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Automated method of tracing proton tracks in nuclear emulsions

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A B S T R A C T

The low performance of the manual recognition of proton-recoil tracks in nuclear emulsions has limited its application to energy spectrum measurement of a pulsed neutron source. We developed an automated microscope system to trace proton-recoil tracks in nuclear emulsions. Given a start point on the proton track of interest, the microscope system can automatically trace and record the entire track using an image processing algorithm. Tests indicate that no interaction of the operator is needed in tracing the entire track. This automated microscope greatly reduces the labor of the operator and increases the efficiency of track data collection in nuclear emulsion.

1. Introduction

Nuclear emulsion used as a charged particle detector has a long history, and has made outstanding contributions in the fields of elementary particle physics, high energy physics [1], nuclear physics and so on for its excellent submicron spatial resolution [2–4]. Nuclear emulsions consist of gelatin substrates, in which silver-bromide microcrystals with a typical diameter of 200 nm uniformly are interspersed [4,5]. When a charged particle passes through the nuclear emulsion, its trajectory is recorded as a sequence of latent images. The latent images appear as a sequence of metallic silver grains with a diameter of about 1 μm [6,7], which become visible under an optical microscope as dots, namely track grains, along the trajectory after a chemical development.

Before fast electronic nuclear detectors come into being, nuclear emulsion is widely used as a neutron detector. Although the usage of nuclear emulsion in neutron experiments gradually decreases with the rapid developments of the fast electronic technique, the nuclear emulsion is still an important and effective choice for measurements of neutron energy spectrum and yield in some cases [2,8], especially when time-of-flight measurement is not suitable.

As a neutron detector, the nuclear emulsion has some unique advantages: simple structure, small volume and low cost; high spatial resolution; high stopping power and no 'dead time' [9]; coverage of 4π geometry [10,11] and 100% detection efficiency for recording proton-recoil tracks from n–p reactions. However, an obvious drawback, that the tracks of proton-recoil have to be measured manually one by one with a microscope, limits the extensive application of the nuclear emulsion. This manual read out process is time consuming and laborious. Therefore, many automatic track recognition systems have been developed [7, 12–16] with the evolutions of electronics, automatic scanning technologies and computing technologies under the promotions of international cooperation experiments, such as OPERA (Oscillation Project with Emulsion tRacking Apparatus). However, these systems are mainly developed for the recognition of tracks of the high energetic particles impinging on a series of parallel thin nuclear emulsions (40–50 μm) almost along the normal of the nuclear emulsion surface as shown in Fig. 1(a) [15,17,18]. The parts of the tracks of high-energy particles in a single thin nuclear emulsion are short and straight and can be fully observed in one field of view (FOV) of the microscope [19,20]. These automatic scanning systems are designed specifically for the scenarios like OPERA. The algorithms used in these systems are not capable of tracing long tracks (hundreds of microns) nearly parallel to the surface of the emulsion plate. Moreover, these systems have large

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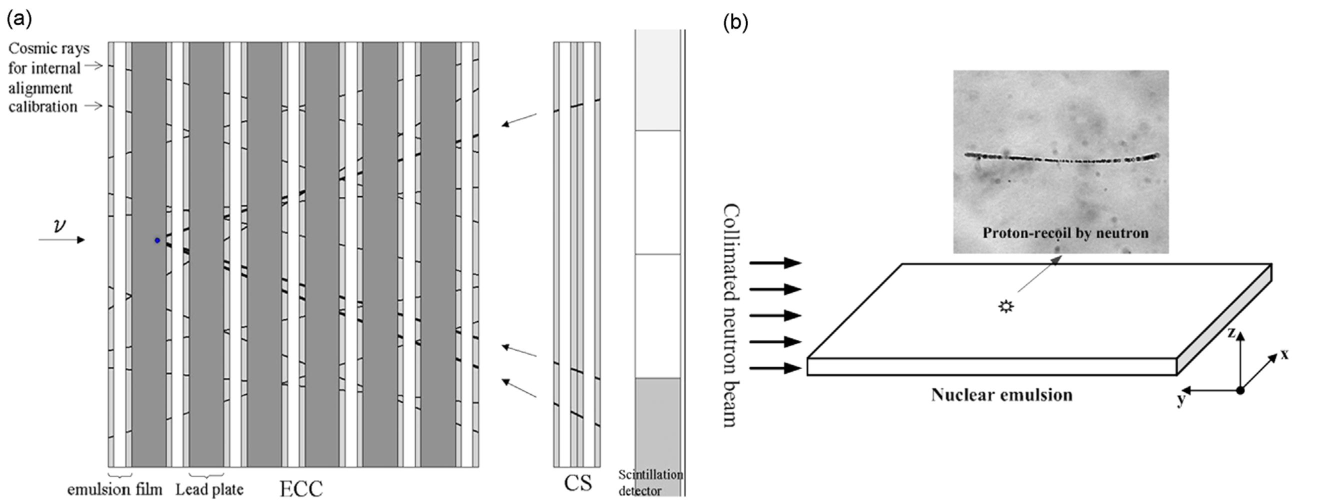

Fig. 1. Comparisons between the characteristics of the tracks in thin nuclear emulsions and those in thick nuclear emulsions. (a) Tracks in a series of parallel thin nuclear emulsions irradiated by high energetic particles; (b) Proton-recoil tracks in thick nuclear emulsions irradiated by a collimated neutron beam.

limitations as, for example, the restricted angular acceptance in tracking, the difficulty in detecting short range tracks which start and stop in the thin nuclear emulsion and recognizing the tracks at angles with the direction of the incident particle (up to 1.3 rad) [21]. Nevertheless, for the proton-recoil tracks produced by the neutrons inducing parallel to the surface of the thick nuclear emulsion (400–500 μm) (shown in Fig. 1(b)) used to measure the pulsed neutron energy spectrum, the techniques for recognizing the tracks of high energetic particles in thin nuclear emulsion are not suitable because all the tracks in 4π solid angle should be recognized and the recoil angles and the lengths of the tracks need to be measured accurately. Moreover, the tracks of the recoil protons in thick nuclear emulsions are long and flexuous at the end, and only parts of some long tracks can be observed in one FOV. Usually, to obtain an entire track of recoil protons, we need to stitch the image sequences of several adjacent FOVs.

Therefore, in order to realize the automatic recognition of the proton tracks in nuclear emulsion to solve the limitations of the manual mode of recognizing tracks, prompt the applications of nuclear emulsions and reduce the burden of the operators, we present an automated method of tracing proton tracks. And we recognize the proton tracks by the method in the nuclear emulsion irradiated by the neutron beam at energy of 14.9 MeV.

2. The proton track recognition system

2.1. Hardware configuration

The system used for the recognition of proton tracks in nuclear emulsion is illustrated in Fig. 2. This system consists of an automatically biological microscope with a computer-controlled motorized stage and multiple objective lenses, a CMOS camera with mega-pixel (1360 pixel × 1024 pixel) resolution mounted on the top of the optical tube, a controller with a vision processor board and the motor control board and a control PC. The detailed information about the hardware of the system can be found in Ref. [22].

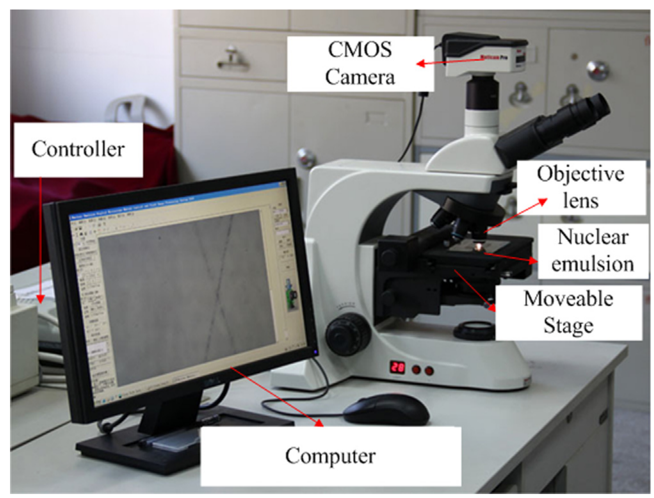

Fig. 2. A picture of the recognition system for proton tracks.

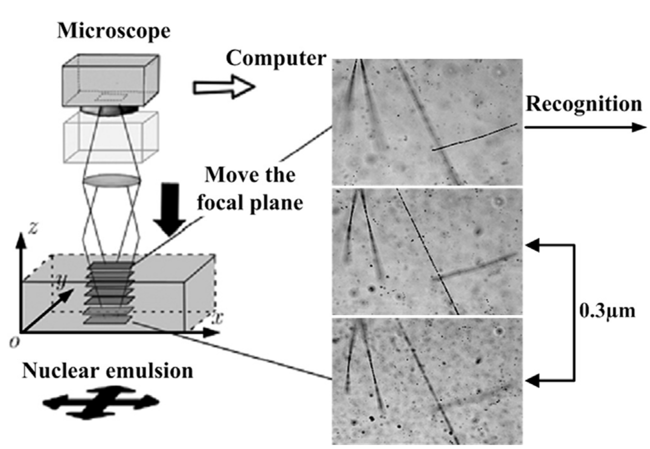

Fig. 3. The processes of recognizing proton tracks.

2.2. Processes of proton track recognition

The processes of the proton track recognition in nuclear emulsion are shown in Fig. 3. Firstly, a tomography of each FOV can be obtained by moving the stage with a step 0.3 μm along the *z*-axis to adjust the focal plane of the objective lens through the whole thickness of the nuclear emulsion. Then all the track images in the entire volume of the nuclear emulsion can be obtained by moving the stage along the *x*-axis or *y*-axis to change the position of the FOV. Furthermore, the track grains in the images are recognized by the image processing methods and the coordinates of the track grains are transformed according to the relative locations between the adjacent FOVs under the same coordinate frame (that of the first FOV). Finally, the proton tracks are