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A phase-encoding method for absolute position measurement using a single track binary code scale

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Abstract
We present a phase-encoding method for absolute position measurement using a single track binary code scale. In the scale, an absolute position binary code (APBC) is represented using a phase-encoded method with changing relative position of binary patterns. By analysing an image of the scale, the APBC can be decoded efficiently. To increase the measurement resolution, we employed a sub-division algorithm where nonlinearity error is compensated by a simple shift-averaging method. Using an experimental setup which consists of a microscopic imaging system, a binary code scale, a precision stage and a laser interferometer, we evaluated feasibility and performance of the proposed method. When pitch of the binary scale is 32 μm, the measurement system detected 50 nm stepwise displacements clearly, and its nonlinearity error was less than 15 nm.

Keywords: Phase-encoding method, Absolute position measurement, Single track binary code, Sub-division

1. Introduction

Optical encoders have been used as typical position feedback sensors in precision engineering fields [1]. For simplicity and cost-effectiveness, incremental encoders are more widely adopted in precision systems than absolute ones. However, since the absolute encoders have some advantages such as no need of initialization and high robustness in emergency, their application fields are expanding recently. The absolute encoder can be implemented using multi-track or single track scales. Single track scales are superior to multi-track ones in the respect of easy alignment and compactness, but they require an efficient decoding algorithm and should overcome limited resolution of a binary scale [2-5].

In this paper, we present an absolute position measurement method using a single track scale where an absolute binary code is encoded by phase shifting the position of one binary state representation. The binary code can be decoded efficiently using the scale image, and sub-division can be implemented by calculating the relative phase of the acquired image. The proposed method is also easily expanded to two-dimensional and angular position measurement. In the following section, we will explain principle of the proposed method, and present several experimental results showing the performance of the absolute position measurement method.

2. Principle

A single track binary scale consists of series of data cells. Each data cell, which is composed of multiple segments, represents one data bit of an absolute position binary code (APBC), and consists of three sections which are a clock section (C), a data section (D), and a neutral section (N). As shown in figure 1, the data section has different binary state compared to the clock section, and the binary state of each cell is expressed by shifting relative positions of the data sections to the clock sections.

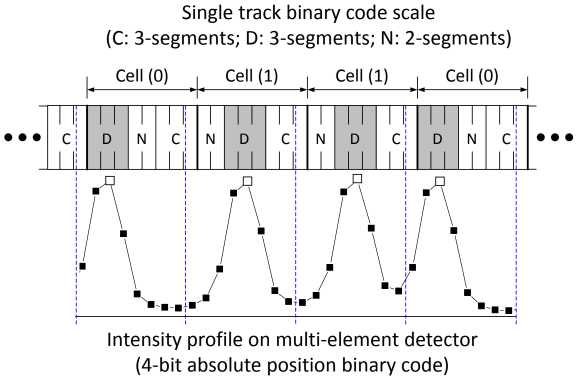

Figure 1. Exemplary single track binary code scale and acquired intensity profile on a multi-element detector

The APBC can be expressed by using an n-bit linear shift feedback register (LSFR) which represents 2^n-1 absolute position codes. Because the LSFR produces a new position code by shifting one data bit and expresses 2^n-1 states recursively, it can represent the absolute angular position code efficiently. The phase-encoding method is also applicable to two-dimensional absolute position measurement by superimposing two linear binary codes orthogonally [4, 5].

The overall data processing procedure can be summarized as figure 2. Firstly, a scale image is acquired by a microscopic imaging system consisting of a multi-pixel detector. The acquired image is shift-averaged to obtain an ideal sinusoidal intensity profile by eliminating the 3rd-order harmonic term [5], so that the nonlinearity error in the sub-division process is reduced. The shift-averaged intensity profile is processed to decode the APBC using the clock sections as alignment key patterns repeated at periodic positions. The absolute code pixels (A_p) and the index (A_{pi} = 1, …, 8), which is the order of A_p in the pixel subset, are obtained by circularly shifting the clock pixel index (C_{pi} = 1,…, 8) which equals to the order of the clock pixel (C_p) in the same pixel subset. From the intensity levels of the absolute code pixels, we can determine the binary code and decode the absolute angle code value using a look-up table (LUT). In the sub-division process, the positions of the data sections are calculated with sub-pixel resolution of the detector by using the intensity values around the pixels corresponding to the data sections. Finally, the absolute position (p_{abs}) is calculated by combining three terms, which are the absolute position code value (p_{LUT}), the absolute code index and the relative phase of the data section (ϕ), and multiplying the signal period of the scale (p) [4].

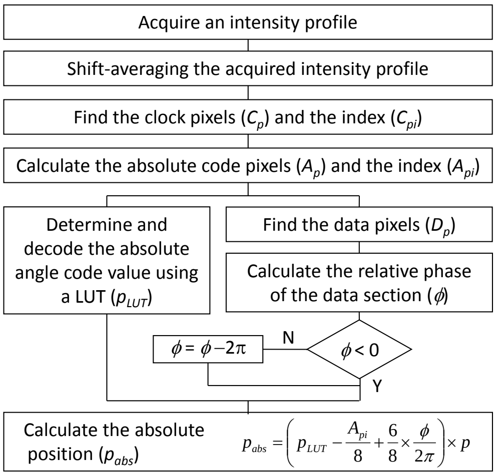

Figure 2. Data processing procedure to obtain the absolute position using the acquired intensity profile of the binary code scale

3. Experiments

To verify the proposed method and evaluate its performance, we setup an absolute position measurement system using a microscopic imaging system [4, 5]. The one- or two-dimensional binary scale was fixed at the moving part of a translational stage, and its displacement was measured using a laser interferometer, simultaneously. Figure 3 shows the measurement result of a stepwise trajectory. The two-dimensional binary scale consisting of segment width of 4 μm, and cell width of 32 μm was used in the experiment. We can clearly discriminate the 50 nm step, which corresponds to 1/640 of one cell width. Because of low structural stability of the experimental setup and noise in the acquired image, the experimental results showed rather big random error. Higher precision can be obtained if the proposed method will be implemented in a sensor head module consisting of a specially designed multi-array detector.

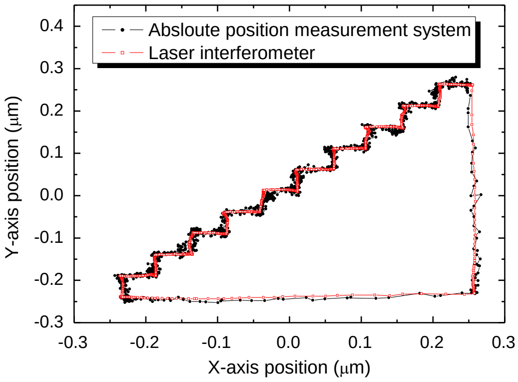

Figure 3. Comparison of readouts of an absolute position measurement system and a laser interferometer (50 nm stepwise trajectory)

The nonlinearity error in the sub-division process was evaluated by comparing the readouts of the absolute position measurement system and the laser interferometer (see figure 4). The 3rd-order harmonic terms in the intensity profile induces the nonlinearity error having 8-period in one cell width. Since these harmonic terms can be eliminated by shift-averaging the intensity profile, the nonlinearity error was reduced remarkably less than 15 nm.

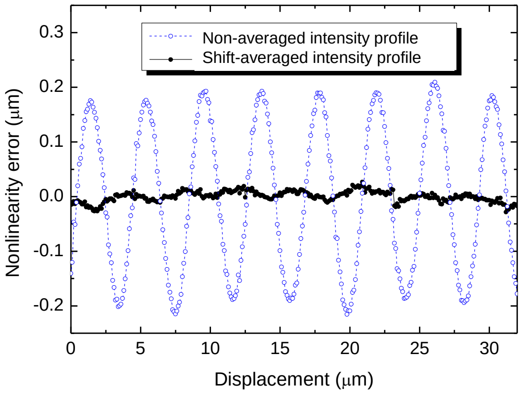

Figure 4. Comparison of the nonlinearity error between non-averaged and shift-averaged intensity profiles

4. Conclusion

An absolute position measurement method was proposed and its performance was evaluated through several experiments. It uses a single track binary scale, where APBC is encoded with the phase-encoding method, and can decode APBC efficiently with sub-divided resolution. The proposed method can be used also in the measurement of two-dimensional and angular displacement. An experimental setup was constructed using a microscopic imaging system, and the acquired image was processed to obtain the absolute position value. In the comparison with the laser interferometer, it could measure a stepwise trajectory of 50 nm clearly and reduce the nonlinearity error less than 15 nm. Since the proposed method can be modularized as a compact encoder sensor, it will be used for various applications requiring accurate absolute position feedback sensors.

Acknowledgement

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