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A novel automatic film changer for high-speed analysis of nuclear emulsions

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Abstract

This paper describes the recent development of a novel automatic computer-controlled manipulator for emulsion sheet placement and removal at the microscope object table (also called stage). The manipulator is designed for mass scanning of emulsions for the OPERA neutrino oscillation experiment and provides emulsion changing time shorter than 30 s with an emulsion sheet positioning accuracy as good as 20 μm RMS.

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1. Introduction

The extensive use of nuclear emulsions as precise tracking detectors in experimental physics has been made possible due to recent advances in the production of novel nuclear emulsions and to the development of automatic scanning devices. The emulsion sheets with dimensions $12.5 \times 10\,\text{cm}^2$, as used in the CERN-LNGS OPERA experiment, are commercially produced by the Fuji Film[3] company.

In order to reconstruct particle tracks, recorded in the emulsion, the emulsion sheet must be developed and scanned. In the old days emulsion scanning was performed by human operators by means of optical microscopes. This technique (so-called "Eye scan") requires large manpower, operators must be highly trained and qualified in order to achieve good track recognition efficiency. As the scale of experiments has grown, the necessity of a computer-controlled automatic procedure became evident.

An important step in this direction was made at Nagoya University. The system called Track Selector was developed in 1982 and used in WA75, CHORUS [1] and DONUT [2] experiments. It evolved its scanning ability from 0.2 microscope views per second in 1982 to 30 views per second in 2001 [3,4]. The view area of approximately $2.25 \times 10^{-4}\,\text{cm}^2$ resulted in about 0.18 and $2.5\,\text{cm}^2/\text{h}$, respectively. A similar progress has been made recently in Europe. A system able to scan $20\,\text{cm}^2/\text{h}$ of emulsion surface with real-time track reconstruction has been developed by European groups of the OPERA collaboration [5,6] and called European Scanning System (ESS).

However, so far the emulsion sheets were fed to the microscope by the hands of an operator. Given the present scanning speed the development of an automatic emulsion sheet changing system has become mandatory. The automatic emulsion sheet manipulator described in this paper has been designed and built as an add-on to the existing design of the OPERA ESS.

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2. Motivation and requirements

2.1. The OPERA neutrino oscillation experiment

The direct observation of $\nu_\mu - \nu_\tau$ oscillations in a ν_μ beam is the main goal of the OPERA experiment [7]. The neutrino beam is provided by the CERN CNGS facility. The detector is placed at the distance of 732 km in the underground hall of the Laboratory of Gran-Sasso (LNGS). The Emulsion Cloud Chambers (further—ECC) technique [8–10] is used to precisely reconstruct the topology of τ decays produced in ν_τ CC interactions with a massive lead/nuclear emulsions target.

The OPERA detector has a mass of 1.8 kton and consists of a lead/emulsion sheet sandwiched ECC target, a target tracker to localize the event within the target and a muon spectrometer [7]. The OPERA ECC target is composed of about 20 0000 ECC elements, called bricks, of $12.7 \times 10.2 \times 7.5\,\text{cm}^3$ each. Each ECC brick contains 57 nuclear emulsion sheets and 56 lead sheets, resulting in 11.4 million emulsion sheets with a total surface area exceeding $130\,000\,\text{m}^2$.

The expected number of bricks to be processed is about 20 per day for an average beam intensity with peak load of about 50 per day. Developed emulsion sheets will be scanned in order to reconstruct particle tracks with the use of scanning optical microscopes. Assuming about 20 scanning microscopes available in the OPERA collaboration, the expected average rate will be 1 brick per scanning microscope per day. Scanning of one brick (57 emulsion sheets) must be done in a few passes, such as scanning of passing through tracks to align emulsion sheets to each other, following back tracks, which exit the ECC brick to locate the interaction point, scanning a volume around the interaction point, following tracks, originating from interaction point, etc. Therefore, the number of times that emulsion sheets must be placed onto the table of the microscope may easily exceed 100 per day. In order to handle this large number of operations, the emulsion sheets placement must be automatized.

2.2. Requirements: positioning accuracy

The reference coordinate system for finding particle tracks in emulsions is based on the so-called "fiducial marks" printed on the emulsion surface by a dedicated projecting system. Such marks are recognized by the scanning microscope [6] and their position can be measured with submicron precision in the stage reference system. By measuring a minimum of 3 marks, an unambiguous affine transformation is established between the two coordinate systems. On the OPERA emulsions 6 marks will be printed in order to provide redundancy, 4 in the corners (10 mm from the emulsion edges) and 2 additional marks at the center of each long side, 10 mm from the edge.

The mark search is performed along a spiral path with 200 μm pitch (the microscope view is about $390 \times 310\,\mu\text{m}^2$). One step on this path takes about 300 ms. Hence, the time needed to find a mark rapidly increases with the distance from the search start point to the mark position: $T = T_0 \cdot (D/P)^2/2$ where $P = 200\,\mu\text{m}$ is a search step pitch, $T_0 = 300\,\text{ms}$ is the time needed for one step and D is the distance to the mark. The first task of the manipulator is to place the emulsion in such a way that marks will be within one microscope view from their nominal position, so that they will be found within 300 ms each. This implies the requirement that the position of the placed emulsion is within 300 μm from the expected.

2.3. Requirements: operation speed

As shown above, assuming nominal rate of brick extraction in OPERA, the number of emulsion replacement operations for one scanning microscope may exceed 100 per day. The time spent for scanning of one brick depends on the scanning strategy. In order to find precise alignment of one emulsion sheet with respect to the other, certain areas containing passing through tracks must be scanned. This procedure is called intercalibration. The time needed for this procedure depends on the size of the area to scan and therefore on the passing through track density. The type of the event also affects the scanning strategy. In the simplest case of the event with a muon, exiting the brick, its track is followed up to the interaction point by the so-called scanback procedure. Then a certain volume around track stopping point is scanned and the interaction vertex is located. The scenario becomes more complicated in case of events with hadrons or electrons.

In average the time needed to scan one brick is presently estimated to be about 16 h. Assuming 24 h a day continuous operation, 8 h is left for brick loading/unloading, plate changing, and establishing reference coordinate system for each emulsion sheet (scan fiducial marks). For the average number of sheet placements 100 this results in 288 s per emulsion sheet available for placement and scanning fiducial marks.

2.4. Requirements: failure rate

The only repeating failure that is tolerable during the operation of the emulsion manipulator is the emulsion loss during taking from the microscope table or from the bank. The system is supposed to perform scanning in automatic mode 24 h a day. An emulsion loss would require human intervention that can be reasonably made only during 8 h a day. A failure happened during this period will not result in a large delay, few minutes are enough to fix it. However, failure happened during 16 h of unattended period will give in average $16/2 = 8\,\text{h}$ of the dead time. In order to ensure the average dead time being within 5%, the failure must not happen more often then once in $8/5 \times 100 = 160\,\text{h}$ or approximately 7 days. Assuming average number of placements being 100 per day, this results in maximum