is used, the adjacent small areas are combined by bilinear interpolation to eliminate the artificial boundary effect, especially to limit the contrast of the uniform brightness area and avoid magnifying noise. The effect is shown in Fig. 3(b). Compared with the global equalization, the histogram of Fig. 3(b) shown in Fig. 3(c) is not flat, but the contrast between the target and the background is significantly improved, which has more advantages in detail enhancement at the cost of an increase in calculation.

3.2. **Morphological filtering for noise reduction**

Noise is another important factor that causes image degradation, which will lead to a decrease in measurement accuracy, and even false or missed detections. It is necessary to eliminate the influence of noise on measurement accuracy for follow-up classify and identify. The possible sources of noise in nuclear track image are: the smoothing effect of the microscope’s point spread function (PSF) makes the image edge blurred, the background noise and impurity stains on the nuclear track film are magnified by the microscope, the CCD’s dark current noise and electronic noise, etc. When choosing the de-noising filtering method, we must give consideration to both the performance of eliminating noise and maintaining the target feature information. Zhang's research shows that morphological filtering can achieve the best effect [6]. The structure element \( b \) is used to carry out the grayscale corrosion and expansion operations on the image \( f \), which can be respectively expressed as:

\[
( f \ominus b)(x,y) = \max \{ f(x-x',y-y') + b(x',y') \mid (x',y') \in D_b \} \tag{2}
\]

\[
( f \ominus b)(x,y) = \min \{ f(x+x',y+y') - b(x',y') \mid (x',y') \in D_b \} \tag{3}
\]

Where \( D_b \) is the field of \( b \). The opening operation can be used to remove the bright details smaller than the structural elements. The closing operation can remove the dark details smaller than the structural elements and can also fill the small holes in the nuclear track without significantly changing
its area. Equations (4) and (5) respectively represent the opening and closing operations on the image $f$ with the structural element $b$:

$$f \circ b = (f \Theta b) \oplus b \tag{4}$$

$$f \bullet b = (f \oplus b) \Theta b \tag{5}$$

Using circular structural elements with different radius to perform closing operation on Fig. 3(b), and the results are shown in Fig. 4(a) and (b). It can be seen that the small noise points in Fig. 3(b) are blurred, and the degree of blur is related to the radius of structural elements, while the shapes of those tracks with larger radii did not change significantly. Alternate use of opening and closing operations can be used to smooth the image and remove noise. The result of morphological filtering is shown in Fig. 4(c). The shapes of these tracks are basically unchanged, and the small dark noise on the background is smoothed, which is conducive to improving the accuracy of threshold segmentation.

![Figure 4. Grayscale morphological filtering.](image)

**Figure 4.** Grayscale morphological filtering.

### 3.3. Segmentation of nuclear track image

Image segmentation is used to extract interested objects, which is the basis of nuclear track recognition and feature extraction. The former processing reduces the influence of uneven illumination and background noise on segmentation accuracy. The basic contour of the track can be obtained by preliminary segmentation. After testing, the global threshold binarization cannot achieve good results in this case. In this paper, a variable threshold based on local statistics is considered for binarization segmentation. Let $\sigma_{xy}$ and $\mu_{xy}$ represent the standard deviation and mean of the pixels in the neighborhood centered on coordinates $(x, y)$:

$$T_{xy} = a\sigma_{xy} + b\mu_{xy} \quad \text{OR} \quad T_{xy} = a\sigma_{xy} + bm_c \tag{6}$$

Where $a$ and $b$ are nonnegative constants and $m_c$ is the global mean. Using local characteristic instead of arithmetic characteristic, formula (7) defines local threshold processing using logic operation:

$$g(x, y) = \begin{cases} 1 & f(x, y) > a\sigma_{xy} AND f(x, y) > bm_c \\ 0 & \text{others} \end{cases} \tag{7}$$

$m$ is the local mean ($m_{xy}$) or the global mean ($m_c$). Changing $a$ and $b$ will get different segmentation results, as shown in Fig. 5(a) and (b). It can be seen that the segmentation in (a) has less noise, but the holes formed in the track are obvious, and part of tracks are missing. The track morphological features
in (b) are preserved more completely, but has more noises. (c) is the result of filling the holes in (b). The tracks in Fig. 4(c) are extracted, but there are still a few small noises.

![Figure 5. Variable threshold segmentation based on local statistics.](image)

The noise can be removed by morphological processing, but the expansion and corrosion operations may affect the morphological features of the tracks. After segmentation, the track region and its contour are obtained as shown in Fig. 6(a).

### 4. Parameter measurement of nuclear track

After preprocessing, the geometric characteristic parameters of nuclear track are measured. According to reference [4, 5], the geometric shape of nuclear track is similar to ellipse (including circle), so the extraction of its geometric features can be approximated as an ellipse parameters measurement. The geometric characteristics of the nuclear track need to be determined with at least 5 parameters, i.e. the nuclear track center coordinates \((x_c, y_c)\), major axis \(a\), minor axis \(b\) and major axis deflection angle \(\theta\), satisfying the following ellipse equation:

\[
\frac{[(x-x_c)\cos\theta+(y-y_c)\sin\theta]^2}{a^2} + \frac{[-(x-x_c)\sin\theta+(y-y_c)\cos\theta]^2}{b^2} = 1
\]  

(8)

Hough transform is often used to detect elliptical targets in images. It needs to calculate and scan the five-dimensional parameter space, which requires a large amount of calculation. Reference [6] points out that the least-square method can obtain higher accuracy in ellipse fitting. The equation of arbitrary ellipse is:

\[
x^2 + Axy + By^2 + Cx + Dy + E = 0
\]  

(9)

Taking \(N (N \geq 5)\) boundary points coordinates \((x_i, y_i)\) in Fig. 6(a), according to the least-square principle, the fitting objective function is as follows:

\[
F(A, B, C, D, E) = \sum_{i=1}^{N} \left( x_i^2 + A x_i y_i + B y_i^2 + C x_i + D y_i + E \right)^2
\]  

(10)

In order to minimize \(F\), the following formula must be established:

\[
\frac{\partial F}{\partial A} = \frac{\partial F}{\partial B} = \frac{\partial F}{\partial C} = \frac{\partial F}{\partial D} = \frac{\partial F}{\partial E} = 0
\]  

(11)
Substituting \((x_i, y_i)\) to solve the equations, the values of coefficients \(A, B, C, D\) and \(E\) can be obtained. The relationship between the five geometrical characteristics parameters of tracks in (8) and these coefficients can be expressed as:

\[
(x_c, y_c) = \left(\frac{2BC - AD}{A^3 - 4B}, \frac{2D - AD}{A^3 - 4B}\right), \quad a = \frac{2(ACD - BC^2 - D^2 + 4BE - A'^2E)}{(A^3 - 4B)(B + \sqrt{A^2 + (1 - B^2)^2}) + 1}, \quad b = \frac{\sqrt{a^2 - Bb^2}}{Ba^2 - b^2}
\]

The connected regions and centroid position in the binary image are marked, as shown in Fig. 6(b). Taking track 6 as an example, the fitting result is shown in Fig. 6(c).

Figure 6. Edge fitting and parameters calculation for nuclear track.

According to reference [7], very small non-track impurities, i.e. No. 5, 7, 8, 9 and 13 in Fig. 6(b), are excluded in consideration of shape factor and area threshold. The fitting results of \((x_c, y_c)\), \(a, b, \theta\) and ellipse eccentricity of the remaining tracks are listed in Table 1. The ellipse eccentricity is the ratio of focal length to major axis. When the eccentricity is 0, the ellipse degenerates into a circle. The area and eccentricity are important basis for classification of nuclear track shape characteristics [6].

| Region | Area / pixel | Centroid / \((x_c, y_c)\) | \(\theta / \degree\) | \(a / \text{pixel}\) | \(b / \text{pixel}\) | eccentricity |
|--------|--------------|---------------------------|-----------------|----------------|----------------|--------------|
| 1      | 17           | (22.53, 143.65)           | -61.5217        | 7.3346         | 3.6028         | 0.8710       |
| 2      | 32           | (22.44, 157.94)           | -87.5131        | 9.8701         | 4.2569         | 0.9022       |
| 3      | 177          | (33.36, 70.48)            | 85.4793         | 16.5576        | 13.7177        | 0.5600       |
| 4      | 178          | (59.65, 53.75)            | 74.7904         | 16.4745        | 13.9422        | 0.5327       |
| 6      | 165          | (64.99, 77.24)            | 77.3772         | 16.1561        | 13.0843        | 0.5866       |
| 10     | 179          | (119.70, 40.07)           | 62.4001         | 15.7212        | 14.5932        | 0.3719       |
| 11     | 43           | (139.65, 169.42)          | -66.1399        | 9.5568         | 8.3624         | 0.4840       |
| 12     | 176          | (158.89, 69.97)           | -72.6173        | 15.4759        | 14.5923        | 0.3330       |
| 14     | 14           | (156.00, 184.50)          | 90              | 6.8173         | 3.2366         | 0.8801       |
| 15     | 183          | (181.97, 154.43)          | 88.2577         | 16.8333        | 13.9481        | 0.5598       |
| 16     | 11           | (181.64, 56.09)           | 61.1082         | 5.5906         | 2.9045         | 0.8544       |
| 17     | 74           | (188.54, 174.00)          | -40.2379        | 18.9909        | 9.4001         | 0.8689       |
| 18     | 91           | (205.32, 188.99)          | 39.5268         | 13.2104        | 8.9083         | 0.7384       |
| 19     | 171          | (207.63, 43.40)           | 62.1185         | 15.4127        | 14.2644        | 0.3787       |
| 20     | 110          | (213.94, 23.65)           | 71.8324         | 12.5519        | 11.2420        | 0.4447       |
5. Conclusions
According to the characteristics of nuclear track image acquired by acquisition platform, this paper proposes a feasible method for automatic measurement of track parameters. Firstly, the contrast limited adaptive histogram equalization is used to correct the uneven brightness of the image; secondly, the gray morphological filter is used to smooth the background noise; the variable threshold based on local statistics is used to extract the targets from background; finally, the least-square method is used to fit the track contour and calculate the geometric parameters of the track. The research results of this paper are helpful to improve the accuracy and efficiency of nuclear track image interpretation. In this paper, the method of image brightness correction is worthy of further discussion, that is, how to better enhance the contrast of the target edge and avoid amplifying noise; without considering the overlap of nuclear tracks in the image, two small overlapped tracks are identified as one, resulting in measurement error. These problems need to be further studied and improved.

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