A NOVEL POSITIONING MEASUREMENT METHOD USING POLAR MICROSTRUCTURE

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INSTRUCTIONS

Although there are many fundamental optical sensor technologies applied in precision measurement [1,2], air refractive index error and wavelengths errors are their main uncertainty sources. A stringent environment such us vacuum is needed to control the above uncertainty sources. This paper presents a novel method which attempts to integrate ultra-precision machining and computer vision technologies is found to be feasible and promising for the precision measurement because of its simple device, space-saving, low-cost, high-robust features.

In this paper, a unique texture surface named polar microstructure was proposed in this paper. Polar microstructure aims to serve a unique global map for the subsequent matching measurement, the template matching algorithm was used for image processing and determine the absolute position of the selected image in the global map. The relevant experiment was conducted to test the uniaxial uncertainty of the proposed method.

POLAR MICROSTRUCTURE

As shown in Figure 1, the polar microstructure is designed based on the concept of polar coordinate system. The surface feature of the polar microstructure is composed of concentric circles and straight lines whose spacing is equal to 50 micrometers, respectively. It is fabricated by a process chain of ultra-precision machining technology combining single point diamond turning (SPDT) and single point diamond broaching (SPDB). It can be fabricated by using Nanoform 350G ultra-precision machining system from Nanotechnology Inc., USA [3].

It is found that the polar microstructure possesses high discrimination rate even the form accuracy of polar microstructures is in micrometer range. Due to the unique characteristics of polar microstructure not only for the geometric patterns but also the sorting of intensity values of pixels, its grey-scale intensity distribution is unique which guarantees the reliability and the robustness.

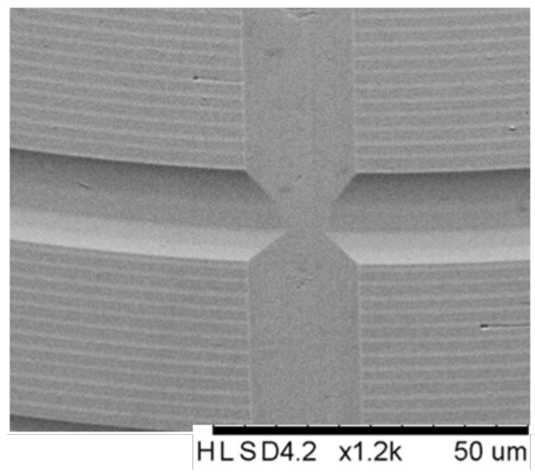

FIGURE 1. Polar microstructure surface

This paper makes use of template matching method as the method for the precision positioning t through image registration of template image and reference image [4]. The Normalized Cross-Correlation (NCC) method has been proven to be one of the most effective and robust methods that supports the measurement of the resemblance between template image and its coincident region at the reference. The NCC value is given by Eq. (1):

$$NCC_{(u,v)} = \frac{\sum_{i=1}^{m}\sum_{j=1}^{n}[R(u+i,v+j)-\bar{R}(u,v)]\cdot[T(i,j)-\bar{T}]}{\left[\sum_{i=1}^{m}\sum_{j=1}^{n}(R(u+i,v+j)-\bar{R}(u,v))^2\right]^{\frac{1}{2}}\cdot\left[\sum_{i=1}^{m}\sum_{j=1}^{n}(T(i,j)-\bar{T})^2\right]^{\frac{1}{2}}} \quad (1)$$

Where $\bar{R}(u,v)$ is the grey-scale average intensity of reference image $R(u,v)$, whereas $\bar{T}$ is the grey-scale average intensity of the template image T. These values are defined as Eq. (2) and Eq. (3):

$$\overline{R}(u,v) = \frac{1}{m \cdot n} \sum_{i=1}^{m} \sum_{j=1}^{n} R(u+i, v+j) \tag{2}$$

$$\overline{T} = \frac{1}{m \cdot n} \sum_{i=1}^{m} \sum_{j=1}^{n} T(i,j) \tag{3}$$

The NCC values delivers between the interval [-1, 1], it means that if NCC = 1, the similarity is the best possible whereas if NCC = -1, the template and the corresponding image are completely different. As a result, the point (u,v) which presents the best possible resemblance between R and T is derived as Eq. (4) and Eq. (5):

$$(u,v) = \arg \max_{(\hat{u},\hat{v}) \in A} NCC(\hat{u},\hat{v}) \tag{4}$$

Where,

$$A = \left\{(u,v) \mid 1 \le \hat{u} \le M-m, 1 \le \hat{v} \le N-n\right\} \tag{5}$$

To evaluate the machining quality of polar microstructure, a comparison between the simulation result and the machining results are shown in Figure 2 and Figure 3.

The iterative closest point (ICP) method is used to register the two simulations and the measurement results so as to locate the same area. Figure 4 shows the contrasting profiles of the simulation and measurement results. The results show that the UPM is feasible to obtain a high-precision and reliable polar microstructure surface.

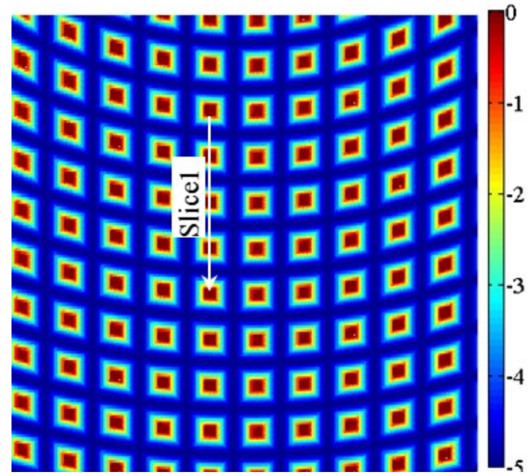

FIGURE 2. Simulated result of surface profile of Polar Microstructure

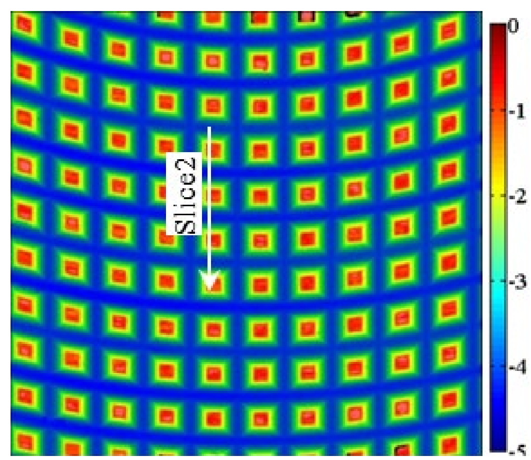

FIGURE 3. Measured result of surface profile of Polar Microstructure

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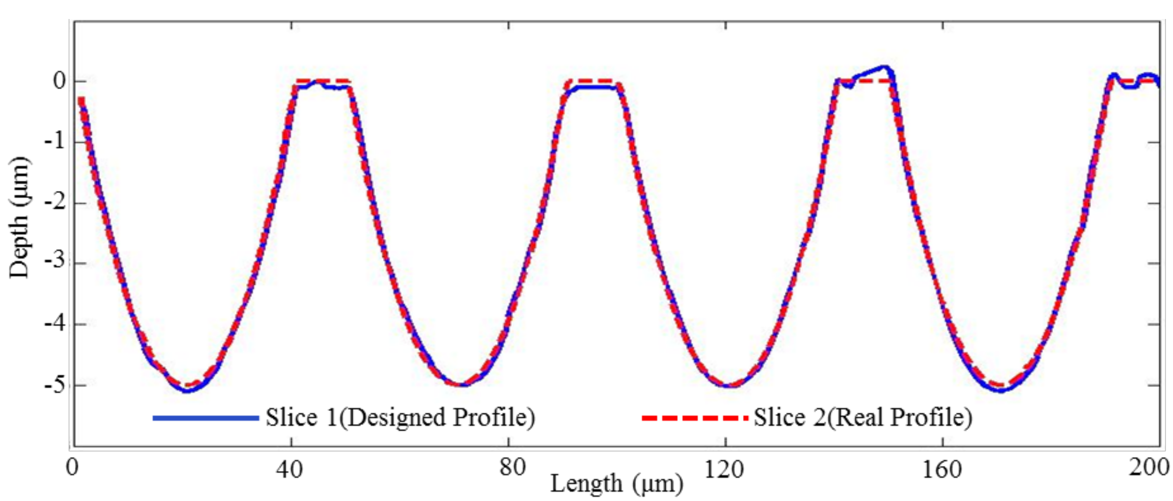

FIGURE 4. Contrasting profiles

EXPERIMENTS AND RESULTS

In this experiment, a nanometer level piezoelectronic drive stage is used to test the uniaxial uncertainty of the proposed method. The experimental setup is shown in Fig. 5 while the polar microstructure and its fixture are mounted on the drive stage. A microscope is used to observe the surface of polar microstructure while the image is captured by CMOS sensor as shown in Figure 6.

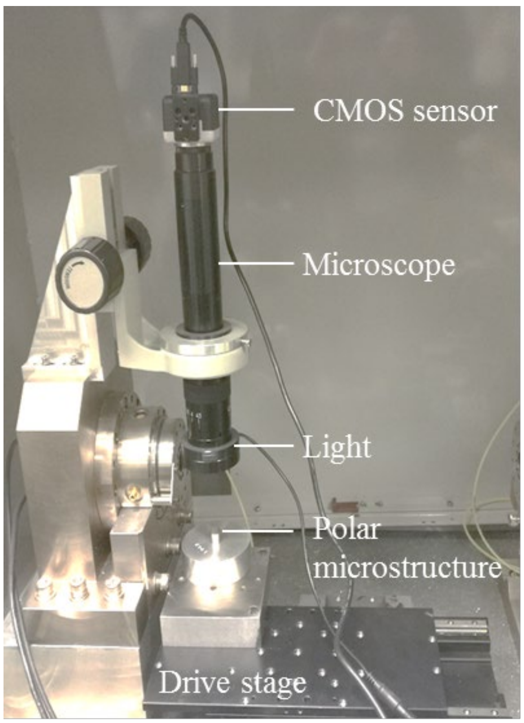

FIGURE 5. Experimental setup

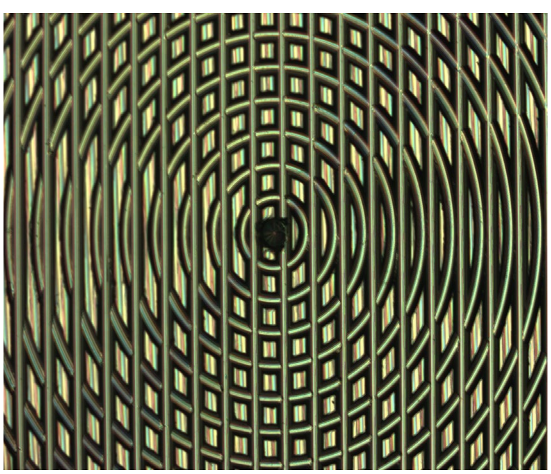

FIGURE 6. Polar microstructure observed with CMOS sensor

To test the position performance of the integrated polar microstructure and template matching method, the experiment is conducted to drive a 500 μm-distance reciprocating for 50 times each along x and y axis, images are captured during each reciprocating cycle. Hence, the integrated polar microstructure and template matching method is used to determine the position of each image which is captured by camera at each step.

It should be illustrated that considering the calculation amount in Eq. (3) as well as to prevent there are some areas which are actually outside the area of global image (G), the top left corner (100 pixels x 100 pixels) of each image captured by camera is chosen as template image (T). When the reference image ($R_{\max}$) which has the most similarity with template image (T) is calculated, the pixel (u, v) which is on the top left corner of $R_{\max}$ is defined as the "result pixel". The actual distance between the "result pixel" with the pixel on the top left corner on the global image (G) is defined as position. After calculation, all the calculated position points are compared to the actual position points.

To illustrate the measurement performance of the integrated polar microstructure and template matching method clearly, the distance ($D_{(i,j)}$) of each measurement point between actual position coordinate value ($x_{werth(i,j)}$, $y_{werth(i,j)}$) and the calculation position coordinate value ($x_{TM(i,j)}$, $y_{TM(i,j)}$) is determined, which can be expressed as Eq. (6):

$$D_{(i,j)} = \sqrt{(x_{werth(i,j)} - x_{TM(i,j)})^2 - (y_{werth(i,j)} - y_{TM(i,j)})^2} \quad (6)$$

The difference $D_{(i,j)}$ between the calculated positions and the displayed positions by the drive stage is acquired and the results are shown in Fig. 7(a) and Fig. 7(b) in X and Y axis respectively. The standard deviations of positioning errors are found to be 198.6 nm and 222.8 nm in x and y axis, respectively.

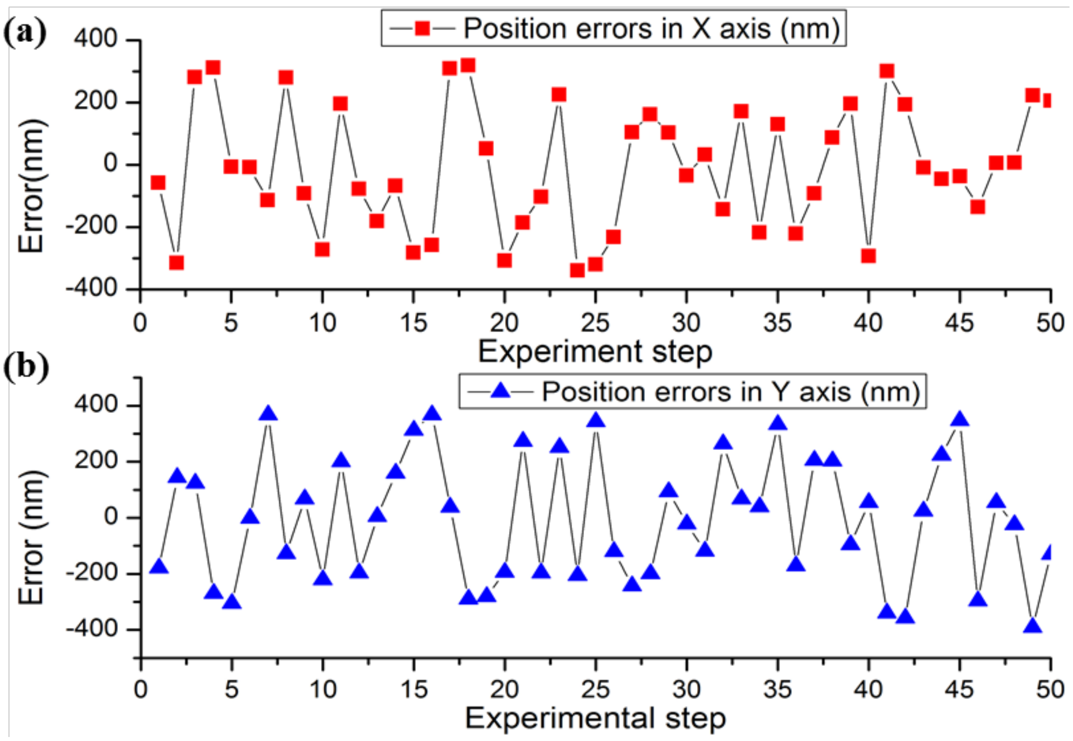

FIGURE 7. (a) Position measurement uncertainty in X axis. (b) Position measurement uncertainty in Y axis.

CONCLUSIONS

A novel method integrating ultra-precision machining and computer vision technologies is found to be feasible and promising for the precision measurement. The polar microstructure surface has been machined by single point diamond turning and single point diamond broaching processes which ensure the machining errors which can be controlled in high precision level. A series of experiments have been conducted to evaluate the positioning measurement accuracy. The experimental results show that the proposed measurement method is able to achieve 200 nm level of uncertainty. It is hopefully to be applied in workpiece positioning and machine tool repeatability in the future.

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