Automatic Scanning for Nuclear Emulsion

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Abstract

Automatic scanning systems have recently been developed for application in neutrino experiments exploiting nuclear emulsion detectors for particle tracks. These systems substantially speed up the analysis of events in emulsion, allowing the realisation of experiments with unprecedented statistics. The pioneering work on automatic scanning has been done by the University of Nagoya (Japan). The so-called New Track Selector has a very good reproducibility in position ($\sim 1\ \mu m$) and angle (~ 3 mrad), with the possibility to reconstruct, in about 3 seconds, all the tracks in a view of 150x150 μm^2. A new system (Ultra Track Selector), with speed higher by one order of magnitude, has started to be in operation. R&D programs are going on in Nagoya and in other laboratories in order to develop new systems. The scanning speed in nuclear emulsion be further increased by an order of magnitude. The recent progress in the technology of digital signal processing and of image acquisition systems (CCD's and fast Frame Grabbers) allows the realization of systems with high performance.

New interesting applications of the technique in other fields have recently been envisaged.

1 Introduction

Nuclear emulsion detectors provide three-dimensional spatial information on particle tracks, with excellent resolution (of the order of 1 μm), as well as high hit density (300 hits/mm) along the tracks. They are, therefore, ideal for the unambiguous detection of short-lived particles. This is crucial to attain the required sensitivity in the CHORUS [1] and OPERA [2] experiments. The feasibility of these experiments is linked to the impressive progress recently made in the field of computer controlled microscopes, with Charged Coupled Devices (CCD) read-out, and in automatic pattern recognition.

*From the CHORUS collaboration

2 Nuclear emulsion

Nuclear emulsions are made of micro-crystals of silver halides (AgBr) as sensitive devices dispersed in a thin gelatine layer. The size of micro-crystals ranges from 0.2 to 0.3 μm and the concentration of the crystals in the emulsion goes from ~ 25 to 50% in volume. The dimension and the type of crystals can be controlled by current advanced industrial technologies developed for nuclear emulsion.

Emulsion Sheets (ES) have emulsion layers on both sides of a transparent plastic base whose thickness ranges from 70 to 1000 μm. The thickness of the emulsion layer can vary from 50 to 500 μm, depending on the specific use.

The incident particle beam has usually a direction perpendicular to the ES surface. When an ionizing particle traverses the emulsion layer of an ES, electron-hole pairs are created in the crystals. Clusters of several silver atoms are formed in several micro crystals by successive ionic processes. Chemical processing is required to make the ES readable by scanning systems. By chemical action the small silver clusters (called latent image) are amplified and silver clusters with diameter of $\sim 0.6\mu m$ are formed, which can be identified by the optical pick-up of the scanning system, i.e. by a microscope equipped with a CCD camera.

Automatic scanning systems have completely changed our idea of nuclear emulsion. Nowadays nuclear emulsion can be considered as a long term data storage device which allows to record complete three dimensional information on charged particle trajectory. This information is read-out by automatic scanning systems.

3 Automatic Scanning Systems

The concept of fully automatic track recognition, which is the base of the algorithm used in the current systems, was proposed already in the '70s [3] [4] at the University of Nagoya (Japan). Unfortunately, the technology was not advanced enough to implement it. The group continued the effort to develop a fully automatic system during the '80s, and we have a first complete application of the automatic system in CHORUS experiment data analysis in the '90s. Nowadays the Nagoya group is close to deliver a third generation of automatic scanning system [5] and an intense R&D program is underway also in Europe by several groups of the CHORUS Collaborations. In figure 1 a schematic view of a typical automatic scanning system can be seen.

3.1 The Nagoya system

The basic components of the Track Selector (TS) are designed to detect tracks with predicted angle in the field of view of the CCD camera. The system uses a Fast Programmable Gate Array (FPGA) + Fast Memory and a grabber board connected to a CCD Camera (512 x 512 pixels at 120 Hz frame rate). The area of view is $\sim 150x150$ μm^2. It is determined by the microscope optics and by the surface of the CCD. The focal depth of the microscope gives an image relative to $\sim 3\mu m$ of emulsion thickness. Sixteen tomographics images of *(e.g.) 100* μm thick emulsion layers are taken and digitised. Every digitised image is shifted horizontally relative to the first layer, so that the predicted angle tracks become perpendicular to the image plane. By superimposing the sixteen shifted digitised images tracks are identified as enhancements of pulse heights. The quality of one track segment is measured by the signal pulse height. Outputs from the TS are the position (x, y, z) and the angle $(\theta x, \theta y)$ of the detected track segments. Currently the Track Selector system is in its second generation with the New Track Selector system. A third generation called Ultra Track Selector (UTS) is now operating and a Super-UTS is under development. The UTS system is capable of analysing 1 cm^2/ hour and to recognise tracks up to 400 mrad with track finding efficiency $\sim$ 98%. The Super-UTS is expected to increase the scanning speed up to 10 cm^2/ hour. The scanning power road map of the Nagoya systems is shown in figure 2.

3.2 Multi track system

Groups of the CHORUS Collaboration are following the approach of the so-called Multi Track Systems (MTS), initiated by the Salerno group with the SySal system [6]. In the following we present the R&D underway by the Naples and Münster groups. Similar studies are being made by the CERN and NIKHEF groups.

In a MTS system all tracks in each field of view are reconstructed regardless of their slope, provided they are within a region of angular acceptance. The raw data are series of tomographic images of the emulsion (from 10 to 50), taken at different depth levels (2.5 to 3.5 μm). A digital filter is used to enhance the signal (track grains) to noise (background grains) ratio for each image. A threshold is applied to the filter output to extract the dark spots that are candidates to become grains. The following step consists in combining grains from different layers to recognise geometrical alignments. The field of view is subdivided in cells about 20 μm wide. Local alignments of grains are then detected within each cell and across boundaries of neighbouring cells. Track segments in the two emulsion layers are finally connected and stored on the local database. The driving principle in the design of this system is the use of state-of-the-art commercial products, both for the hardware and for the software. This makes the system itself flexible enough to be upgraded following the rapid progress in the technology. Tests were made using a large plate microscope stage (80 x 40 cm^2) by Micos-gmbH[1]. The microscope is equipped with fast stepping motors or DC motors both on the horizontal and on the vertical axes. Both a fast CCD camera (512 x 512 pixels at 120 Hz) and high-resolution CCD camera (1024 x1024 pixels at 30 Hz) are used with this system . A field of view of about 200 x 200 μm^2 is provided with an integration time of about 2 ms. The Performance could be further improved by using fast MegaPixel cameras with, at least, 500 Hz frame rate, which will be soon available on the market.

The current system uses a Matrox Genesis[2] board [7] with 1 Digital Signal Processor (DSP). This board is a commercial frame grabber and video images analysis device. The board is equipped with a Neighborhood Operation Accelerator (NOA), a Matrox custom processor and a dedicated DSP Texas Instruments TMS320C80, which contains four integer point processing units and a master processor. Up to four boards with 2 DSP and 2 NOA can work together to analyse the image. With this number of processors the system is capable of filtering, digitising and clustering one frame in less than 10 ms. This allows to envisage a speed of 1 mm/s during data taking from the emulsion. The time needed to analyse a complete field (both emulsion sides) would thus be about 300 ms. The tracking is performed in parallel to the main acquisition sequence. By using a Pentium III class processor with 500 MHz clock, all tracks in a complete field are found in about 200 ms. In perspective about 3 fields per second could be analysed taking into account the time needed to move to adjacent views. About 14 minutes could then be required to fully reconstruct all tracks contained in one centimeter squared of ES.

An approach oriented towards the use of software and of advanced commercial products in image processing is also followed by the CERN and NIKHEF groups of

[1] Micos GMBH, 7224 Umkirch (Germany)
[2] Genesis is a trademark of Matrox Electronic System Ltd.

CHORUS. They have developed, in collaboration with industry, a new optics with a large field of view and optimised it for emulsion scanning. In the future, automatic scanning could profit from this development both in speed and quality.

4 Application in other fields

The full programmability and flexibility of current systems for nuclear emulsions image analysis give the possibility to easily apply them in a different research fields. In the Naples and Münster laboratories, in collaboration with a biophysics group of Naples University, the feasibility of a full automatic system for chromosomal analysis is under study, applying a technology transfer between physics and biophysics. A semi-automatic system (operator-assisted) for chromosomes counting is being tested at Naples University. The speed of the system is ten times faster than the manual scanning procedure. Chromosomal analysis is a routine method in several medical applications (prenatal diagnosis, cancer cytogenetics, biological dosimetry). The most important limiting factors in clinical cytogenetics are the time of scoring, its accuracy and reproducibility, and the sample size that can be analyzed in a reasonable amount of time. The analysis of chromosome images have many contact points with nuclear emulsion analysis and it can profit from the acquired experience and from the power of the current systems.

5 Conclusions

The impressive progress of the automatic scanning systems technologies has stimulated the revival of nuclear emulsion as particle tracks detectors. The use of these systems together with nuclear emulsion allows the realisation of experiments with unprecedented statistics. On the other hand, the current systems are flexible enough to be used in some other fields where a fast digital image analysis is required.

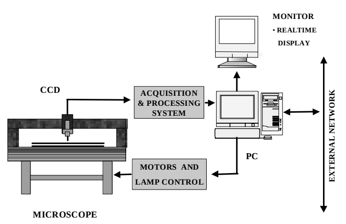

Figure 1

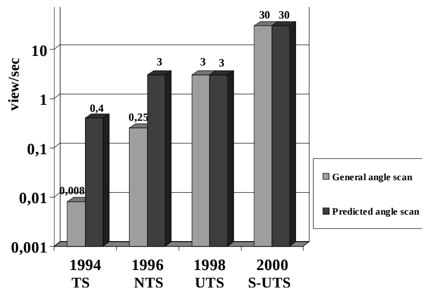

Figure 2

Figure 1: Schematic view of the components of a typical automatic scanning system for nuclear emulsion.

Figure 2: Scanning power road map of Nagoya System

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