Capacitive sensors based kinematic modeling of an indexed metrology platform.

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Abstract

The utilisation of portable coordinate measuring machines (PCMMs) has considerably increased during the last years, mostly due to their flexibility for accomplishing in-line measuring tasks as well as their reduced costs and operational advantage as compared to traditional coordinate measuring machines (CMMs) [1]. Thus, it is important to improve the current techniques seeking for simpler, faster and more reliable calibration, verification and identification kinematic parameter procedures for PCMMs. In this work, a geometric mathematical model of an indexed metrology platform (IMP) is provided. This model is based on the readings of six capacitive sensors and the optimized geometric features of the sensors and their targets and is used during the verification procedures of PCMMs.

1 Methodology

The IMP designed in [2] consists of an upper platform and lower platform, designed in such way that the upper platform rotates around the fixed lower platform and descends every 60°, thus having six possible different positions of the upper platform with respect to the lower platform (Fig. 1a). To express coordinates of measured data in the lower platform global coordinate system (GCS) during the verification of PCMMs, a geometric mathematical modeling, based on six capacitive sensors (Fig. 1b) fixed to the lower platform (Lion Precision Probe C5-E Compact Driver), is needed. The aim of this mathematical model is to obtain the homogenous transformation matrices (HTM) that link the coordinate system of the upper platform to the GCS of the lower platform for each of the six different positions. This model uses the optimized geometric features of the platform's capacitive sensors and their targets fixed to the lower and upper platform respectively, both measured with a CMM during the calibration of the IMP explained in [2].

2. Mathematical formulation of the IMP in verification procedures.

The optimized geometric features used to calculate the capacitive sensors zero points and the interception points on their targets shown in figure 1c are: the measuring directions cosines of the capacitive sensors axis and the normal to the sensor and target planes.

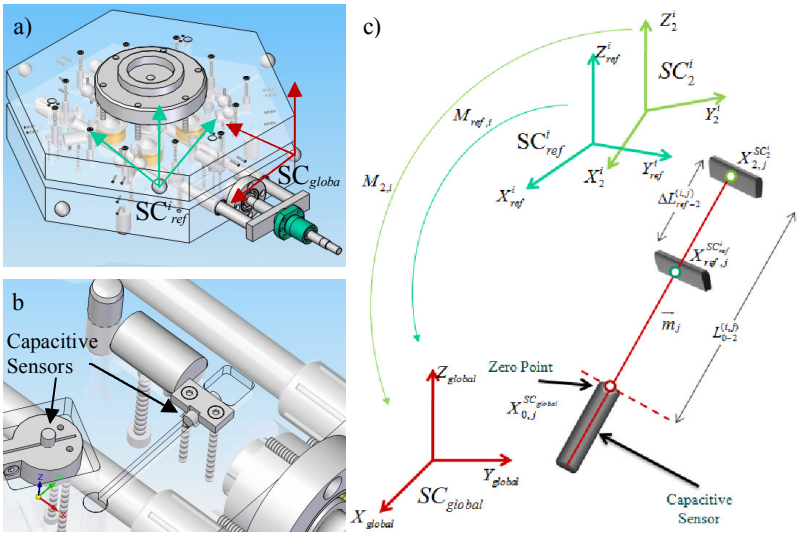

Figure 1: a) Indexed metrology platform. b) Horizontal and vertical capacitive sensor. c) Geometric scheme of a capacitive sensor and its corresponding target.

Where notation for Figure 1c is as follows:

- SC_{global} : Global coordinate system $\begin{bmatrix} X_{global} & Y_{global} & Z_{global} \end{bmatrix}$ of the lower platform.

- SC^i_{ref} : Reference coordinate system $\begin{bmatrix} X^i_{ref} & Y^i_{ref} & Z^i_{ref} \end{bmatrix}$, of position i of the upper platform, for $i = 1,2,...,6$ obtained from the calibration procedure.

- $M_{ref,i}$: Reference HTM of position i that allows to express readings from SC^i_{ref} of position i to SC_{global} , for $i = 1,2,...,6$, calculated from the calibration procedure.

- $M_{2,i}$: Searched HTM of position i that allows to express readings from SC^i_2 to SC_{global} , for $i = 1,2,...,6$.

- $X^{SC_{gloabal}}_{0,j}$: Zero point vector $\begin{bmatrix} x^{SC_{global}}_{0,j} & y^{SC_{global}}_{0,j} & z^{SC_{global}}_{0,j} & 1 \end{bmatrix}^T$ of the j capacitive sensor, expressed in global coordinate system, for $j = 1,2,...,6$.

- $X_{ref,j}^{SC_{ref}^{i}}$: Vector $\left[x_{ref,j}^{SC_{ref}^{i}} \quad y_{ref,j}^{SC_{ref}^{i}} \quad z_{ref,j}^{SC_{ref}^{i}} \quad 1 \right]^{T}$ of the reference point that corresponds to sensor *j* of position *i*, for *j = 1,2,…6* and *i = 1,2,…,6*, expressed in the reference coordinate system, obtained from the calibration procedure.

- $X_{2,j}^{SC_{2}^{i}}$: Searched point vector $\left[x_{2,j}^{SC_{2}^{i}} \quad y_{2,j}^{SC_{2}^{i}} \quad z_{2,j}^{SC_{2}^{i}} \quad 1 \right]^{T}$ of the target of sensor *j* of position *i*, for *j = 1,2,...,6* and *i = 1,2,...,6*.

- m_j : Direction cosines vectors $\left[\cos\alpha_j^{SC_{global}} \quad \cos\beta_j^{SC_{global}} \quad \cos\gamma_j^{SC_{global}} \right]^{T}$ of the capacitive sensors optimized measuring direction, for *j = 1,2,...,6* capacitive sensors expressed in SC_{global} .

- $\Delta L_{ref-2}^{(i,j)}$: Difference between the *j* capacitive sensor reading (from the reference position *i*) and the *j* capacitive sensor's captured value of position *i*, in the optimized measuring direction.

For position 1, for example, we can formulate a mathematical model based on the optimized geometric features (calculated in the calibration procedure of IMP), the set of saved data from the reference position of the ith-position (reference coordinate system (SC_{ref}^{i}), reference HTM, vector of the reference point, capacitive sensors readings) and the capacitive sensors readings obtained during the verification procedure for position 1. This model of nonlinear system of equations has as unknowns the searched HTM parameters:

$$M_{2,1} X_{2,j}^{SC_{2}^{1}} = T_{ref-2}^{(1,j)} M_{ref,1} X_{ref,1}^{SC_{ref}^{1}} = Y_{ref-2}^{(1,j)} \tag{1}$$

$$M_{2,1} X_{2,j}^{SC_{2}^{1}} = T_{0-2}^{(1,j)} X_{0,j}^{SC_{global}} = Y_{0-2}^{(1,j)} \tag{2}$$

where

$$T_{ref-2}^{(1,j)} = \begin{bmatrix} 1 & 0 & 0 & \Delta L_{ref-2}^{(1,j)} \cos\alpha_j^{SC_{global}} \\ 0 & 1 & 0 & \Delta L_{ref-2}^{(1,j)} \cos\beta_j^{SC_{global}} \\ 0 & 0 & 1 & \Delta L_{ref-2}^{(1,j)} \cos\gamma_j^{SC_{global}} \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

and

$$T_{0-2}^{(1,j)} = \begin{bmatrix} 1 & 0 & 0 & L_{0-2}^{(1,j)} \cos\alpha_j^{SC_{global}} \\ 0 & 1 & 0 & L_{0-2}^{(1,j)} \cos\beta_j^{SC_{global}} \\ 0 & 0 & 1 & L_{0-2}^{(1,j)} \cos\gamma_j^{SC_{global}} \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

If we take $x = \left(M_{2,1}^{11}, M_{2,1}^{12}, ..., M_{2,1}^{44}, X_{2,1}^{SC_2^1}, ..., X_{2,6}^{SC_2^1} \right)^T$ as the vector of unknowns which contains the searched matrix, we obtain the function of nonlinear equations:

$$F(x) = \begin{pmatrix} M_{2,1} X_{2,1}^{SC_2^1} - Y_{ref-2}^{(1,1)} \\ \vdots \\ M_{2,1} X_{2,1}^{SC_2^1} - Y_{ref-2}^{(1,6)} \\ M_{2,1} X_{2,1}^{SC_2^1} - Y_{0-2}^{(1,1)} \\ \vdots \\ M_{2,1} X_{2,1}^{SC_2^1} - Y_{0-2}^{(1,6)} \end{pmatrix} \quad (3)$$

which can be solved by means of the algorithm of Levemberg-Marquardt with software Matlab. This procedure is repeated for each of the five remaining positions in order to find their corresponding HMTs.

3 Conclusions

In this work, the main elements of a mathematical model which consists of the transformation matrices that describe the kinematics of an indexed metrology platform based on six capacitive sensors was presented. This model will allows us to use the indexed metrology platform in the verification procedures of PCMMs.

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