Self-calibration using advanced algorithms on a multi-probe system

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High-precision equipment

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High-precision engineering example

For high-precision motion systems, measurement accuracy is key. Ideally, its position data is linearly dependent on the actual position. In reality nonlinear behavior is present, such as an encoder scale with local scale deformation due to mounting stresses.

Introduction

Typically, the measurement systems are calibrated to reduce the inherent nonlinearities. Very often, these calibrations are time consuming and require an external calibration tool such as a reference measurement system. An online self-calibration of a position measurement system is proposed that leads to an error profile that is virtually free of integration errors. This method, an extension of the inclination method, allows for an in-line calibration that does not require a separate calibration tool and can be conducted on-the-fly. This multi-probe self-calibration method for calibration scale imperfections enables more frequent re-calibration (even online), without the requirement of access for a reference measurement system. Furthermore, the extension allows for a tradeoff between an improved calibration accuracy and a high spatial density of the calibration grid. Finally, a lower cost can be realized with this method when compared to the regular approach.

Method

The inclination method [S. Kiyono et al. (1994), Precision Eng. 16, 212-218] uses measured integrated differential profiles (groups) as error shapes. Each group is sampled with a step length L, which is equal to the distance between two probes on the mover (figure 1). The application of three sensor heads on the same mover allows for a reconstruction of the nonlinearity errors of the encoder on a much denser spatial grid: the spatial resolution is reduces to S, the greatest common divisor of the sensor head intermediate distances (figure 2).

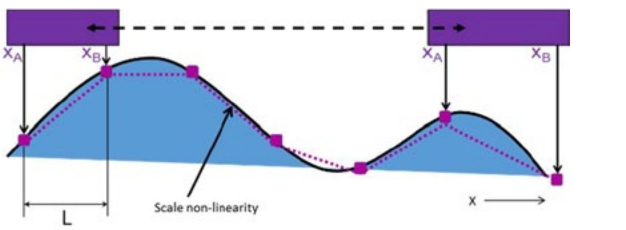


Figure 1: Inclination method for a group with grid pitch L. The squares represent the equally spaced measurement points

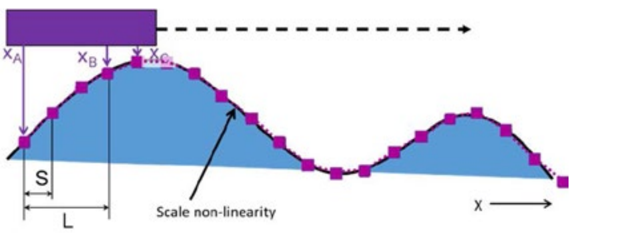


Figure 2: Using more than two sensor heads allows for a directly coupled measurement on all calibration grid points

A smart algorithm distils and pre-processes the relevant data from a continuous movement of the mover over the scale. It eliminates the need to step through all calibration grid points. An error profile is then calculated (online but not real-time) and can be used immediately for self-calibration of the system.

Algorithm

The scale errors e, along with the true stage positions y, are derived from the encoder measurements m with a least-squares approximation.

$$m = A \begin{bmatrix} e \\ y \end{bmatrix} \Rightarrow$$
$$\begin{bmatrix} e \\ y \end{bmatrix} = (A^T A)^{-1} A^T m$$

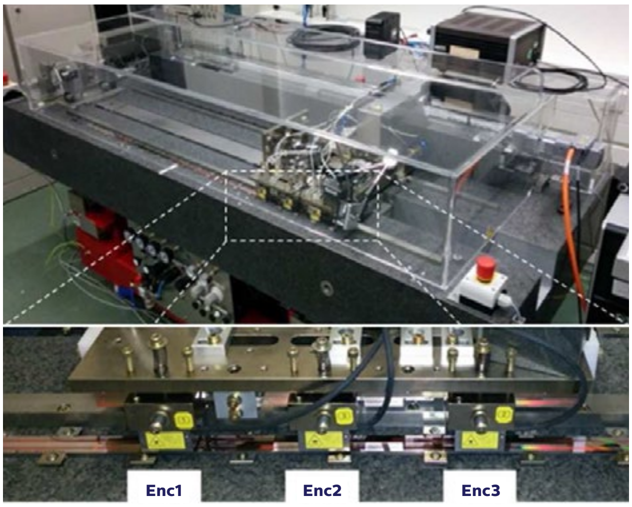
Here, A is the matrix which links the measurement data with the local scale error and the stage position and contains constraints, build from the geometry of the setup. The scale calibration uncertainty σ_p can be derived similarly from the (uncorrelated) sensor uncertainty σ_m:

$$\sigma_P = \sqrt{diag((A^T A)^{-1} \sigma_m^2)}$$

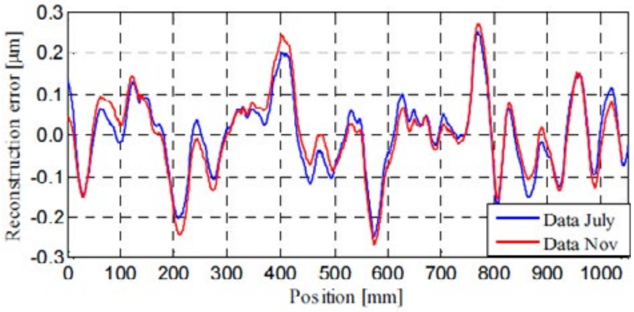
The estimated scale errors are input for an interpolation algorithm to compute the corrected stage position in between the calibration grid.

Experimental validation

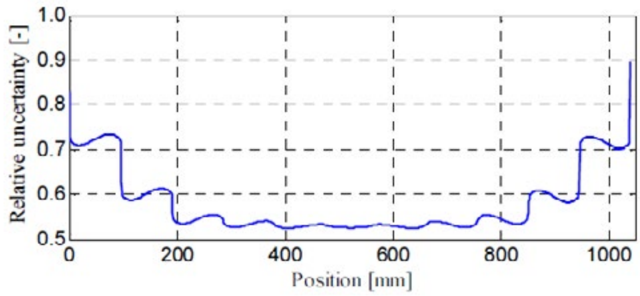
An experimental setup with 3 encoder heads is used for verification, see picture. A linear mover on air bearings moves over a vibration-isolated granite table. A polycarbonate cover dampens temperature changes. The test setup allows for reconfiguration of the encoder heads on the mover.



The figure below shows two processed error profiles thatwere obtained on the same setup, but with different configurations of the sensor heads, and for measurements that were 4 months apart. The reconstructed nonlinearity profiles are nearly identical. The period of 58 mm, clearly visible in the reconstructed nonlinearity, corresponds to the pitch of the scale clips.



From the sensor layout, grid pitch and number of measurement points, it is possible to calculate the calibration uncertainty relative to the sensor uncertainty. Redundant coupling between two grid calibration points decreases the uncertainty. The amount of steps necessary to make this coupling adversely effects the uncertainty.



As such, more encoder heads result in better performance, as long as their intermediate distance is chosen smartly. As an example, the method is applied here to a linear drive. Trivially, it is also suitable for rotating devices, moreover, it can be extended to multi-DoF devices. Check for updates on www.innovationservices.philips.com/high-precision!

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