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TECHNIQUES
OF PHYSICAL EXPERIMENT

Automatic Methods of the Processing of Data from Track Detectors on the Basis of the PAVICOM Facility

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Abstract—New automatic methods essentially simplify and increase the rate of the processing of data from track detectors. This provides a possibility of processing large data arrays and considerably improves their statistical significance. This fact predetermines the development of new experiments which plan to use large-volume targets, large-area emulsion, and solid-state track detectors [1]. In this regard, the problem of training qualified physicists who are capable of operating modern automatic equipment is very important. Annually, about ten Moscow students master the new methods, working at the Lebedev Physical Institute at the PAVICOM facility [2–4]. Most students specializing in high-energy physics are only given an idea of archaic manual methods of the processing of data from track detectors. In 2005, on the basis of the PAVICOM facility and the physics-training course of Moscow State University, a new training work was prepared. This work is devoted to the determination of the energy of neutrons passing through a nuclear emulsion. It provides the possibility of acquiring basic practical skills of the processing of data from track detectors using automatic equipment and can be included in the educational process of students of any physical faculty. Those who have mastered the methods of automatic data processing in a simple and pictorial example of track detectors will be able to apply their knowledge in various fields of science and technique. Formulation of training works for pregraduate and graduate students is a new additional aspect of application of the PAVICOM facility described earlier in [4].

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INTRODUCTION

Nuclear emulsion has been used in particle physics experiments for many decades. Long use of this method is obviously supported by a unique spatial resolution and a possibility of the separation of particle tracks. None of the detectors of elementary particles applied at present can provide the spatial resolution of the emulsion: for a grain size of 0.7–1 μm, grain deviation from the reconstructed particle trajectory does not exceed, on average, 0.8 μm and under certain conditions can be reduced to 0.2 μm. Application of a double-sided emulsion provides a possibility of the determination of incidence angles with an error smaller than one milliradian. Moreover, due to their simplicity and a pictorial character, emulsion detectors have great advantages, as compared to other detection systems, in the demonstration of some phenomena of particle physics for pregraduate and graduate students specializing in physics.

During the physics-training course of the Physical Faculty of Moscow State University, students study a neutron-irradiated nuclear emulsion in one of the laboratory works. The emulsion has a thickness of about 40 μm and was irradiated by a collimated neutron beam from a polonium–beryllium source. The task of the laboratory work is the determination of the energy of primary neutrons. For this purpose, students must measure the length of tracks and angles of emission of several recoil protons.

Previously, these measurements were performed manually using optical microscopes, and students had to find and fix particle tracks visually. However, on the modern level of the development of technique, complete automation of the processing of nuclear emulsions and creation of microprocessor-based systems have become possible: particle tracks are identified and their spatial configuration is reconstructed by a computer using special programs. This became possible due to a wide application of modern CCD cameras for registration and digitization of optical images, performance of modern computers, progress in the manufacturing of precision technique and creation of optical tables moved with high precision by computer commands. The automatic measurement method in track detectors almost completely eliminates the exhausting visual labor of microscopists and accelerates processing by approximately three orders of magnitude, as compared to semi-automatic methods. Moreover, the

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Fig. 1. View of the automatic PAVICOM-2 microscope.

new method provides a possibility of processing large amounts of experimental data, essentially increases the expected event statistics in a wide range of experiments, and predetermines development of new experimental projects which can use large-volume targets and large-area emulsion and solid-state track detectors [1].

At present, about 40 automatic systems for the processing of nuclear emulsion operate worldwide, including about 20 systems in Europe. In Italy, France, and Germany, the number of such automatic facilities has been growing rapidly over the past two years, in particular, in relation with the preparation of the OPERA experiment of the search for neutrino oscillations [1], in which the amount of nuclear emulsion is tens of tons (!). Russian physicists also participate in this prestigious and ambitious international project. The problem of the increase in the number of scientists with an appropriate level of expertise who is capable of operating such a complex automatic equipment is quite pressing. Annually, about ten students at different Moscow Higher Institutions (Moscow Physical Technical Institute, Moscow Engineering Physics Institute, Moscow State University, Moscow State Institute of Steel and Alloys, Institute of Natural Sciences) master new methods, working at the Lebedev Physical Institute in the PAVICOM facility. However, a large number of students specializing in high-energy physics are only given an idea of archaic methods of the manual processing of a nuclear emulsion using optical microscopes. The new laboratory work for students at the Physical Faculty of Moscow State University devoted to investigation of the process of neutron traversal through a nuclear emulsion was developed as one of the first steps of broadening the abilities of training experts in modern automatic methods of experimental nuclear physics. The new laboratory work was developed on the basis of the PAVICOM facility (a completely automatic measurement facility) created at the Lebedev Physical Institute [2, 3], which is the only facility in Russia satisfying modern world standards.

SCANNING OF EMULSION AT THE PAVICOM FACILITY AND CREATION OF A LIBRARY OF FILES FOR PROCESSING

The PAVICOM facility performs the following actions automatically:

(i) search and digitization of charged particle tracks in the detector material;

(ii) computer track recognition and tracing;

(iii) systematization and primary processing of data.

The principle of operation is as follows: the objective of the microscope creates the image on the CCD matrix. An analog video signal formed by the video camera is transmitted to the input of the digitization and image capture card. The card digitizes the video signal, transmits these data to the computer memory, and displays the real-time digitized signal on the monitor.

The facility consists of two setups differing by some parameters [4, 5]. Emulsions for the training work of the Physical Faculty were scanned on the PAVICOM-2 facility [6].

The automatic PAVICOM-2 microscope (Fig. 1) was created on the basis of the MPE-11 microscope manufactured by LOMO. The basic units of the PAVICOM-2 facility are:

(i) the Carl Zeiss precision table with the control block;

(ii) the digital CCD camera;

(iii) the personal computer.

The limits of automatic movement of the table in the horizontal plane are 0–100 mm, and in the vertical direction about 1 cm. Step motors controlled by the controller receiving commands from the computer move the table in all coordinates. The precision of measurement of the x and y coordinates in the horizontal plane is 0.25 μm and along the Z axis is 3.96×10^{-3} μm.

The matrix of the CCD camera has a dimension of 768×576 pixels and a color depth of 8 bit (256 color grey scale). The image on the matrix is created by the objective of the microscope with an amplification of up to ×60.

Nuclear emulsions irradiated by neutrons were scanned with the following parameters: the objective of the optical system ×60 (in this case, the field of view made 80×60 μm); scanning step in the X axis 75 μm, in the Y axis 55 μm, in depth 2 μm (for one field of view, scanning was performed at 18 depths). Totally, 10 fields of view in X and 30 fields of view in Y were scanned. The scanning software created files with images in the JPEG format and a text file with coordinates of these images.

SOFTWARE FOR VIEWING AND PROCESSING OF IMAGES

A special program Emulsion Viewer was written for the viewing and processing of scanned JPEG files. This program implements the following functions:

(i) compilation of an image from a large number of JPEG files;

(ii) viewing of this image in different scales;

(iii) pointing to images of points, determination of their coordinates, and storage of these coordinates in a file.

These properties allow one to use this program both for the training work and for scientific purposes.

The program was written with Borland C++ Builder and uses only its standard components [7] without any additional libraries. A large image compiled from JPEG files is viewed in the following way: a large BMP picture is placed on the main frame of the program. JPEG images are "drawn" one by one on this BMP picture adjacent to each other using standard functions. Each time when the cursor moves on the image, the program determines which of the JPEG pictures should be depicted on the monitor for the chosen scale and displays them.

For an image from a file to be shown on the monitor, the file should be loaded in RAM. Only those files which are displayed on the monitor for the chosen scale are loaded in RAM for optimal operation. The program is also capable of mirror inversion for image viewing. The program interface (Fig. 2) provides the option of moving over the image, changing the scale, determining the coordinates, and changing the options of image loading. The source code of the program for training is open. This provides the option of not only demonstrating and studying physical phenomena, but also formulating a real task of the development of software for a physical experiment. A student can be asked to write an additional module, for example, for the connection of tracks, determination of the track curvature, and so on. In this case, it is possible not only to apply the obtained knowledge of object-oriented programming, but also to master some methods of image recognition, in particular, in the case of the reconstruction of the spatial position of a particle track on the background of fog grains in the emulsion. Thus, the developed work allows different levels of complexity of its formulation—from simple measurement of track parameters to independent development of a part of the software. Therefore, final implementation of a training work should be adapted to the level of teaching of programming and statistical methods of processing in a particular higher institution.

A possibility of the development of skills of the object-oriented programming and the mastering of the methods of image recognition is very useful not only for the automatic processing of data from track detectors [8–10]. Similar programming and data analysis

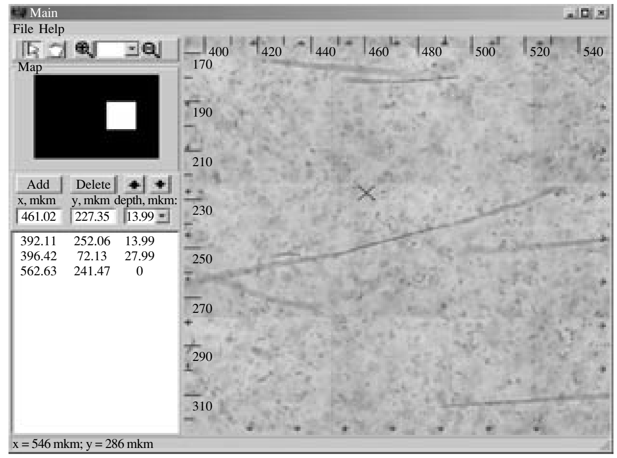

Fig. 2. Image on the monitor during operation of the processing program. Parts of the tracks of recoil protons are seen on the demonstrated fraction of the emulsion image.

methods are widely used in many electronic nuclear physics experiments, in applied works, and in modern industrial equipment [11, 12]. This means that experts with these skills are needed.

CONCLUSIONS

High-tech methods of the processing of experimental data from track detectors are the basis of formulation of a number of modern physical experiments. Implementation of these methodically novel experiments, in its turn, requires trained experts capable of operating automatic equipment. A possibility of the formulation of such training works for pregraduate and graduate students of physical faculties is an additional aspect of the application of the PAVICOM facility. It is proposed to use the most up-to-date equipment of the Russian Academy of Sciences for automatic scanning of the material from track detectors chosen in a particular higher institution for demonstration of some phenomena of particle physics. Mastering of the new methods of data processing in the example of the proposed training work will facilitate the advent of physicists applying automatic processing of track detectors and the rise of the level of training of graduates of physical faculties having mastered mathematical tools of the systems of image recognition and capable of applying this knowledge in different fields of science and technique, on the whole.

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