Available online at www.sciencedirect.com
ScienceDirect
Procedia Chemistry 00 (2009) 000–000
www.elsevier.com/locate/procedia
Procedia Chemistry

Proceedings of the Eurosensors XXIII conference

# Absolute and high precision 3 degrees of freedom position sensor

F. Cosandier, C. Canales, G. Boetsch, R. Clavel*

*Laboratory of Robotic Systems (LSRO2), Ecole Polytechnique Fédérale de Lausanne (EPFL), Station 9, Lausanne CH-1015, Switzerland*

**Abstract**

We present a compact 3 degrees of freedom (dof) (X-Y-θz) absolute position sensor offering a sub-micrometric resolution. The travelling range is 15x15mm$^2$ (translations) and ±180° (rotation), with an absolute precision better than 10µm over the whole travelling range and of less than 1µm of resolution (0.02° for rotation). The position acquisition frequency is 10Hz. The sensor is composed of a CCD camera chip, a silicon target with a pattern of holes constituting a digital code and a luminescent polymer sheet to light the holes. The reading of the pattern code is performed by image processing.

Position Sensor, Absolute, Digital, Rotation, Low-cost, CCD

## 1. Introduction

The absolute position sensor is composed of four main elements: a moving target in silicon patterned with holes (Fig. 1.a), a light source to light the Si-target, fixed over the moving target, a flat CCD camera to observe the pattern and custom designed software for image processing and position computation [1].

The pattern of holes represents a digital coding, made of large and small holes for encoding the absolute position of the Si-target. The whole pattern contains 12 by 14 coding units (Fig. 1.b). Each unit has 4 bits for the x-position index as well as for the y-position index. The large blobs are coded as binary 1 and the small blobs as binary 0 (Fig. 1.c). The squared holes sizes are 100x100µm$^2$ for the small blobs and 160x160µm$^2$ for the large ones. The two large rectangles (anchors) are used as unit detectors.

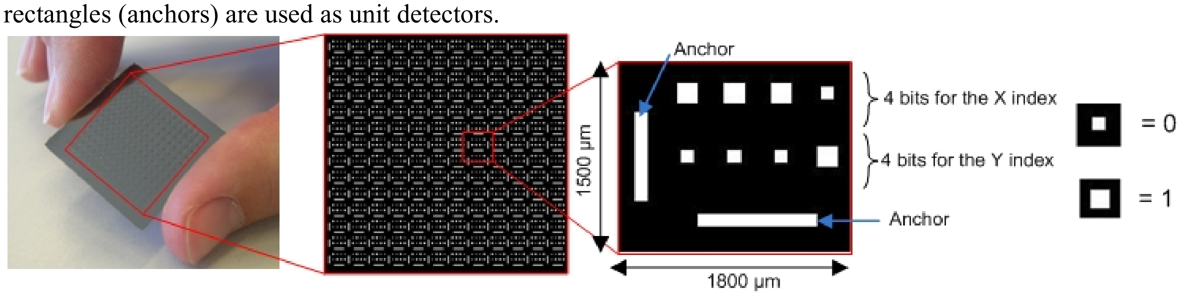


Fig. 1. (a) Si-target; (b) digital pattern; (c) absolute coding unit.

## 2. Si-target Manufacturing

* Florent Cosandier. Tel.: +41 21 693 3807; fax:+41 21 693 3866.
*E-mail address*:florent.cosandier@epfl.ch.


Fig. 2. manufacturing process.

The 27x27.6mm$^2$ Si-targets are manufactured by microfabrication at the CMI at EPFL using the process flow shown in the fig. 2. The Si-target holes are through, allowing the light to reach the CCD sensor. A well-adapted and standard microstructuring method for high aspect ratio etching is the *deep-reactive ion etching* (DRIE).

An 8µm positive resist layer is spin coated on a 380µm wafer with 2µm $SiO_2$ layer. This layer is removed by photolithography on the holes spots. Oxygen plasma is used to pierce the $SiO_2$ layer. Afterwards, the vias are opened with the DRIE process also in oxygen plasma. Finally, the remaining oxide is removed by a KOH cleaning process and the wafers are cut by diamond saw.

## 3. Algorithm for position detection

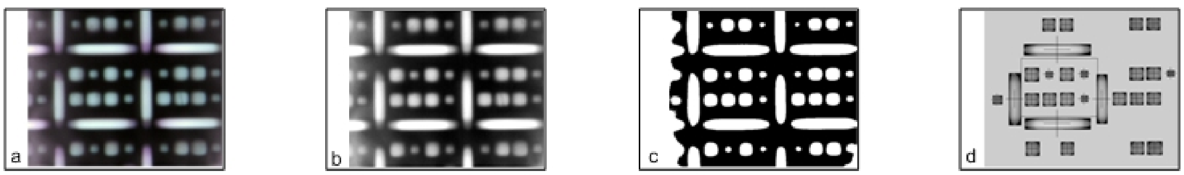


Fig. 3. (a) raw image; (b) green channel; (c) binary image; (d) non-bordering blobs image.

After the 1280x1024 pixels image is acquired several steps are mandatory before realizing the image processing. First of all the green channel has to be treated separately, because of the purple artifacts that are visible on the fig. 3.a. Once the green channel is isolated (Fig. 3.b), a Gaussian blurring effect is applied. Afterwards, a binary threshold lets the blobs appear (Fig. 3.c).

A blob detection method is applied on the binary picture, giving the blob size, position and area. Depending on these values, the blobs touching the image edges are wiped out; the determinant blobs have to be seen entirely.

The centroid position is then calculated for each blob depending on its pixel's level (Fig. 3.d). The list of blobs is divided into four blob lists containing the small blobs, the big blobs and the horizontal and vertical blobs that are the reference blobs for each unit.

The Si-target orientation is then calculated according to the relative positions of the vertical anchor and the horizontal anchor. In order to read the digital coding constituted by the big and small blobs, a vectorial rotation is applied to the blob coordinates, so that all the units are set straight. The reading rule is that the four blobs on the top of the unit give the x grid index and the four down give the y grid index. Moreover, the blobs on the right are the more significant and the grid index position is given by the blobs values and their positions. For example, the grid index on the fig. 3.d is 5 for the X-axis and 7 for the Y-axis. Lastly, the absolute position of the Si-target is calculated based on the grid size, the pixel size, the grid index and the current location of the active unit.

## 4. Characterization of the sensor

### *4.1. Setup for sensor characterization*

A setup has been built in order to characterize the sensor performances. The CCD camera remains static while the Si-target is moved using an x-y-$\theta_z$ piezoactuated moving stage. Optical encoders with 50nm resolution are used to obtain a precise position feedback of the X and Y target position. Our objective was to characterize the precision, resolution, repeatability and static noise of the sensor. The values obtained are summarized in the table 1.

### *4.2. Characterization of the precision, resolution, repeatability and static noise of the sensor*

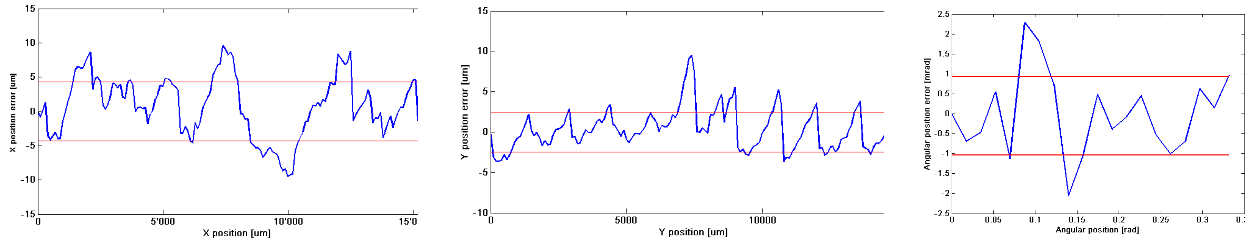


Fig. 4. (a) Precision of the X-axis position; (b) Precision of the Y-axis position; (c) Precision of the $\theta_z$-axis position.

The fig. 4.a and 4.b show the absolute precision of the sensor along the X, Y and $\theta_z$-axes, on the whole travelling range for X and Y. These values are calculated as the difference between measured values of the sensor and the values given by the optical encoders mounted on the characterization setup. The sensor values are evaluated on 150 points along the traveling range, every 100 µm for the X and Y-axes and every 1° for the $\theta_z$-axis.

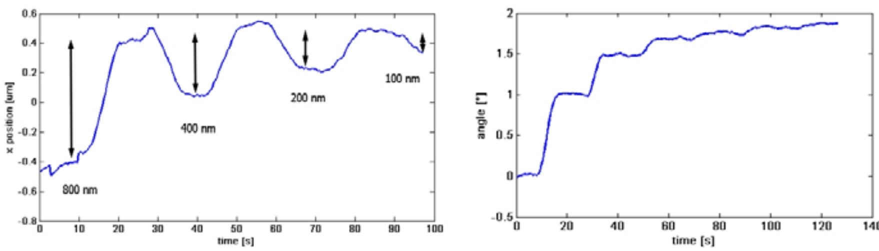


Fig. 5. (a) Resolution of the X-axis position; (b) Resolution of the $\theta_z$-axis position.

The fig. 5.a shows a moving average of the response to steps of different sizes. These steps are done with piezoactuators. The DC tension applied on the piezoactuators is respectively 400V, 200V, 100V and 50V and the corresponding step's size on the X-axis and Y-axis are 800nm, 400nm, 200nm and 100nm. The smallest detectable displacement is approximately 100nm. Some comparable measurements were observed on both X-axis and Y-axis. The fig. 5.b shows a moving average of a measurement of the angle for different step sizes: 1°, 0.5°, 0.2°, 0.1°, 0.05°, 0.02°, 0.01° and smaller. The smallest detectable angular displacement is approximately 0.01°.

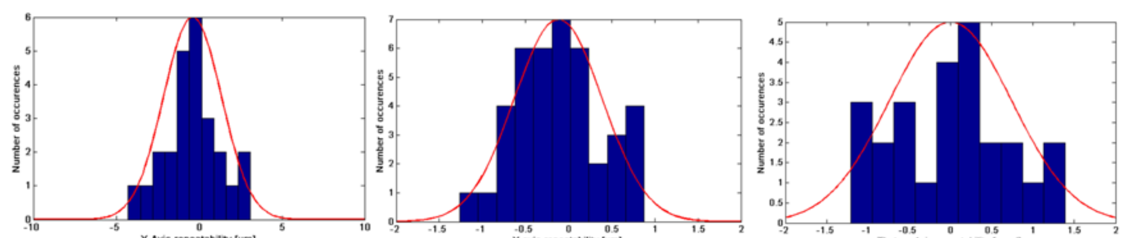


Fig. 6. (a) Repeatability of the X-axis position; (b) Repeatability of the Y-axis position; (c) Repeatability of the $\theta_z$-axis position.

The repeatability (Fig. 6) of the position sensor has been characterized while the Si-target was repeatedly moved of 1mm for both X and Y-axes and 1° for the $\theta_z$-axis. The back and forth move was repeated about 25 time for each dof.

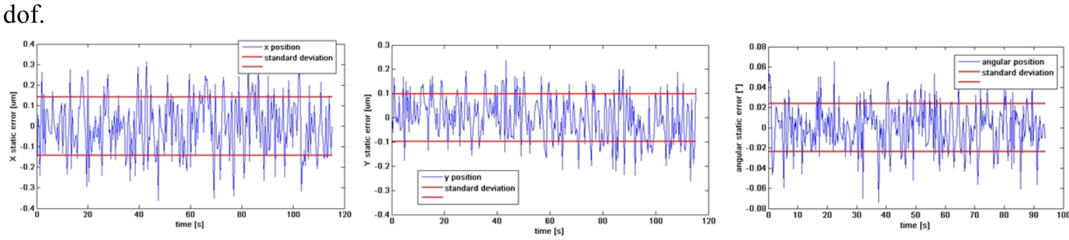


Fig. 7. (a) Static noise of the X-axis position; (b) Static noise of the Y-axis position; (c) Static noise of the $\theta_z$-axis position.

In order to characterize the static noise of the sensor on each dof, we keep the sensor on a static place during approximately a hundred seconds. The fig. 7.a, 7.b and 7.c show the measured values on the X-axis, Y-axis and $\theta_z$-axis.

Table 1. Characterization results.

| Measurement | X | Y | $\theta_z$ |
|---|---|---|---|
| Precision (σ) | 4.3 µm | 2.4 µm | 983µrad |
| Resolution | 100 nm | 100 nm | 175µrad |
| Repeatability (σ) | 1.75 µm | 0.51µm | 543µrad |
| Static noise | 142 nm | 97 nm | 401µrad |

## 5. Application example: Sensor integration for touch probing system

In the frame of the European project Golem, a micro-manipulation and characterization platform has been developed. This platform has for aim to characterize the assembly of components glued on a substrate using DNA. A high precision moving stage was required for the platform. By integrating a high precision position sensor in this X-Y-$\theta_z$ stage, numerous additional features are possible such as position storage, stitching of several images, and precision metrology by touch probing. The following section will present the high-precision 3-dof stage with the position sensor and the touch probing system.

Contrary to conventional moving stages which are a serial combination of several 1-dof manipulators, the stage presented in this paper has the advantage to offer a simple and compact design. Three 2-dof piezo actuators modules [2] are mounted on the base plate of a microscope. A mobile plate is placed over the piezo modules. As the mobile plate is simply laying over three contact points, it is considered as “non-guided”. This non-guided kinematics has the advantage to provide 3 dof in a low profile package (less than 20mm) and for a competitive price (no need for high precision guiding elements or complex assembly).

In order to perform touch probing on micro-samples, a 3-dof force sensor has been developed. The force sensor is brought in the vicinity of the part to measure. The part to measure is then moved using the X-Y-$\theta_z$ stage. Each time the part touches the probe of the force sensor, the position of the stage is stored. By repeating this sequence of touching the edge and moving the part, it is then possible to map the complete edge of the part.

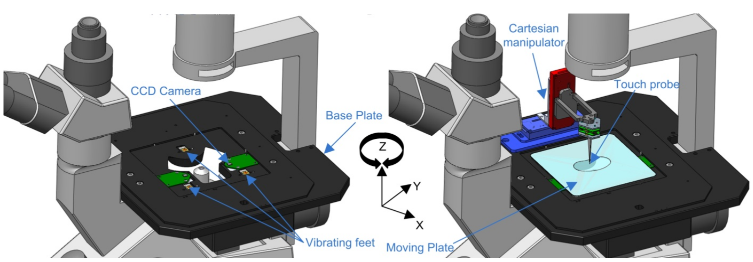


Fig. 7. (a) manipulation platform without the moving stage; (b) manipulation platform with the moving stage.

## Acknowledgements

This research is supported by the European Commission under the Sixth Framework Program (NMP STRP 033211 - GOLEM).

## References

1. L. Urbanek, T. Cimprich, N. Dave, F. Abdelkefi and J-M. Breguet. *Compact 3-Degrees Of Freedom absolute position sensor based on a CCD chip*. ISOT 2007, Lausanne
2. A. Bergander, C. Canales, G. Boetsch, T. Maeder, G. Corradini and J-M. Breguet. *A modular actuator system for miniature positioning systems*. Actuators 2008, Bremen