A Mathematical Morphology Algorithm for Detection and Counting of Nuclear Tracks

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Abstract. Solid state nuclear track detection plays an extremely important role in the field of nuclear technology, but artificial cognition is extremely time-consuming and labor-consuming. In this paper, an automatic measurement system of solid state nuclear track is proposed, in which the microscopic image of the nuclear track is obtained by the camera and processed digitally, and then use software to identify the image content. Based on the image restoration theory, this paper preprocesses such as noise elimination and luminance correction, and the mathematical morphology algorithm is used for track counting and parameter estimation. The comparison results between automatic recognition and manual recognition show that the algorithm can effectively identify track points from images under different conditions and improve work efficiency.

1. Introduction
Since young discovered that charged particles irradiating certain solids can leave marks on them in 1958 [1], solid state nuclear track detector has gradually developed into an important particle detector, which has greatly promoted the development of nuclear physics, nuclear technology and applications. Heavy charged particles with a certain kinetic energy incidence to the solid insulation, causing radiation damage and leaving tiny tracks on the paths they pass through. Solid state nuclear track detection technology is an extremely important nuclear technology to obtain the number, charge, mass, energy and other information of heavy charged particles based on the measurement of the density and geometric parameters of these tracks [2-4].

The recognition of track image is one of the key in solid state nuclear track detection technique. The traditional method is artificial interpretation--the researchers observe, identify, classify and count tracks under optical microscopes. Artificial interpretation not only results in measurement errors due to subjective factors (such as differences in understanding of rules), but also is burdensome, tedious, and inefficient. Especially when observing a large number of samples, this method often fails to achieve the expected goals [5-9].

This paper proposes an automatic measurement system for solid state nuclear track. In this system, we use software to recognize the microscope track image which is obtained by a camera. This is of great scientific significance and can liberate a large number of researchers from the tedious work of track image interpretation, and devote themselves to the further research. The key to the research is the track recognition algorithm. The nuclear track plate vulnerable to scratches, bubbles and impurities in the process of production, storage and etching, resulting in the final nuclear track images are often accompanied by various types of noise [7,9]. The profile of the track changes with the difference of the
incident angle of the particle. Or more than two tracks overlap and so on, all of these situations put forward stringent requirements on recognition algorithm [7,10].

2. Nuclear Track Image Acquisition Platform

Taking the real-time digital image processing platform as the core, optical microscope, CCD camera, monitor and other equipment as peripherals, the microscopic digital images of nuclear track are collected (Fig. 1a). The video signal input from an external CCD camera is collected by the real-time processing platform, and the pixel information matrix is generated after preprocessing. The digital track image data is encoded output through the video port to an external monitor to provide synchronous observation and saved as an image file in a specific format. The nuclear track images shown in Fig.1(b)–(c): (b) the track number is small, the contrast is poor, and there is a small amount of overlap, (c) the number of tracks is large, the noise is obvious, the contrast is poor and there is a lot of overlap. It is quite difficult to completely divide these overlapped tracks, and (d) the contrast of the track image is good and there is no overlap.

![Track image acquisition platform and typical track images.](image)

3. Track Counting System

3.1. Degradation Modeling and Restoration of Track Image

Factors such as defocusing of the microscope and camera system and noise of the image sensor constitute a degradation system of track images. The degradation process is modeled as a degradation function $H$ and an additive noise term. The images actually collected and used for subsequent analysis and processing are obtained by performing the degraded system on the original image, as shown in Fig. 2. With a good estimate of $H$, a suitable restoration filter can be designed to minimize interference caused by image degradation to automatic recognition.

![The degradation model and restoration process of track image.](image)
Considering the degrading process of track images as a linear, spatially invariant system, then the degradation model can be expressed as:

\[
g(x, y) = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} f(\alpha, \beta) h(x - \alpha, y - \beta) d\alpha d\beta + n(x, y) \tag{1}
\]

\(f(x, y)\) is original, non-degraded track image, \(g(x, y)\) is degraded image (actually acquired track image), \(h(x, y)\) is the PSF (point spread function) of the degraded system, \(n(x, y)\) is the additive noise.

For example, when using a CCD camera to acquire images, the light intensity and sensor temperature are the main factors that affect image degradation. According to the noise sources in the process of making track plate in the laboratory, the characteristics of microscope optical system, the performance of imaging sensors, and the individual standards and differences in the way of distinguishing track when counting manually, the model of \(h(x, y)\) and \(n(x, y)\) is established, and the corresponding image restoration algorithm is designed based on this model. In the process of track image restoration, minimize the objective function:

\[
L(f) = \|Qf\|^2 + \|g - Hf - n\|^2
\]

In (2), \(g\) is the degraded image, \(\hat{f}\) is an estimate of the original image, \(Q\) is a matrix selected to perform some linear operation on \(\hat{f}\), and \(\lambda\) is the Lagrange factor. Different restoration objectives can be achieved by specifying different \(Q\).

### 3.2. Image Contrast Correction and Binarization

After restoration and de-noising, using histogram equalization to adjust the contrast of the image. Because in the case where the track image grayscale is concentrated in a certain segment, equalization can usually achieve good results. The equalization transformation function has the following form:

\[
s = T(r) = (L - 1) \int_0^r p_s(w) dw
\]

Where \(L\) is the image gray levels, and the right side of the equation is the cumulative distribution function (CDF) of the gray value \(r\) of the input image. Then the binary processing of the image:

\[
g(x, y) = \begin{cases} 0, & f(x, y) \leq T \\ 255, & f(x, y) > T \end{cases}
\]

\(T\) is the binarization threshold in (4). The selection of the threshold is particularly important in the binarization process, which directly affects the accuracy of subsequent counting and parameter estimation. It is proposed to use Otsu method to calculate gray threshold. Otsu is the maximum between-cluster variance method, which can calculate the adaptive threshold and is simple and efficient. The maximum between-cluster variance \(\sigma^2_B\) is as follows:

\[
\sigma^2_B = \omega_0 (\mu_0 - \mu_T)^2 + \omega_1 (\mu_1 - \mu_T)^2
\]

Where \(\omega_0\) and \(\omega_1\) are the probability of foreground and background pixels respectively, \(\mu_0\), \(\mu_1\) and \(\mu_T\) are the average grays of foreground, background and whole image respectively. The binarization results of track images (Fig.1 b ~ d) are shown as Fig.3 a ~ c.
3.3. Mathematical Morphology Processing

It can be seen from Fig.3 that after the restoration and de-noising, the noise of (a) and (c) is not obvious, but there are many noise point in (b). The mathematical morphology method is used to reduce these noise in Fig.3, and the results are shown as Fig.4.

Due to the influence of noise, the center of the original track is vacant, the edge is cracked, and the boundary of the track obtained after thresholding is not smooth. This situation can be improved by corrosion and dilatation operations. The corrosion operation is used to eliminate the smaller and meaningless objects, and the dilatation operation can fill the holes in the track. After the dilatation operations, most of the voids generated after corrosion have been completely filled. Although there are
still a few hollows, it has little effect on the subsequent track counting, and after corrosion and dilatation, the track boundary becomes smoother and more conducive to track counting.

![Fig 5. Results of erosion and dilation operations.](image)

The corrosion and dilatation operations will change the area of the original object. In order to solve this problem, dilatation and corrosion operations are performed at the same time, so that the original size of the track can be maintained while the overlapped tracks are separated.

3.4. The Counting and Parameter Measurement of Tracks

Count the tracks in Fig.5. The specific steps are as follows:
- Each white block is marked with a rectangle, and the length and width of each rectangle are recorded;
- Measure the maximum length of each white block in the image;
- Count and mark each rectangular block;
- Add up the total number of independent white blocks.

![Fig 6. Track marking and counting.](image)
The position of the track is determined by the center-of-mass coordinate. For two-dimensional discrete function \( f(x, y) \), its \((j + k)\) order moment is:

\[
M_{jk} = \sum_{x=1}^{N} \sum_{y=1}^{M} x^j y^k f(x, y); k = 0, 1, 2...
\] (6)

The center-of-mass coordinate \((\bar{x}, \bar{y})\) is defined as \( \bar{x} = M_{10} / M_{00}, \bar{y} = M_{01} / M_{00} \).

3.5. Results

Fig. 6 and Tab 1. show the results and analysis of counting and measurement of three typical nuclear track images. It can be seen that in the case of noise and poor contrast, image filtering restoration, de-noising and contrast correction will improve the accuracy of subsequent counting. The loss of counting accuracy is mostly caused by the overlap of tracks, which is particularly obvious in Fig. 5a and Fig. 5b, where several overlapped tracks are miscounted into one. For those track images without obvious overlap, it can be accurately counted, just like Fig. 5c. Mathematical morphology processing will bring certain errors to the measurement of track parameters.

| Counting Image | Track Conditions                     | Algorithm Counted | Manually counted | Detection Rate (%) |
|----------------|-------------------------------------|-------------------|-----------------|-------------------|
| Fig. 1(b)      | Low density, noisy, overlapped       | 17                | 20              | 85                |
| Fig. 1(c)      | Low density, noisy, significant overlapped | 61                | 73              | 83.56             |
| Fig. 1(d)      | High density, bright, non-overlapped | 15                | 15              | 100               |

4. Conclusion

An algorithm for counting the chemically etched tracks on surface of SSNTDs was proposed in this paper. The algorithm consists of three parts: an image acquisition phase, an image preparation phase, and a track counting phase. The programs have been developed and implemented in MATLAB. It can be seen from the results that this algorithm is still not perfect for the segmentation of overlapped tracks, which needs to be further studied. In order to solve the problems of low accuracy, low efficiency and difficulty in meeting the practical application of automatic recognition algorithm of solid state nuclear track image, this paper use the theory and method of image restoration, mathematical morphology and target recognition to study the new algorithm of automatic restoration and recognition for nuclear track images, which will help to solve the problems that it is difficult to accurately recognize, segment and measure the irregular and overlapped tracks in complex noise background.

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