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A novel error compensation method for an absolute optical encoder based on empirical mode decomposition

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ABSTRACT

Absolute optical encoders have emerged as a preferable choice of accurate positioning measurement for high-end manufacturing. To further improve the measurement accuracy of the absolute optical encoder, a novel error compensation method is proposed based on the empirical mode decomposition (EMD) method. This method is operated as follows: First, the measurement error achieved by an absolute optical encoder is decomposed into a number of intrinsic mode functions (IMFs) and the residue based on EMD. Then, a novel Hilbert marginal spectrum (HMS) based scheme is proposed to extract the underlying trend of the measurement error. Finally, the underlying trend is eliminated from the measurement error to improve the measurement accuracy. Experimental results indicate that the proposed compensation method extracts the underlying trend of the measurement error very well and improves the measurement accuracy of the absolute optical encoder.

1. Introduction

Due to the flexibility and low cost, optical encoders are widely employed in the high-end computerized numerical control (CNC) machines nowadays. Incremental optical encoders and absolute optical encoders are two dominant optical encoders to substitute the laser interferometer [1,2]. The incremental optical encoder can operate at the speed of above 150 m/min, while their cost are much cheaper than the laser interferometer. However, incremental optical encoders have some inherent problems such as reset delay, redundancy errors, and losing the positions during the power failure. In contrast, the absolute optical encoders have been shown to have the capability to solve these inherent problems [3–8]. In particular, the authors in [6–8] have proposed different approaches to improve the measurement performance of the absolute optical encoder by means of architecture schemes and image processing scheme, respectively. Although these are able to improve the measurement accuracy in a certain degree, they cannot clearly reveal the inherent mechanisms of the measurement data.

The measurement data achieved by optical encoders are inevitably influenced by some environmental factors, such as vibration and temperature change etc. In the literature, there are some existing studies dealing with a single environmental factor to improve the measurement accuracy of the optical encoder [9–12].

The vibration occurring in the real manufacturing conditions affects the interference pattern produced by the relative movement between the two gratings. This leads to poor measurement performances of optical encoders [9,10]. In practice, the vibration is caused by a variety of manufacturing factors such as the vibration of the CNC machine, the material of the encoder and the movement of the scanning carriage of the encoder. Thus, it is hard to use a linear or a simple nonlinear model to reveal the

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mechanism of such a complicated vibration.

Besides, the optical encoder is established with a controlled temperature in a free condition. However, the temperature inevitably changes fluctuates over time in the real manufacturing environment. For example, when the encoder has operated for a long time, the temperature will rise. In this case, the glass of the optical encoder is inevitably different in shape from that in the free condition. The intervals of the measurement scales changes since the measuring scales of the encoder are deposited over the glass surface. This thus results in poor measurement accuracy of the optical encoder. In particular, the longer the measurement length is, the greater the measurement error is deviated [11,12]. It is well-known that the deformation of the shape of the glass with the change of the temperature is a non-linear and non-stationary process.

To sum up, due to the vibration and temperature change, the optical encoder works in a complicated environment, and the two environmental factors are coupled with each other to influence the measurement accuracy rather than simply superimposed, thus making improving the measurement accuracy even more complicated. In particular, it is infeasible to combine the exiting methods that deal with a single environmental factor together to improve measurement accuracy of the optical encoder in the real environment. This thus motivates us to propose a new approach to solve this problem.

In this work, we find that the influences coupled by environmental factors involving vibration and temperature change exactly imply some inherent physical mechanisms. By applying the trend analysis of the time series, we show that the measurement error consists of an inherent component and an additional component, where the former is caused by vibration and temperature change, and the latter is a random error reflecting other uncertain factors. By analyzing the measurement error obtained by the absolute optical encoder, we find out that the inherent component can be characterized as the underlying trend of the measurement error. Therefore, the measurement accuracy can be improved if the underlying trend of the measurement error is eliminated from the measurement error. Note that the measurement data used in this work is obtained from our previous established absolute optical encoder in [8], more details about the encoder is present in Section 2.

Motivated by this observation, we present a new error compensation method for the absolute optical encoder based on empirical mode decomposition (EMD), which is a promising method for underlying trend extraction [13–23]. First, the measurement error is decomposed into some intrinsic mode functions (IMFs) and the residue via EMD. Then, the Hilbert marginal spectrum (HMS) of each IMF is calculated. Next, a scheme is presented to select the eligible IMFs, and combine them with the residue to compose the underlying trend of the measurement error. Finally, by eliminating the measurement error, the measurement accuracy is improved.

The rest of the paper is organized as follows. Section 2 briefly introduces the architecture of our previous established absolute optical encoder and the obtained measurement error. In Section 3, a novel error compensation method for the absolute optical encoder based on EMD is demonstrated in detail. Sections 4 and 5 present experimental results and conclusions, respectively.

2. The architecture of the absolute optical encoder and the measurement error

The architecture of the absolute optical encoder, previously presented in our previous work [8], is illustrated in Fig. 1, and briefly introduced here. The encoder consists of a complementary metal oxide semiconductor (CMOS) sensor, a beam splitter, an eyepiece, an objective lens, a collimation lens, a light source and a glass gratings substrate with absolute coding patterns. During working phases, the encoder captures a group of absolute coding patterns within the measurement range. Then, at the decoding process, an image processing method is employed to reliably form a group of absolute codes via the M-sequence of pseudo-random code rule. When grasping a group of absolute codes, absolute positions can be achieved. Finally, a test system consisting of the encoder and a laser interferometer is used to achieve the measurement error data. Please refer to [8] for more details.

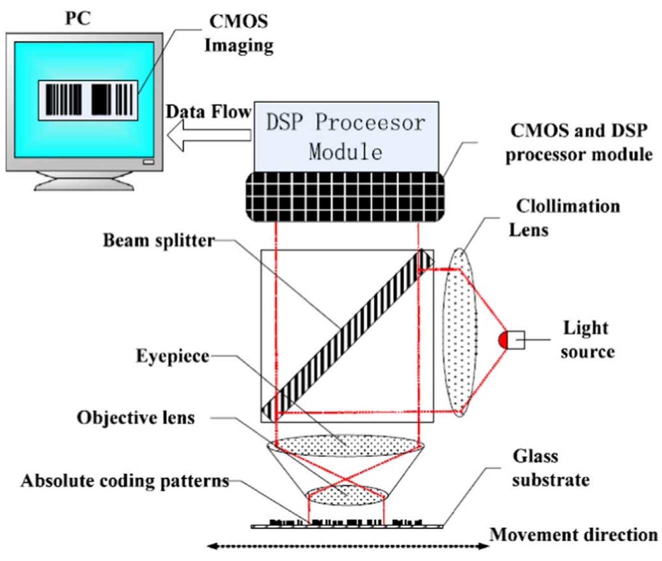

Fig. 1. The architecture of the absolute optical encoder [8].