Use of Pattern Recognition Methods in Track Analysis of Solid Detectors

N Starkov
Lebedev Physical Institute, Leninskii prospect 53, Moscow, 119991, Russia
E-mail: starkov@sci.lebedev.ru

Abstract. This report is based on the results of use the PAVICOM facility during investigations of nuclear and elementary particles tracks [1]. This facility has been constructed in Lebedev Physical Institute and includes three automatic microscopes. They allow to analyse particles tracks in different kinds of material: nuclear photo-emulsion, plastic and minerals (olivine). As a result images of tracks and their geometrical characteristics very differ in various experiments. This circumstance demands to use of various image recognition methods depending on properties of images and aims of an experiment. During work in different experiments the members of PAVICOM group designed numerous algorithms of processing of particles tracks in complicated events. In this report some of them are represented.

1. Preliminary processing of images
Initial images include not only particles traces but also many external elements: scratches, breaks, spots and go on. The task of the preliminary processing is to eliminate the external elements and extract particles traces. For this purpose different kinds of transformations are used [2]. There are three main kinds of transformations. The first of them is point one which transforms one pixel of an initial image into one pixel on a next one (contrast amplification, logical operations and go on). The second is a local transformation when some area near a pixel of an initial image is transformed into one pixel of a final one. These transformations are usually called filters. And the third kind is global transformation. In this case all pixels of an initial image are transformed into one pixel of a final one (different kind of Fourier, Hadamard, Walsh and other transformations). The most often used transformations are filters. They are capable to correct an image, to find a cluster boundary, to smooth of background and etc. On figure 1 the sample of preliminary processing is represented.

![Figure 1](image_url)

**Figure 1.** The result of preliminary processing. (a) – initial image; (b) - after filtering; (c) - final image.

2. Count of tracks number in complicated events
In the most events the count is not difficult because the number of clusters is one of characteristics of preliminary processing result. But there are events when it is not easy to do. For example in figure 2 the traces of nuclear fragments of a radiator in a plastic detector after etching are represented. They derived after expose of a radiator with neutron flux and the measure of this flux is the aim of the experiment. The figure 2(a) corresponds to low load but figure 2(b) corresponds to large one. The number of clusters in the last case does not correspond to flux because many tracks cross each other and the direct count of clusters does not lead to proper result. In this case it is necessary to use special fuzzy logic method [3]. In this approach a statement is not true or false but there is some probability $M$ to be true and probability $1-M$ to be false. In our case we introduce the probability matrix $M_{S,N}$ whose values are probabilities that the cluster of $S$ pixels area is result of the $N$ tracks crossing. This matrix can not be calculated because it depends on a kind of radiator, plastic properties, conditions of experiment and go on.

![Figure 2](image1.png)

**Figure 2.** The images of nuclear fragments traces in plastic detector. (a) – low load; (b) – large load.

Its values are defined in a teaching process during conversation between an operator and a special program. This program shows to the operator one cluster and he must estimate the tracks number which this cluster includes. At the end of this procedure the probability matrix is created and becomes ready to process complicated events with large load. For example the result of processing of the image on figure 2(b) is following: the clusters number is 283 but the tracks number is 554.

Other complicated event to count of the tracks number is represented on figure 3(a) which shows the traces of alpha particles in plastic after electro-chemical etching. In this case the difficult is connected with complicated form of the clusters. At usual processing they are divided on numerous disconnected parts. The use of the special algorithm allows us to extract every cluster in totality (figure 3(b)).

![Figure 3](image2.png)

**Figure 3.** The images of alpha-particle traces in plastic after electro-chemical etching. (a) – initial; (b) – after clustering.
3. Reconstruction of clusters form and their parts
In some events the aim of cluster processing is a reconstruction its form and an extraction of different parts. On figure 4(a) the trace of a heavy nucleus in olivine at a near stop point is represented [4]. In this case the trace has complicated form with the distension at the end as a result of sharply increasing of ionization losses (Bragg’s peak). The geometrical characteristics of different parts of this track carry important information about particle properties. Therefore some special filters were designed to extract contour of track and investigate the particle properties (figure 4(b)).

![Figure 4](image)

**Figure 4.** The image of etched trace of heavy nucleus in olivine. (a) – initial; (b) – after contour recognition.

Other important example of the form reconstruction is connected with an investigation of nuclear stars created as a result of decay. In this case the aim is reconstruction of a vertex and rays in space. In this case an auxiliary grid and logical operations are usually used. On figure 5(a) the clustering result of the nuclear star is shown. To extract parts of the star the additional auxiliary grid of straight lines going under 45 and 135 degrees is superposed on the clusters image and the AND logical operation is applied to both images. As a result the “skeleton” of the star is created with the set of short cuts (figure 5(b)). The lines drawn through the middles of this cuts are directed along the rays of the star creating ray axis but their crossing is the vertex (figure 5(c)).

![Figure 5](image)

**Figure 5.** The extraction of star rays. (a) – after clustering; (b) – the result of the AND logical operation applied to the cluster image and the auxiliary grid; (c) – the reconstructed rays.

4. Total reconstruction of event including its kinematical analysis
In this part the interaction of \(^{6}\text{He}\) nuclei in photonuclear emulsion is considered [5]. The aim of this experiment is to study out the configuration of two additional neutrons. There are two possibilities: every neutron is in opposite direction concerning an alpha-particle or near each other creating a quasi-particle dineutron. The emulsion chamber was used as a detector. It included six layers of thick (600 mcmt) emulsion without a base. Initial energy 60 MeV of \(^{6}\text{He}\) was chosen so as the total length of the chamber is more than stop length of nuclei. The scanning of the emulsion on the PAVICOM facility
with 1 mcm step on depth allows to reconstruct the tracks in space. This procedure includes iterative algorithm of collection traces on different levels on depth (figure (6)). On every level the rectangle of looking-for area is created to continue the investigation on the next level. The clusters of scattered particles have oblong form. This additionally points the movement direction of particle and makes looking-for the area narrower. The viewing of neighbourhoods of the created parts of tracks allows to correct them, to find out the interaction vertexes and to reconstruct the event (figure (7)).

Figure 6. The track prolongation algorithm for transversal and scattered particles.

The following kinematical analysis is carried out using an estimation of secondary particles stop length and geometrical characteristics of interactions vertex. The scattering of $^6$He on protons with two or one neutron transfer allows the total unambiguous kinematical analysis. Every of these two reactions correspond to different neutron configurations in $^6$He nucleus. They are separated each other by kinematic very well. The detailed kinematical analysis of these reactions allows to conclude that both neutron configurations are presented in $^6$He but the weight of the dineutron is slightly less.

5. Use of neural network in processing of RICH detector data

RICH (Ring Image CHerenkov) detector detects Cherenkov light emitted by particle going through matter with speed more than light one. This light goes along a cone surface and creates quasi ellipse and quasi hyperbola on a PMT plane which in our case is 1m$^2$ area (figure 8). The cone angle and size of figure on PMT plane depend on a particle speed but the intensity of light is proportional to a particle charge square. At these circumstances it is convenient to use neural network (NN) [7] for processing of RICH detector data which are a set of all coordinates of fired PMT and total amplitude of their signal (A). The input vector of NN includes width of quasi ellipse and A. The output vector includes charge and speed particle. We use NN having three hidden layers with ten nodes on every of them. The special program imitating RICH detector work was prepared and 2400 events were generated for training procedure. After the training procedure a test procedure was performed using 840 additionally generated events.
The result of NN work is represented in figure 9. The measurement accuracy of charge is about 100% but of speed accuracy is about 96%. 

Figure 8. The images of lighted (empty cycles) and fired (full cycles) PMT under action of Cherenkov light emitted by proton (a) and He (b) at different speeds $\beta=v/c$ and angles $\Theta$ (degree).

Figure 9. Comparison between true (triangles) and derived by NN (cycles) values (a). The speed distribution for $Z=2$ and $\beta=0.933$ (b).

References
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