Surface Encoder Based on the Half-shaded Square Patterns (HSSP)

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A surface encoder based on the Half-shaded square pattern (HSSP) is presented. The HSSP working as reference grid is composed of the straight lines which are easy to be fabricated and make measuring time short. Since the periodic cell is separated in ON/OFF by the 45 ° straight line, the duration from the starting point of scanning to the first rising edge and the duty cycle of the pulse train vary with respect to the position of the starting point. And the relationship between X and Y position and the duration, and duty cycle is described in the simple linear equation. Therefore, it is possible to measure X and Y position with the measured duration and duty cycle without calculating load. Through the test set-up, the feasibility of the proposed surface encoder was verified. Also the future works for improvement of performance were suggested.

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NOMENCLATURE

D = duty cycle
T = period of the pulse train
τ= duration of the pulse
T_0=duration from the starting point to the first rising edge
V= scanning rate
L= length of the square

1. Introduction

Various kinds of planar positioning systems have been developed in the field of precision manufacturing and measurement.[1-4] The most outstanding displacement sensor for these systems is the laser interferometer whose dynamic range is up to 10^9 under well-defined environment, but it requires large space for via-optic components and its operating condition is too strict to apply to general metrology. Therefore, these features make the whole measurement process using laser interferometers bulky. Especially, the metrology problem due to allocation of the optical elements requires at least 9 interferometers to measure 6 DOFs(three translation and three rotation) for the precision stages such as wafer stepper, therefore the initial implementation cost for the whole process is very high. Therefore, we propose the surface encoder based on the half-shaded rectangular patterns which can be fabricated easily and cheaply.

The previous researches on the surface encoder have been reported by Wei Gao.[5-8] Their surface encoder consists of two fundamental elements: a sinusoidal grid, which is referred to as the angle grid, and a two-dimensional (2D) slope sensor. The angle grid has a three-dimensional (3D) micro-structured surface, which is a superposition of sinusoidal waves in the X-direction and the Y-direction. The sinusoidal profile of the angle grid surface is designed to have spatial wavelengths of 100 μm and amplitudes of 100 nm in both the X-direction and the Y-direction. Also the area of the grid surface, which determines the measurement range of position, is designed to be from several tens of millimeters to several hundreds of millimeters in diameter. Since the angle grid surface is used as the reference of position measurement, it is necessary to fabricate the sinusoidal surface with a high accuracy (sub-micrometer level for the wavelength and nanometer level for the amplitude) over a large area.[9, 10] But, the high precision fabrication methods usually requires high cost and it is not easy to expand the area of the grid surface keeping its accuracy uniform. Furthermore, as the surface profile is described as the sinusoidal function, this encoding methodology requires time consuming interpolation, which limits its measuring speed, to extract position. Therefore, we suggest the novel surface encoder whose reference pattern is easy to be fabricated and position measuring time is short compared with existing methods.

In chapter 2, we describe the principle of the proposed surface encoder including detailed description of the Half-shaded square pattern (hereafter abbreviated as HSSP) which is composed of the straight lines only and methodology to measure XY position. The experimental set up and the fundamental test results to validate the feasibility of the proposed methodology are given in chapter 3. Also we propose several research topics to improve the performance and make measurement of the tilt motion possible using the proposed surface encoder in chapter 4.

2. Surface Encoder Using Half-shaded Square Patterns

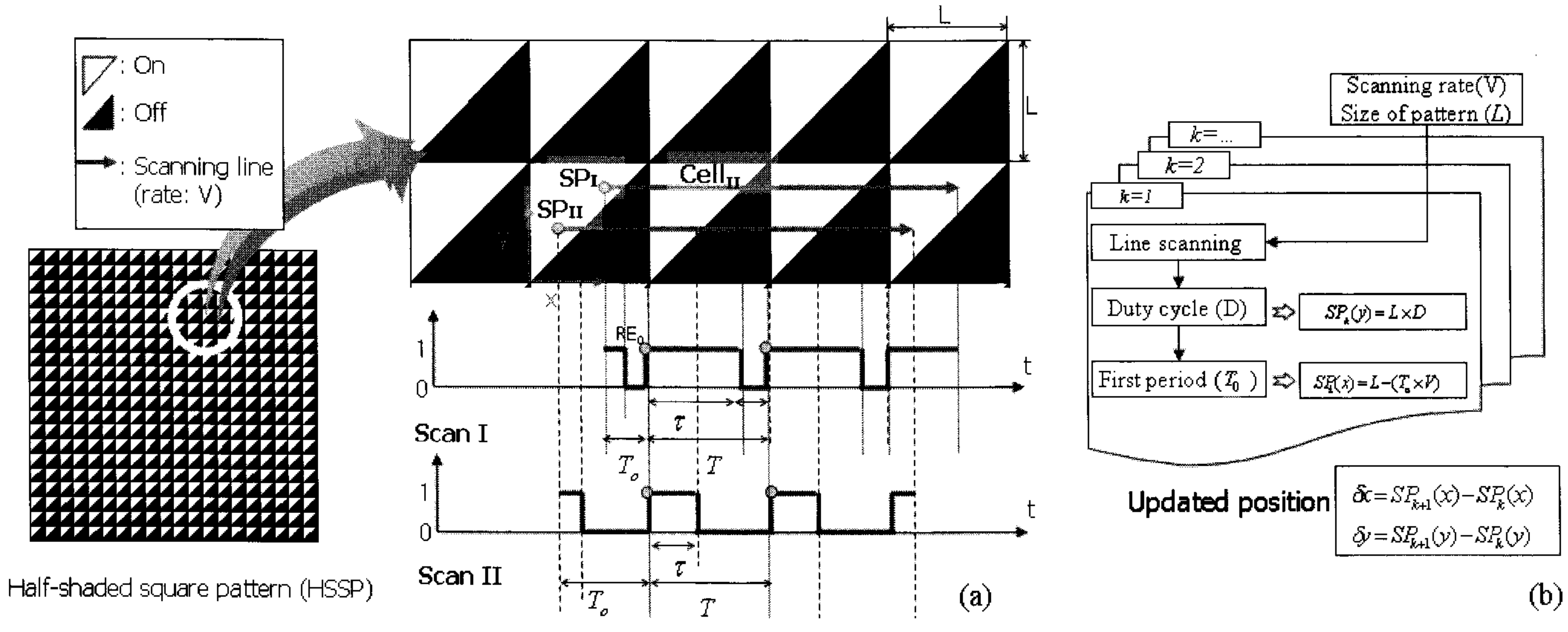

Fig. 1 (a) Half-shaded square pattern (HSSP) and the pulse trains for the each scanning, (b) position calculation algorithm

2.1 Half-shaded Square Pattern (HSSP)

In this study, the focused planar displacement sensor is based on the method of counting pulses which defined as digital signal such as ON/OFF. Therefore, we propose the reference grid, which generates ON/OFF signal with respect to the movement in the plane and provides two-axial position information with single kind of pattern repeated periodically. The HSSP given in Fig. 1 has the features as follows :

- Topological straight lines
- Periodic patterns with simple shape
- Separation of ON/OFF by 45° line in a cell
- Position-dependent duty cycle of the generated pulse

As the pattern is composed of the multiple half-shaded rectangles, it is easy to fabricate and to expand the operating range. The distinguished merit of this pattern is that the duty cycle of the pulse changes linearly according to the position in Y-direction due to 45° straight line in a cell. So, without extra calibration or interpolation, it is possible to measure two-dimensional position. The detail measuring principle for each axis is described in the next section.

2.2 Measuring Principle

The position-signal capture of the proposed surface encoder is realized using the line scanner, which scans the reference grid in high rate even if the grid remains stationary and the pulse train generated during the line scanning is given in Fig. 1(a). Differently from the conventional encoder generating the pulse trains whose duty cycle is constant, for the HSSP scanned with a constant sampling rate, we can obtain the pulse train whose period is constant and duty cycle varies with respect to Y position. Concretely describing, its duty cycle (D) and the duration (T_0) from the scanning starting point (SP) to the first rising edge vary proportionally with respect to the Y and X position of the SP, respectively. By measuring the duty cycle and the duration (T_0), the Y and X position can be measured. And the comparison of updated X and Y position of the SP for each scanning gives the translation of the reference grid in the plane. Fig. 1(b) shows the process of the position calculation. The scanning rate should be faster than the moving speed of the measured target.

2.2.1 X position

The X position can be calculated using the duration (T_o) from the SP to the first rising edge (RE_o) defined in Fig. 1. Regardless that the position of the SP in a cell is located on the ON or OFF, the same algorithm can be used to calculate the X position for every scanning due to the invariant position of the first rising edge. Since we know the scanning rate (V), we can extract X position of the SP in a cell by

$$SP(x) = L - (T_o \times V) \tag{1}$$

2.2.2 Y position

The Y position can be obtained by measuring the duty cycle of pulse train in cell II, because the duty cycle changes according to the Y position. Since the pulse for measuring duty cycle is periodic, any cycle after the first rising edge can be a candidate for calculation. But as the scanning rate determines the measuring rate of the sensor, the long scanning is unnecessary.

In Fig. 1(a), we can compare results for the scanning of the various Y positions and figure out the change of the duty cycle. The Y position is calculated by the simple equation like

$$SP(y) = L \times D \tag{2}$$

3. Experiments

Since our major object is to investigate the feasibility of the proposed surface encoder in this paper, the experimental setup is established just to verify the measuring principle. Therefore, instead of implementing the line scanner, we translate the reference grid, which is composed of the HSSP printed on the transparent plate and a mirror changing the position of the SP. This gives the same effect of the proposed line scanning methodology, but it has to be modified for the practical use.

3.1 Experimental Setup

Fig. 2 shows the optical layout and the developed experimental setup. The experimental setup consists of a reference grid (HSSP and mirror), linear actuator, micro-stage, and several optical elements. A laser diode (LD) with focusing lenses is used for a light source. The focused laser beam from the LD passes through the polarization beam splitter (PBS) with a λ/4 wave plate onto the grid surface covered by the transparent HSSP. As illustrated in the left of the figure, the laser light is reflected from the mirror under the HSSP for ON signal and is directed by the PBS into photo diode (PD). The reference grid is attached on the micro-stage which is mounted on the linear actuator for moving and line scanning in X-direction. And the Y position is adjusted by the micro-stage.

3.2 Experimental results

To verify the feasibility of the proposed surface encoder, the fundamental experiment which measures two-axial position while translating the reference grid was carried out. Fig. 3(a) shows the pulse train generated for the scanning when the SP is at the initial position. And Fig. 3(b), 3(c), and 3(d) show the measured pulse trains when we moved the SP in X-direction, Y-direction, and X&Y-

direction, respectively. From these results, it is verified that the duty cycle and the first duration change according to the variation of the X and Y position of the SP.

The movements from the initial scanning point are 1 mm in X-direction and 0.5 mm in Y-direction, and the calculated movements by Eq.(1) and (2) are 0.999 mm and 0.5619 mm, respectively. Although the HSSP is printed by the laser printing device with relatively high DPI, there may be the misalignment of the both coordinates, the pattern irregularity, and the signal loss, resulting in the about error between the measured values and the calculated ones. So, there is much room to be improved in the side of resolution and linearity. The pattern can be fabricated more minutely using lithography for reticle or mask pattern, FIB(Focused Ion beam), and nano-machining center etc. Therefore, we suggest the future works to improve the performance and to measure the tilt motion as well as the planar motion in next chapter.

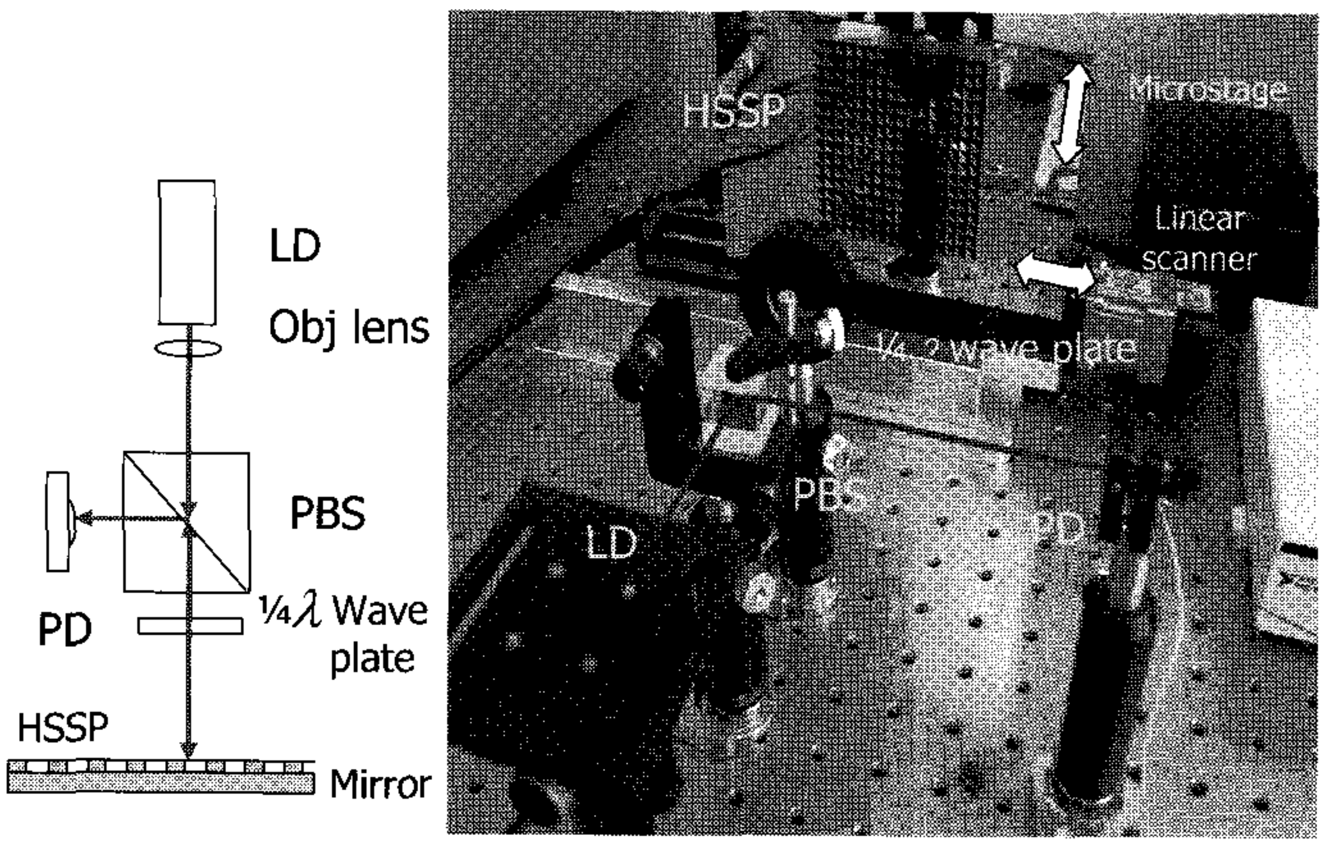

Fig. 2 Optical layout and experimental setup

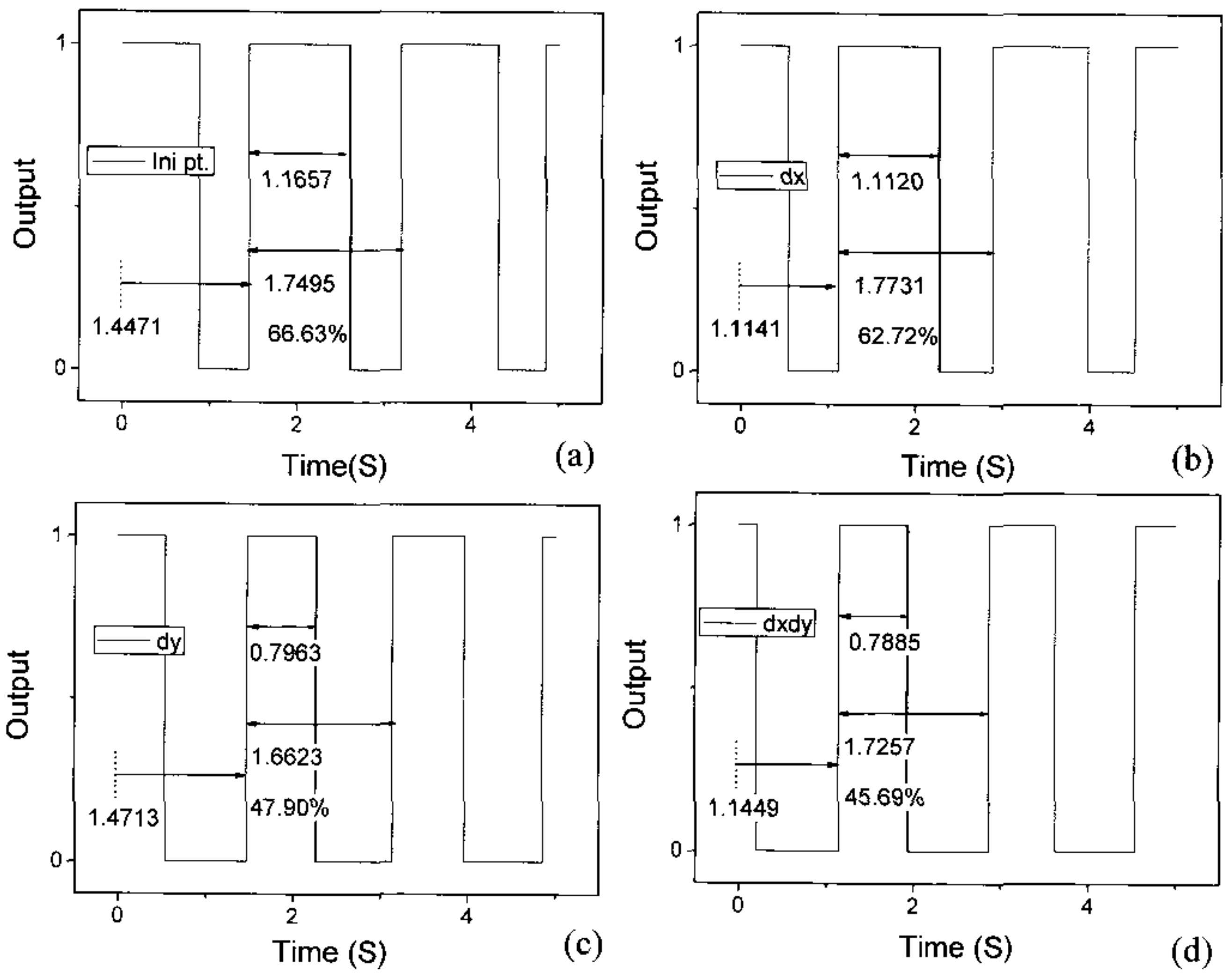

Fig. 3 Experimental results (a) at the initial scanning point, (b) after motion in X-direction, (c) after motion in Y-direction, and (d) after motion in X and Y direction. (scanning rate: 3 mm/s, L: 5 mm)

4. Conclusion & future works

A new surface encoding methodology based on the HSSP was presented. The HSSP is composed of straight lines which are easy to be fabricated and shortens the calculation time. Since the HSSP generates ON/OFF signals by the separation of 45° line in a cell, the X and Y position can be calculated by measuring the duration from the starting point of scanning to the first rising edge and the duty cycle of the pulse train. As the relationship between the moving range and the measured information is linear, the calculation process is very simple. Experimental results demonstrated that the proposed surface encoder is a feasible system for X and Y position measurement. But for a practical position measurement system, there are several things to be considered. Therefore, we suggest the critical issues to be considered for the performance improvement as follows :

- Scanning system with high/constant rate, and high linearity
- Compensation for the effect of the beam size on the border line
- Optimal size ratio between cell and beam spot waist
- Calibration of the pattern error and interpolation in the HSSP
- Algorithm to count the passing times of the crossing borders
- Methodology to measure tilt motion with a single line scanning

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