euspen's 19th International Conference & Exhibition, Bilbao, ES, June 2019
www.euspen.eu

Assessment of moving stage performances used in scientific instrumentation

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Abstract

We present here a solution to assess the performances of moving stages that equip microscopes. It is based on the nanoGPS Oxyo® technology, where an encoded patterned scale that is imaged by the microscope. The image of the patterned slide is decoded into position and orientation with nm precision.

We have successfully implemented this method on Optical Microscopes on Scanning Electron Microscopes (SEM). We report the information on the precision and accuracy of their moving stages, along with the drift of the microscope stand. We show that this approach can be very useful for detecting troubles and malfuncionning of microscopy stages, but also improper fixing of the stage assembly or sample. It is also useful to appropriate stages for Coordinate Transformation Systems for correlative microscopy.

Calibration, coordinate measurement, microscope, positioning

1. Introduction

Motorized stages are important components in microscopy and instrumentation. Their accuracy is critical for multiple tasks that are common in microscopy, such as re-localization of observations, accurate mapping, and automation. However, getting the real numbers about accuracy and precision of moving stage required expensive laser interferometers and time-consuming arrangement with mirrors. It is not practical for users or integrators of motorized stages, nor for periodic quality checks. In contrast, imaged-based position sensing methods can be very appropriate for to determine observation coordinates on a microscope [1-4]. Recently, we proposed a method to determine stage positions of imaging instrument based on imaged-based position sensing (5].

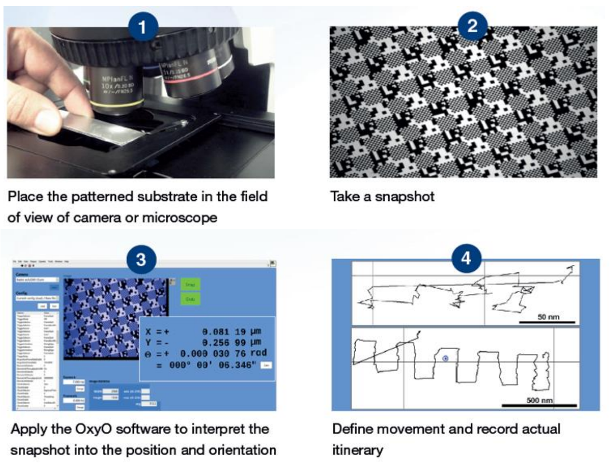

Figure 1. Description of use nanoGPS Oxyo® patterned scales and software to investigate moving stage performance on an imaging instrument.

This technology, termed nanoGPS Oxyo®, makes it simple to design and implement automated position checking procedures, as the position can be directly obtained from the image of the the scale placed on the sample holder, as shown on Fig. 1. While the stage coordinates provided by the stage do not coincide with the scale coordinates obtained from the decoding of the scale images, the cartesian transformation between the two coordinate systems can be established by determining the coordinates in the two systems determined of three stages positions. As cartesian transformation conserve distances and angles, the distances (and angles) between calibration points should be the same in both coordinate systems. Any difference in distance between the two coordinate system can be interpreted as an error in at least one of the coordinate system.

2. Experimental details

We investigated 2 Optical Microscopes (Olympus BX model) equipped with Marzhauser motorized moving stages. One microscope was equipped with the "scan" model, that deduces position from the motor control, while the second (OM2) was equipped with a "scan Plus" model equipped with magnetic encoders, which should expectedly provide better precision and accuracy. The nanoGPS Oxyo® scale was a 125x125mm² scale made of glass, with a coefficient of thermal expansion $8.10^{-6}K^{-1}$. The reading of the scale was performed using the 10x objective of the microscope. Separate experiments [5] established that the precision of the method is about 1nm, and accuracy is better than 100nm over a 10cm distance, provided the scale is operated at its nominal temperature. Simple calculation indicate that a 1°C variation creates a 0,8µm thermal expansion for a 10cm distance, and that stages that are built in aluminium have a still larger expansion of 2,3µm per 10cm of length. As the microscopy experiments reported here were performed in laboratories that were not controlled in temperature, one may expect that thermal expansion may lead to errors on distance of several µm per dm.

We also investiaged a Scanning Elecrom Microscope (Zeiss Merlin) equipped with its original stage. The nanoGPS Oxyo® scale was a 3mmx3mm scale patterned on a Silicon substrate, placed on an Aluminium sample holder.

As the stability of the microscopy imaging train also affects the precision and accuracy of the position determination through nanoGPS Oxyo®, it has been evaluated by running continuous position determination on the scale, with no movement imposed to the stage. The drift over 10 minutes was found to be less than 1 µm on the optical microscopes, and less than 2 µm on the SEM. Defocusing/refocusing operations on the optical microscope were found to create some slight position shift (less than 0.24µm maximum; 0.09µm rms).

The stages were investigated by running instructions to the moving stage, to follow the 12 points trajectory described on Fig. 1. As the SEM scale was rather small, only the P’2-P’1-P0 and and inner point trajectory was run in this case. On each point, an image of the scale was taken and interpreted into coordinates, and the stage coordinates were recorded as well.

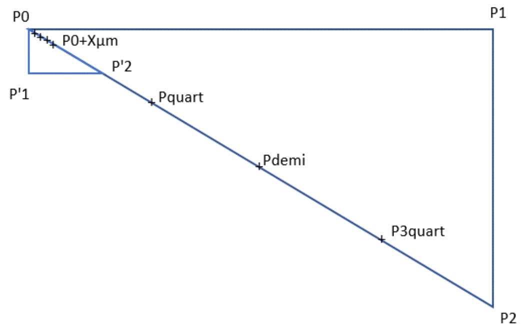

Figure 2. Predefined 12-points trajectory used to assess stage performance. Starting point is P2, then P1, P0, ...

3. Results

The accuracy of the stage repositioning could be evaluated by determining the distances on the Oxyo scale between two nominally identical position according to the stage coordinates. It can be seen that the microscope equipped with a stage that includes an encoder has significantly better precision than the one without an encoder. It is also interesting to notice that the repositioning on the first observation points observed on the encoded stage (OM2) exhibits a 5µm hysteresis, while all further repositioning in this or other points exhibits an hysteresis that is less than 0.5µm. This might be an indication of some slight mechanical instability, either in the sample clamping ot table clamping, that vanishes after the first stage movement.
Another important fact to report is that the initial experiments on SEM stage indicated that repositioning errors were of 100µm or more. By having the stage repaired, and also setting properly a software option that avoids spurious beam shift, we managed to obtain repositioning accuracy better than 0.5µm.

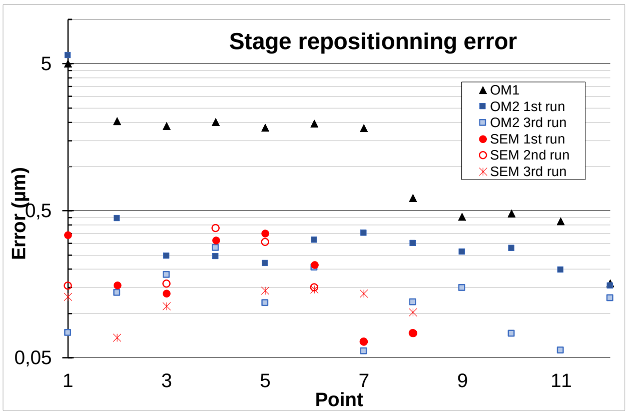

Figure 3. Stage repositioning errors determined using nanoGPS Oxyo scale, for Optical Microscopy Stage 1 (OM1), Optical microscopy stage 2 (OM2), and Scanning Electron Microscope Stage (SEM)

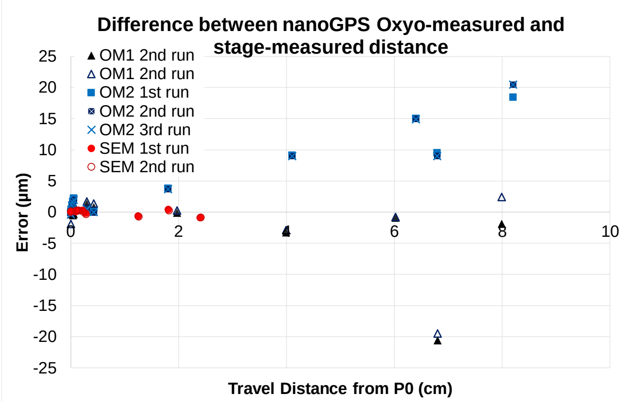

Figure 4. Comparison between travel distances from P0 measured using nanoGPS Oxyo scale coordinates, and stage coordinates, for the different stages equipping the different microscopes.

4. Application to Coordinate Transfer

It is more and more important for scientists and engineers operating microscopes, to gather complementary information from different microscopes on different Points of Interests of a sample [4]. As a consequence, the development of convenient colocalization and relocalization solutions are much wanted. Those often rely on a Coordinate Transfer System (CTS), where some fiducial attached to the sample holder is used to associate a fixed cartesian coordinate system to the system, and a calibration operation that is used to determine the coordinate transformations between the stage and sample coordinate systems. Experiments presented here allow us to propose some figure of merits to compare stage performance in view of their use in a CTS system.

5. Conclusion

We have described a convenient method to investigate precision and accuracy of moving stage performance. We use this process to select stages for use in precision microscopy applications such as re-localization or co-localization between instruments.
This solution is expected to be also useful to stage manufacturers, both at the factory and at the customers’ site. At the factory, it provides a cost- and time-effective way to determine precision and accuracy of each stage. At the customers’ site, it is useful for troubleshooting, including spotting issues were the drift of the microscope body create repositioning errors that are wrongly ascribed to the moving stage. Because it is based on imaging, this diagnostic can be performed remotely, possibly as a quality certification service.
not only at the production factory but also in their operational environment, and at customers’ sites, both in a laboratory and industrial environment.

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