THE DEVELOPMENT OF DETECTOR ALIGNMENT MONITORING SYSTEM FOR THE ALICE ITS

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Abstract

A real-time detector alignment monitoring system has been developed using commodity USB cameras, spherical mirrors, and laser beams introduced via a single mode fiber. An innovative control and online analysis software has been developed by using the OpenCV (Open Computer Vision) library and PVSS (Prozessvisualisierungs- und Steuerungssystem). This system is being installed in the ALICE detector to monitor the position of ALICE's Inner Tracking System subdetector. The operational principle and software implementation will be described.

INTRODUCTION

The Large Ion Collider Experiment (ALICE) [2] consists of six layers of silicon detectors. All the layers are organized into a set of ladders. Figure 1 shows how a series of ladders is arranged into one of six cylinders around the beam pipe such that there is some overlap between each detector with radii ranging from 4 to 44 cm around this cylinder.

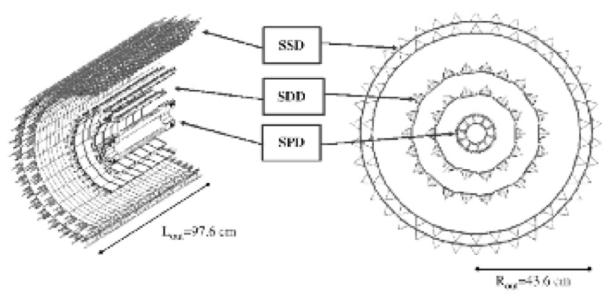

Figure 1: The layout of ITS showing the arrangement of the six ladders using three different silicon detector technologies.

The silicon pixel detectors are chosen for the innermost two layers, and silicon drift detectors for the following two layers. The outer two layers of ITS are equipped with double-sided silicon strip detectors. The principal tasks of the ITS are localization of the primary vertex with a high resolution (better than 100 μm), reconstruction of the secondary vertices from decays of particles, tracking and identifying particles with a momentum lower than 100 MeV/c (particles which would not reach the TPC) and improvement of the angular and momentum resolution (in conjunction with the data taken by the TPC) of particle with a momentum greater than 100 MeV/c.

To accomplish these tasks, the knowledge of the exact alignment of the ITS is critical. The ITS alignment monitoring system (ITSAMS) is designed to monitor any change in position with respect to the TPC. Figure 2 shows the position of the ITS relative to the TPC.

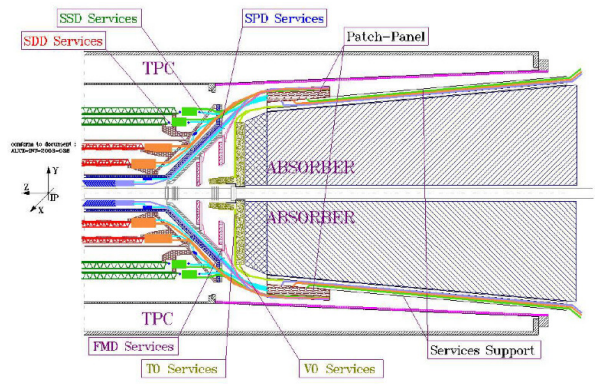

Figure 2: A cross section view of the ITS, showing the layers of the ITS, the support cones, cabling and other services and other detectors.

HARDWARE DESIGN

The ITS Alignment Monitoring System detects any distortions of the ITS that may occur during operations as well as down times. The system is designed to monitor a few accessible and strategic points on the ITS with respect to the readout plane of the TPC. The schematic of the system is shown in Figure 3.

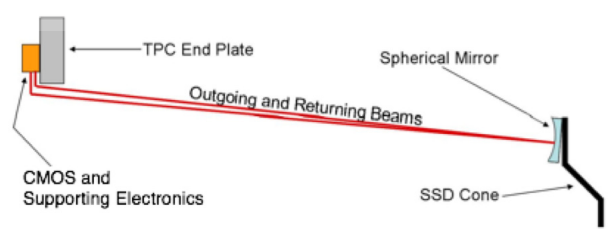

Figure 3: A conceptual drawing of the ITSAMS. On the left, a CMOS array and the collimated beam source mounted to the TPC end plate. On the right, the spherical mirror mounted on the SSD cone.

The ITSAMS design requirements include high precision, small physical size, low thermal output, low weight, relatively large dynamic range, and low cost.

The ITSAMS is composed of four units. Each unit consists of a diode laser, a camera, and a spherical mirror. The diode lasers and the cameras are mounted on the TPC

end plate, and the spherical mirrors are mounted on the SSD cone. Units are mounted at 45°, 135°, 225°, and 315° as shown in Figure 4 around the SSD cone and the TPC end plate. The spherical mirrors are designed to focus the laser beam directly on the camera's CMOS sensor.

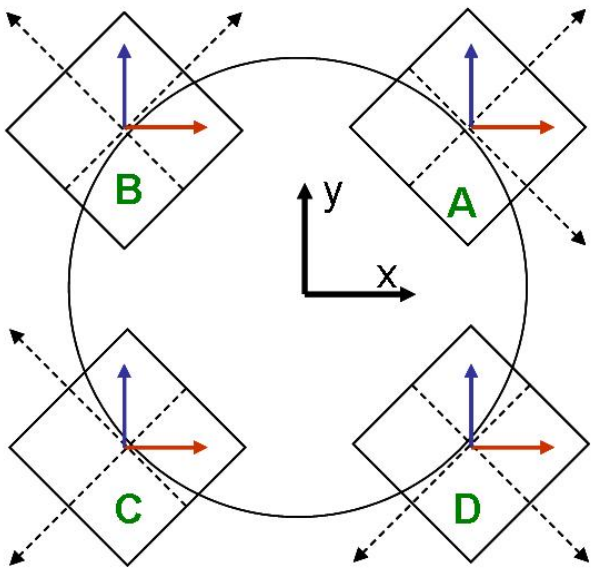

Figure 4: The relationship between the four ITSAMS camera coordinate systems and the ALICE master coordinate system.

The motion of the spherical mirror relative to the CMOS sensor is continuously monitored for any movement of the ITS. Since the ITSAMS use CMOS cameras with pixels measuring approximately 3.7 microns, pixel averaging should yield an absolute movement precision of 1-2 microns.

The cameras used in the ITSAMS are ordinary off-the-shelf USB webcams. A number of different webcams where tested both for use in a 0.5 T magnetic field and in a radiation environment. The CCD base cameras typically failed in the magnetic field test. In the end, RocketFish CMOS webcams [3] survived both the 0.5 T magnetic field test and 40 krad/cm^2 gamma and neutrons/cm^2 from a nuclear reactor. All sub-components will be exposed to radiation and/or magnetic field in ALICE.

All the data transmission from the camera to the host computer is done using the USB 2.0 standard. Since USB transmission has a five meter maximum distance limitation, it was necessary to use an active repeating extender. USB fiber bridges with integrated hubs, which are located in the patch panels just outside the TPC within five meters of the cameras, are used to carry the image data from the camera to the computer in the ALICE counting house for monitoring purposes. From the rack space, the signal is then sent through a USB-CAT5 bridge to the computer in the ALICE counting house as shown in Figure 5.

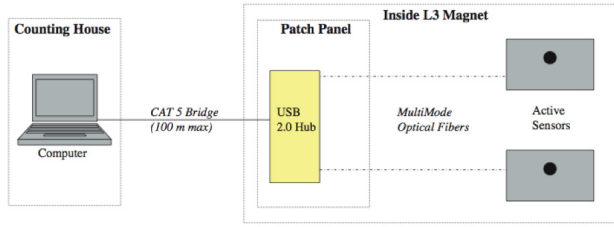

Figure 5: A conceptual drawing of the data path for ITSAMS.

The alignment beams used for the ITSAMS are produced by a small laser diode mounted along with the camera. The laser beam is coupled to a single mode optical fiber, which is terminated with a collimator to produce a minimally divergent laser beam. The beam is reflected from the mirror to the CMOS image sensor located on the TPC end near the laser diode.

The same flat mirror is also used to reflect the returning laser beam back up to the camera. In this way, less than 1 cm of clearance between the TPC and the ITS utilities is needed.

SOFTWARE DESIGN

The ITSAMS is controlled by a personal computer running ITSAMS analysis software. The software application, written in C++, utilizes the OpenCV (Open Computer Vision) library from Intel Corporation [4]. The ITSAMS analysis software first triggers each camera to acquire an image, analyze the acquired image, find the x-y coordinate of the laser beam on the image, and finally writes that information to an ordinary text file.

OpenCV was chosen to interface to the camera, as it was relatively easy for us to write a code that can distinguish each of the four cameras compared with that code for the same task using Microsoft DirectShow. Cross-platform compatibility concern for the potential future path was also an issue for code utilizing DirectShow.

This ITSAMS analysis software is invoked by PVSS (Prozessvisualisierungs- und Steuerungssystem) [5] graphical interface of the same computer.

The current version of the image analysis is done in the following steps. First, the images are acquired via the camera using OpenCV. For the image analysis, once again, we employ the built-in functions of OpenCV.

After the image acquisition, several blurring filters are applied. Then, the contour of the laser intensity is determined for several different threshold values based upon the signal amplitude. Once the contour fit is applied, the center of the beam is calculated from an ellipse fit to the contour that has been drawn.

This gives us multiple x-y coordinates for the same image. The mean and the standard deviation of the x-y coordinates of the center of the beam gets stored on an ASCII text file, which is read by PVSS.

PVSS is used for the user interface for the ITSAMS. PVSS is also responsible for alarming and archiving.

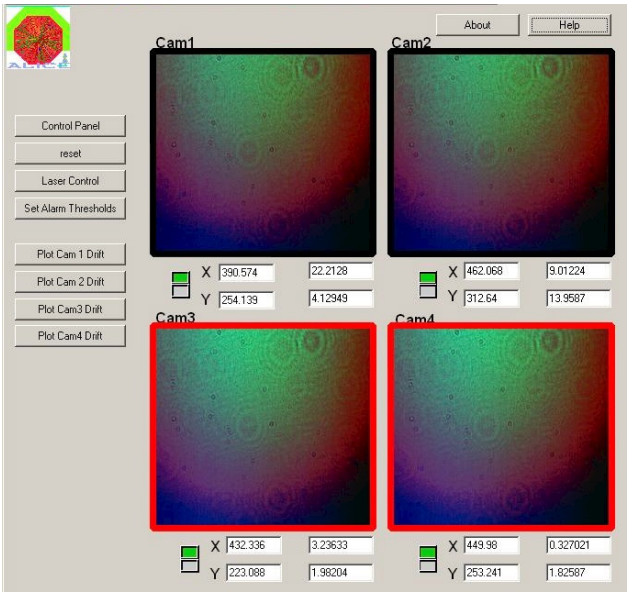

Figure 6: A screenshot of the ITSAMS in PVSS.

The ITSAMS also allows us to use the acquired image for the initial alignment use. While we cannot have live view of all the cameras due to the USB 2.0 protocol restriction for the active extender used, it is still possible to cycle through repetitively giving the operators the semi-real-time view of the ITSAMS shown in Figure 6.

We are currently in the process of upgrading the code for the image analysis software. We are testing the relative precision of a Hough transformation [6] used to determining the center of the beam spot in the acquired image.

CONCLUSIONS

The ITSAMS currently being installed can yield high precision monitoring of the relative motion of various strategic points on and around the ITS. The entire system is inexpensive and physically small addressing space issues around the ITS. The use of passive components on the ITS limits grounding and thermal issues, and requires power only at the TPC locations. The use of webcams provide a more cost effective solution than comparable systems currently available for alignment monitoring purposes, while meeting the alignment monitoring requirements for the ALICE ITS.

ACKNOWLEDGEMENT

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