Abstract

A new type of highly transparent (95%) 2D position sensor has been developed which allows the accurate positioning (5 μm r.m.s.) of successive elements to which each sensor is attached, transversally to a laser beam used as a reference straigth line. The usefull area of the sensor is about 15×15 mm^2.

Development of an optical sensor for 2D multi-points alignment

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1 Introduction

An optical sensor (SATRAPS*) has been developed at Saclay. It will be used as an optical element in a track simulator over a distance of 6 meters (using several SATRAPS) for the global alignment test benchmark of the ATLAS [?] muon chambers.

The useful area needed for this application is typically 10×10 mm^2 for a global resolution of the order or below 20 μm.

2 Principle

A SATRAPS is made of Neodymium (1%) doped glass plate, 40 mm wide and 3 mm thick. The plate faces are optically polished with a precision of 0.5 μm ($\lambda/2$) over a 30×30 mm^2 area. Fluorescent light (at about 1060 nm) produced by a laser beam crossing the plate is detected using 16 silicon photodiode pixels (3×10.52 mm^2 each) glued all around the plate (4 pixels on each side). See Fig. 1.

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*SAclay TRAnsparent Position Sensor

Figure 1: Principle of the SATRAPS. The glue is not shown.

Pixels current are amplified ($\times$ 3.10^6) and converted into tension, then filtered and finally digitized (with a 16 bits precision over 10 V). Typical tension of 1 to 5 volts are measured with a 12 mW laser power, depending on the pixel position with respect to the beam impact position.

The laser is a diode laser working at 685 nm. At this wavelength, the optical sensor is highly transparent (95%) allowing alignment of multiple elements.

An algorithm has been developed (see the Results section) to reconstruct the laser spot position. It uses the measurements of the currents obtained on the pixels interpolated with a calibration grid.

3 Experimental set-up

In order to evaluate the SATRAPS laser spot positioning precision, we have used the following set-up. A fixed diode laser beam is focused (the laser spot diameter is about 300 μm) on a movable SATRAPS 30 cm away. Displacements in a plane transverse to the beam are obtained with two micrometric tables (1μm precision) perpendicular to each other ($\pm$25μrad). There are two other SATRAPS in this set-up : one between the diode laser and the movable one and the third one 15 cm after it. They are used to correct for the beam pointing variation with time (see Fig. 2).

Figure 2: Experimental set-up with three SATRAPS, one movable, and two fixed (for laser pointing variation correction).

4 Results

To determine an unknown laser spot position ($x_0^{\rm u}$, $y_0^{\rm u}$), characterized by its 16 pixels tensions $V_{i=1,16}^{\rm u}$, a calibration is needed. It is obtained via a reference grid. This grid is built using the illumination of the SATRAPS (by the diode laser) for different known positions, thanks to the micrometric tables, at which we readout and record the 16 pixels tensions ($V_{i=1,16}^{\rm ref}$). The size of the grid is 25×25 mm^2 with 1 by 1 mm steps.

The positions x (resp. y) are parametrized by a polynomial function with 16 parameters $\rm a_i$ (resp. $\rm b_i$) :

$$x \text{ (resp. y) } = \sum_{\rm i=1}^{16} \rm a_i \text{ (resp. } b_i) \; V_i$$

Using all the reference grid positions with their associated $V_i^{\rm ref}$, the 32 $\rm a_i$ and $\rm b_i$ parameters are determined from a χ^2 built according to the previous equation.

With these 32 parameters and replacing $V_i^{\rm ref}$ by $V_i^{\rm u}$ the unknown positions $x_{\rm Step\ 1}^{\rm u}$ and $y_{\rm Step\ 1}^{\rm u}$ are computed.

At this level, the difference between ($x_{\rm Step\ 1}^{\rm u}$, $y_{\rm Step\ 1}^{\rm u}$) and the true position (x_0^u, y_0^u) (known from the micrometric table positions) is normally distributed with a 50 μm precision (r.m.s.). A 2D B-Spline [?] algorithm performed on the reference grid is used to determine hypothetical points ($x^{\rm ref}_{\rm hyp}$, $y^{\rm ref}_{\rm hyp}$), close to the ($x^{\rm u}_{\rm Step\ 1}$, $y^{\rm u}_{\rm Step\ 1}$) region, associated with hypothetical tensions ($V^{\rm ref}_{i=1,16\ \rm hyp}$).

By performing the same type of polynomial fit with these hypothetical points 16 new parameters for x, $a_{i\ \rm hyp}$ (and also 16 for y ; $b_{i\ \rm hyp}$), are obtained.

As for the first step, these determine a final reconstructed position ($x^{\rm u}_{\rm final} = \sum_i a_{i\ \rm hyp}\ V^{\rm ref}_{i\ \rm hyp}$) but this time with a resolution of few microns (below 10 μm r.m.s.).

The two other fixed SATRAPS allow to correct for laser beam pointing instability (after a calibration grid has been performed for each of them), reducing the final resolution to 5 μm r.m.s. .

5 Perspectives

We are now testing the sensitivity of the resolution to the laser spot size difference, between the reference grid points and the unknown points, on the SATRAPS. Indeed a large spot size may induce different fluorescent light distribution on the pixels contrary to a small spot size thus increasing the final resolution. Monte-Carlo studies have been performed in order to understand this effect. It should not increase the resolution by more than 7 to 10 microns. This still to be verified in real life.

6 Conclusions

We have developed a new type of highly transparent 2D position sensor. For a stable spot size, from a diode laser beam, the resolution on a useful area of about 15×15 mm^2 is 5 μm r.m.s. with only 16 pixels readout. The size of the SATRAPS (and thus the useful area) could be increased with a constant pixel number keeping the resolution at this level.

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References

[1] ATLAS, Technical Proposal, CERN/LHCC/94-43, 15 December 1994.

[2] NAG Fortran Library Program, NAG Ltd, Oxford, United Kingdom.