Error Budgeting of a Sensor Based on the Inverse Square Law

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Abstract

In this paper, the advances of a prototype for measuring lineal displacements with micrometric resolution are presented. This device, which is based on the use of opto-electronic sensors, has had a number of redesigns in order to improve its performance. On the one here presented, the arrangement consists of two LEDs used as light emitters and two PSD photodiodes as receptors, facing each other. This generates a more compact and lower cost solution than the commercial ones (LVDT, optical encoders, etc.). The repeatability of the sensors has been studied as a first step for a later accuracy analysis. In the experiments carried out the fulfilment of the square law has been verified. With the experiments results, the error budgeting of the device is been determinate and is presented on this paper.

1 Introduction

The importance of micro and nano-metrology is continuously increasing, and one of its consequences is the tighter exigency in precision engineering applications. Therefore, one of the needs detected is the one regarding linear displacement sensors, capable of measuring in a range of a few mm [1] with an accuracy of a few µm, low cost and small size. In this context, a new prototype for measuring one dimensional displacements with micrometric resolution is being developed. One of the possible applications of these sensors is its use in self-centring probes for machine-tools verification in a quick, simple and reliable way with ball artefacts. In this field of work several prototypes of probes have been developed in the past and later optimized, both in their mechanical design and in the sensors used [2].
After several developments using PSD sensors with LED diodes as light emitters, a new concept of 1D-displacement measuring low-cost sensor based on the inverse square law has been developed. Nevertheless, all these solutions are simpler and less expensive than other sensor systems such as, for example, optical encoders [3].

2 Prototype Basic Setup

The arrangement of this device is based on previous works about the use of the inverse square law [4]. The main components are two red LEDs L6108 and two photodiodes S2386 from Hamamatsu. Other components also required are a power supply, a linear guide with a slide unit, some fixture elements for the LED and photodiode and a processing and digitizing system.

The system has been designed to work with short distances (4~12 mm) between the LED and photodiode, therefore it is necessary to use a more generalized version of the inverse square law taking into account the radius of the emitting surface of the LED (Figure 1). Nevertheless, it has been neglected the effect of Lambert's law.

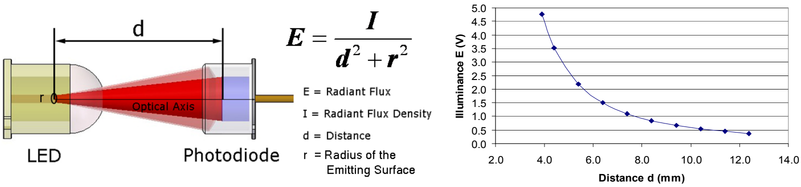

Figure 1: Measuring principle for the inverse square law and experimental test.

3 Methodology

An experimental characterisation of the prototype is presented in this paper. Mainly, it consists on the use of a one-coordinate measuring horizontal-machine (1C-HMM) placed on a flatness table as displacement system for the sensor to ensure the relative movement among the guide and the slide unit, and a laser interferometer used as reference instrument (0.1 μm in resolution). A drawing of the experimental setup used can be seen in Figure 3.

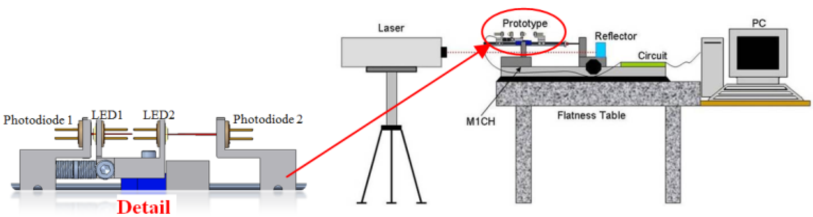

Figure 3: Experimental Setup with a prototype basic detail

In addition, the system has been covered to protect it from background light. Nevertheless, it has been experimentally verified that the main error source for the system comes from changes in the LED light output [4] because of small variations in the laboratory temperature (20 ± 1 ºC).

3.1. Experiment results

First of all, in order to characterized the sensor, the system has been tested with the procedure previously described measuring the illuminances *E* at various distances for a length of 8.5 mm. The results from the sensor and the laser interferometer have been fitted to the inverse square law with the least-squares method to obtain the values of *I, r* and d_0 (this is the initial unknown offset distance between LED and photodiode).

Secondly, the repeatability of the system with respect to the relative lineal displacement was analyzed. Basically, the experiments consisted on taking measurements on one point during a time period long enough as 12 hours. This way could be verified the high influence of small temperature variations (Figure 3).

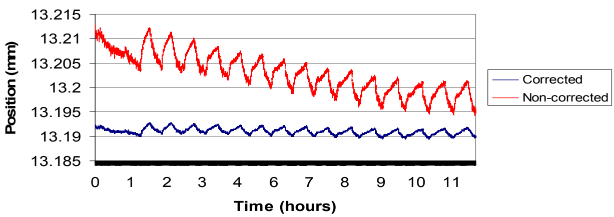

Figure 3: Position variation due to thermal changes during a 12 hours test.

Lastly, it has been proposed a correction method based on the combination of the measures from both photodiodes in order to minimize its influence (equation 1).

$$d_{photodiode\_1} + d_{photodiode\_2} = \varepsilon \quad (1)$$

This sum is a constant value because of the system design, therefore, any deviation should be mainly due to a thermal effect on the LEDs and can be estimated and corrected with equation 2 (Figure 3).

$$\frac{\Delta d}{\Delta I} \approx 2 \cdot E \cdot d \quad (2)$$

4 Error Budgeting

After testing the device, it has been evaluated its measuring uncertainty according to [6]. The main uncertainty sources are: the calibration process, the laser interferometer, the changes in the power emitted by the LEDs due to the temperature, and the expansion of mechanical parts (linear guide, fixture elements). The results before and after applying the correction method are shown in Table 1.

Table1: Uncertainty results in micrometers

	Before Correction	After Correction
Umax (k=2)	20,9	7,8

5 Conclusions

The advances in a prototype, based on opto-electronic sensors, for measuring lineal displacements with micrometric resolution have been presented. This device is a more compact and lower cost solution than the commercial ones: LVDT, encoders...
In the experiments carried out the fulfilment of the square law has been verified and the repeatability of the sensor has been clearly improved by using a double measuring system. Nevertheless, better results can be obtained if the influence of the temperature can be minimized during the characterization process: faster process, better isolation from the environment…

6 References

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