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Measuring capability of a confocal sensor integrated in a two-stage long-range nanopositioning platform

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Abstract

The NanoPla is a high precision 2D positioning platform developed, manufactured, and assembled at the University of Zaragoza, offering a large range of 50 mm × 50 mm with submicrometre accuracy. Initially designed for metrological applications, the first prototype integrates a chromatic confocal sensor in its moving platform as the primary measuring instrument. Complementing this, a system of three capacitive sensors is incorporated into the NanoPla to measure parasitic motion along the Z-axis as the platform levitates within its working range, thanks to this system, parasitic motions can be corrected from the confocal sensor measurements. The NanoPla has been designed to measure statically, a procedure in which the levitating platform lands at the measuring point before recording readings. However, it also exhibits dynamic measurement capabilities, allowing for data acquisition while the moving platform is levitating. In this study, two reference artefacts are measured using the NanoPla's confocal sensor, both statically and dynamically. The obtained results are compared with those from other metrological instruments, such as a focus variation microscope, to evaluate the NanoPla's measuring capability.

Nanopositioning stage, confocal sensor, measuring capability.

1 Introduction

Nanotechnology applications such as nanomanufacturing or nanometrology require precise positioning systems serving as supplementary stages for measuring or manipulating samples. Accurate positioning is a critical requirement for applications like scanned probe microscopes, lithography, and surface profilometers. These applications find relevance in various industries, such as electronics, wherein nanostructures and features give rise to objects with dimensions in the centimetre range. Consequently, the demand for accurate, repeatable, and long-travel-range positioning systems is rapidly escalating.

To address this requirement, the University of Zaragoza has developed a large-range nanopositioning stage, called NanoPla, that is able to perform a planar motion along a range of 50 mm × 50 mm with a submicrometre resolution. The NanoPla design and implementation have been subject of previous works [1]. The first prototype of the NanoPla is intended for the metrological characterization of large surfaces at a submicrometre scale. For this purpose, a confocal sensor has been integrated as measuring instrument [2].

Previous works focused on the integration of the measuring instrument in the NanoPla, and the analysis and minimization of the error sources that affect the measuring result. In this work, reference artefacts are going to be measured by the NanoPla in order to assess its measuring capability.

2. The NanoPla as a metrology system

A picture of the actual Nanopla setup is shown in Figure 1. The NanoPla is divided in three parts: an inferior and a superior base that are fixed, and a moving platform that is placed between them. The moving platform levitates thanks to three air bearings, and it is driven by four linear Halbach motors that perform planar motion. The position feedback in XY-plane is provided by a 2D plane mirror laser system. The positioning system controls the position in the XY-plane and rotation around Z-axis of the moving platform. The position in Z-axis and the rotation around X- and Y-axes are only monitored by a capacitive sensor system, their control is not necessary thanks to the air bearings stiffness (13 N/µm).

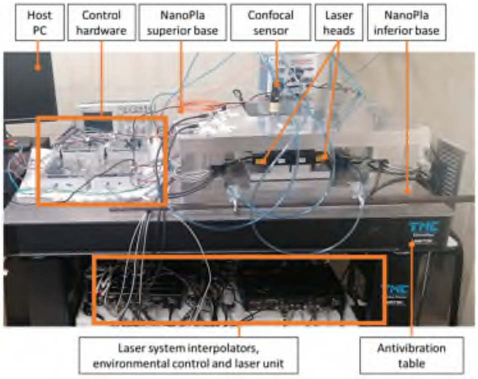

Figure 1. Picture of the NanoPla setup.

As mentioned, a Chromatic Confocal Sensor (CCS) has been integrated in the moving platform of the NanoPla as a measuring instrument. The selected CCS (CL4-MG35, from Stil) is capable of measuring in 1D along the NanoPla Z-axis, in a 4-mm range with a resolution in the measuring axis of 122 nm and a static noise that is dependent on the measuring surface characteristics. The measuring procedure for which the NanoPla was designed is the following: The sample is positioned in a sample holder placed in the fixed inferior base. The levitating moving platform displaces the measuring instrument to the desired measuring position. Once the moving platform has reached the desired position, it lands, and it stays static while the measuring instrument records the measurements. However, the NanoPla also allows to perform a dynamic measurement, that is, the CCS can record the measurements while the levitating moving platform displaces over the sample, without having to land.

3. Method and materials

In this work, we study the measuring capability of the NanoPla by measuring steps of two different reference artefacts. The NanoPla measurements are compared to the ones performed in other metrological systems. In every case, the steps are measured according to the standard ISO 25178-70:2014.

3.1. Reference artefacts

The first reference artefact is a calibrated contour standard from Alicona, with steps of 100 µm, 500 µm, 1000 µm and 2000 µm. The second artefact has been designed ad-hoc for this project with 10 steps from 250 µm to 3800 µm and manufactured by Electrical Discharge Machining (EDM). The steps of both artefacts have been measured with the calibrated focal variation microscope (FVM) Infinite Focus SL from Alicona, as a reference instrument.

3.2. Confocal sensor measuring capability

The measuring capabilities of the CCS were assessed by measuring the calibrated Alicona contour standard in an external setup, aiming to determine the errors introduced by the CCS as a measuring instrument. The external setup consists of a fixed holder for the sensor, and a commercial linear stage that moves the sample driven by a screw linear stepper motor. The measurements were performed both statically, with the linear stage stopping at every measuring point, and dynamically, that is, recording the measurements while the linear stage was displacing. The static measurements show that the sensor measurements are compatible with the ones provided by the calibration certificate of the standards, with a measuring error lower than 1 µm for every step. Regarding the dynamic measurements, it was observed that the relative speed between sample and sensor does not affect the measurement performance of the sensor. However, due to the sensor sampling frequency, higher speeds result in less measured points, which results in a higher measuring error when calculating the steps height. At speeds lower than 1 mm/s, the results of the dynamic procedure were similar to the ones obtained by the static procedure.

3.3. NanoPla measurements

The reference artefacts have been measured in the NanoPla, following the static and dynamic procedure. In the static procedure, measurements are taken at each measuring position (at intervals of 0.15 mm), providing a snapshot of the height at those specific points (Figure 2a), not allowing to measure roughness. While in the dynamic procedure, height measurements are continuously recorded as the platform moves, offering a more comprehensive view of the height variations throughout the displacement (Figure 2b), and allowing to measure roughness. To minimize the moving platform parasitic motion, the dynamic measurements were performed at a speed of 4 µm/s.

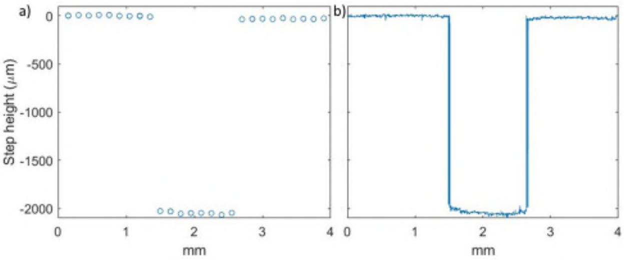

Figure 2. a) 2000-µm step measurement with the static procedure. b) 2000-µm step measurement with the dynamic procedure.

4. Measurement results

The obtained results show that there is compatibility between the NanoPla measurements in the static and the dynamic procedure, and the reference measurements performed in Alicona FVM. As an illustrative example, Figure 3a shows the measurement results of the calibrated standard 2000-µm step, while Figure 3b shows the results of ad-hoc artefact 1000-µm step. In every case, the measurement results are presented with their respective measuring uncertainties (k=2).

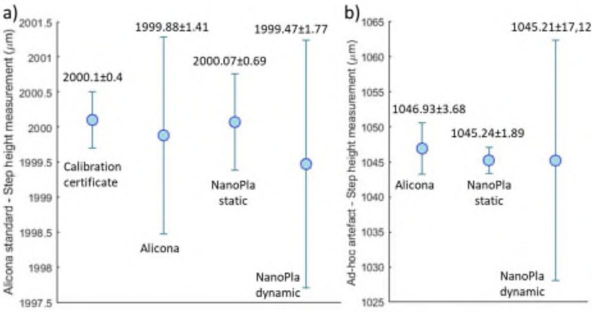

Figure 3. a) Alicona standard 2000-µm step measurement. b) Ad-hoc artefact 1000-µm step measurement.

Considering the measurement uncertainties, the compatibility indexes (E_n), calculated according to ISO 13528:2015, between the reference measurements of Alicona FVM and the NanoPla measurements are lower than 1 (0.41 in the worst case).

The uncertainties of the measurements have been calculated for all the procedures. The NanoPla uncertainty budget was addressed in a previous work [3]. In both, the static and the dynamic procedure, the NanoPla highest measuring uncertainty contribution is the measuring noise recorded by de CCS. This noise is highly dependent on the measured surface, higher roughness results in higher measuring noise. In addition, it is observed that the NanoPla levitation in the dynamic procedure amplifies that noise.

To address the roughness measurements, the Alicona contour standard roughness (ISO 21920-2:2021) was measured in Alicona FVM, the CCS in the external setup, and the CCS integrated in the NanoPla. As shown in Table 1, the dynamic measurement in the NanoPla amplifies the roughness due to the coupling of parasitic motions of the levitating platform.

Table 1. Roughness measurements of the contour standard surface.

Measuring system	**Alicona FVM**	**CCS in external setup**	**CCS in the NanoPla**
R_a (l_n=4mm)	0.28 µm	0.70 µm	8.59 µm

4. Conclusions

The measuring capability of the NanoPla system with a confocal sensor integrated was addressed. Although the NanoPla results are compatible with the reference measurements the NanoPla measuring uncertainty is higher when performing dynamic measurements: the coupling of parasitic motions of the levitating platform amplifies the measuring noise and the roughness measurements. Future works should focus on improving the positioning control system to reduce these parasitic motions.

References

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