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Integration of a piezostage and a measuring instrument in a two-stage long-range nanopositioning platform

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Abstract

The NanoPla is a large-range nanopositioning stage that was designed, manufactured and built at the University of Zaragoza, and whose design and implementation have been subject of previous works. The moving platform of the NanoPla performs a planar motion along a range of 50 mm × 50 mm with a submicrometre resolution. The first prototype of the NanoPla is intended for the metrological characterization of large surfaces at a submicrometre scale. In these applications, the metrological instrument is attached to the moving platform, and the sample is placed on a piezostage that is fixed to the inferior base that is static. Thus, the NanoPla implements a two-stage architecture, where the positioning process along the large working range is performed by the instrument attached to the moving platform, while the scanning motion is performed by the piezostage that moves the sample along a small range of 100 µm × 100 µm × 10 µm. This work focuses on the integration of the measuring instrument and the piezostage in the NanoPla, the definition of its kinematic model, and the identification of the errors that affect the measurement procedure. These errors are caused by component inaccuracies, and geometrical errors due to the relative misalignments between parts.

Nanopositioning, piezostage, kinematic model, geometrical errors.

1. Introduction

The NanoPla is a large-range nanopositioning stage that was designed, manufactured and built at the University of Zaragoza, and whose design and implementation have been subject of previous works [1]. The NanoPla moving platform performs a planar motion along a range of 50 mm × 50 mm with a submicrometre resolution. The first prototype of the NanoPla is intended for the metrological characterization of large surfaces at a submicrometre scale. In these applications, the metrological instrument is attached to the moving platform, and the sample is placed on a commercial piezostage (NPXY100Z10A from nPoint) that is fixed to the inferior base. Thus, the NanoPla implements a two-stage architecture, where the positioning process along the large working range is performed by the instrument attached to the moving platform. Once the measuring instrument is positioned over the area of the sample to be measured, the platform and the instrument remain static. Then, the scanning motion is performed by the piezostage that moves the sample along a small range of 100 µm (X) × 100 µm (Y) × 10 µm (Z).

The NanoPla is completely functional, thus, at this point of the project, this work focuses on the integration of the measuring instrument and the piezostage in the NanoPla. Then, the kinematic model of the complete NanoPla system is defined, and the error components of the translation vectors and rotation matrixes are analysed. The major error sources that are expected to affect the positioning accuracy are kinematic errors, thermo-mechanical errors and motion control [3].

2. NanoPla system overview

The NanoPla consists of three stages, an inferior and a superior base that are fixed, and a moving platform that is placed in the middle (Figure 1). The positioning control system of the NanoPla basically consists of a 2D plane mirror laser system and four Halbach linear motors that allow performing planar motion along the large working range. The positioning system controls the position in the XY-plane and rotation around Z-axis of the moving platform, while the position in Z-axis and the rotation around X and Y-axes are only monitored by a capacitive sensor system. The positioning system and the measuring procedure were described and analysed in previous works [2].

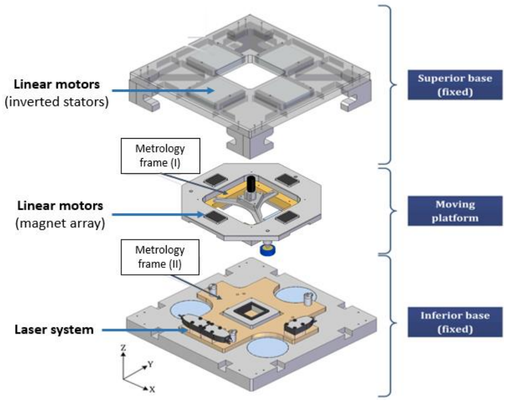

Figure 1. Exploded view of the NanoPla.

3. Integration of the measuring instrument and the piezostage

The measuring instrument is fixed to the metrology frame of the moving platform through a bracket (Figure 2). This bracket consists of two parts: the first part is a holder screwed to the metrology frame, and the second part, which fastens the measuring instrument, is attached to the first one by a kinematic coupling preloaded by magnets. The second part is an adapter specific for each instrument and allows an easy integration of different measuring systems in the NanoPla.

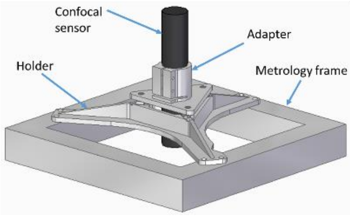

Figure 2. Measuring instrument attached to the metrology frame.

On the other hand, the piezostage is attached to the metrology frame of the inferior base through a levelling system consisting of three micrometres (Figure 3). The micrometres are fixed to the metrology frame, while the piezostage lays on their spherical tips by means of a kinematic coupling of spheres and cylinders, preloaded by magnets. The measuring sample lays on the piezostage, which can be levelled by adjusting the micrometres.

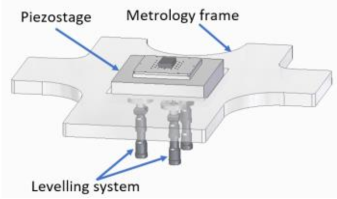

Figure 3. Piezostage, metrology frame and levelling system.

4. Kinematic model

Once the piezo stage and the measuring instrument have been integrated in the NanoPla system, its kinematic model can be defined. Figure 4 shows the scheme of the measurement loop.

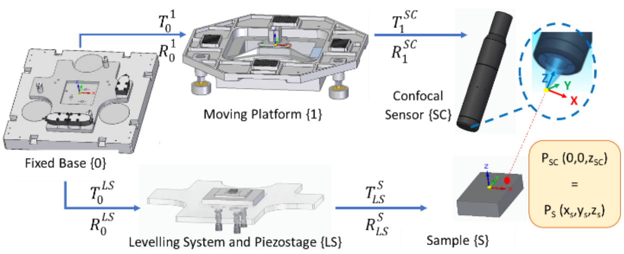

Figure 4. Global scheme of the NanoPla measurement loop.

Two chains are defined; the first chain starts with the inferior base {0} that is kept fixed. Attached to its metrology frame, there is the levelling system {LS} consisting of three micrometres, each one with relative displacement in Z-axis. The piezostage is attached to the levelling system, and it moves the sample {S} in X, Y and Z-axes. The end point of this first chain is the point of the sample that intersects with the scanning beam of the confocal sensor, P_s. The second chain also starts with the inferior base. The moving platform {1} lays on the inferior base and provides displacement in the XY-plane to the confocal sensor {SC} attached to it. The end of the second chain is the point of the scanning beam that intersects with the sample, P_{SC}. Thus, P_{SC} is a vector (0, 0, z_{sc}), where z_{sc} is the readout provided by the sensor (z_{SC}^{exp}) along its axis, minus its reading errors (ε_{SC}):

$$z_{SC} = z_{SC}^{exp} - \varepsilon_{SC} \qquad (1)$$

The starting point of both chains is the fixed base, while their end point, P_s and P_{SC}, is also coincident. Relating the two chains, Equation 2 is obtained.

$$P_S = [R_{LS}^S]^{-1} \cdot [[R_0^{LS}]^{-1} \cdot [R_0^1 \cdot (R_1^{SC} \cdot P_{SC} + T_1^{SC}) + T_0^1 - T_0^{LS}] - T_{LS}^S] \qquad (2)$$

Where R_i^j is the rotation matrix from {i} to {j} systems; and T_i^j is the translation vector between {i} and {j} origins. Table 1 summarizes the components of these vectors and matrixes, and the ranges within which they will be comprised.

Table 1. Description of translation and rotation matrixes.

Parts	T_i^j, R_i^j	Components	Range
{0}-{1}	T_0^1	Displacement: $x^{\{1\}}, y^{\{1\}}$	50 mm
		Positioning errors: $\delta_x^{\{1\}}, \delta_y^{\{1\}}, \delta_z^{\{1\}}$	33 nm, 33 nm, 100 nm
	R_0^1	Spurious rotations: $\varepsilon_x^{\{1\}}, \varepsilon_y^{\{1\}}, \varepsilon_z^{\{1\}}$	1 × 10^{-6} rad
{1}-{SC}	T_1^{SC}	No relative motion	-
	R_1^{SC}	Angular misalignments: $\varepsilon_x^{\{SC\}}, \varepsilon_y^{\{SC\}}$	TBD*
{0}-{LS}	T_0^{LS}	Displacement: $z^{\{LS\}}$	10 mm
		Positioning errors: $\delta_z^{\{LS\}}$	0.2 µm
	R_0^{LS}	Rotations: $\varepsilon_x^{\{LS\}}, \varepsilon_y^{\{LS\}}, \varepsilon_z^{\{LS\}}$	0.06 rad, 0.13 rad, 0.14rad
{LS}-{S}	T_{LS}^S	Displacement: $x^{\{S\}}, y^{\{S\}}, z^{\{S\}}$	100 µm, 100 µm, 10 µm
		Positioning errors: $\delta_x^{\{S\}}, \delta_y^{\{S\}}, \delta_z^{\{S\}}$	50 nm
	R_{LS}^S	Spurious rotations	Negligible

*To be determined experimentally

Ideally, T_0^1 should only include the displacement in X and Y-axes produced by the positioning system ($x^{\{1\}}, y^{\{1\}}$). However, it also includes positioning errors in X and Y-axes ($\delta_x^{\{1\}}, \delta_y^{\{1\}}$) and spurious motion in Z-axis ($\delta_z^{\{1\}}$). R_0^1 includes the spurious rotations of the platform ($\varepsilon_x^{\{1\}}, \varepsilon_y^{\{1\}}, \varepsilon_z^{\{1\}}$) that take place during the displacements caused by misalignments between parts. The confocal sensor is fixed to the moving platform, thus, T_1^{SC} is null, and R_1^{SC} includes misalignments of the assembly that result in angular deviations around X and Y-axes of the confocal sensor ($\varepsilon_x^{\{SC\}}, \varepsilon_y^{\{SC\}}$). The confocal sensor reading errors (ε_{SC}) must also be considered in the vector P_{SC}. The levelling system controls the position in Z-axis ($z^{\{LS\}}$) and orientation of the piezostage ($\varepsilon_x^{\{LS\}}, \varepsilon_y^{\{LS\}}, \varepsilon_z^{\{LS\}}$), with an associated positioning error ($\delta_z^{\{LS\}}$). T_0^{LS} is the translation vector of the piezostage ($x^{\{S\}}, y^{\{S\}}, z^{\{S\}}$), with its associated positioning errors ($\delta_x^{\{S\}}, \delta_y^{\{S\}}, \delta_z^{\{S\}}$). Spurious rotations of the piezostage are negligible.

5. Conclusions

In this work, first, a confocal sensor and a piezostage have been integrated in the NanoPla. Then, the kinematic model of the NanoPla system has been defined, identifying all the displacements, geometriacal errors and spurious motions that affect the final measurement. Future work should focus on the development of calibration procedures that allow the characterization of these errors in order to compensate them and to define the NanoPla measurement uncertainty.

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