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Position measurement of a 3-DOF inchworm using a vision system

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Abstract

In this paper, we propose the position measurement of a 3-DOF (degree-of-freedom) inchworm using a vision system. From the experimental results, the resolution is about 5 μm. The 3-DOF inchworm does not use any guide mechanisms, and it has unlimited working area. The vision system therefore is suitable for the position measurement. The proposed method employs an inexpensive USB camera which has 2048 x 1536 effective pixels. Since the observed area is 60 mm x 45 mm, the resolution is about 30 μm. The position of the inchworm is calculated by the position of circular marks on the inchworm. The position of the mark is detected by using circular Hough transforms. For obtaining a high resolution position measurement, the moving average calculation is used. The advantage of this method is a large measurement area with 5 μm resolution. This system is applicable for the position compensation of the 3-DOF inchworm.

resolution, inchworm, measurement, vision system, piezoelectric actuator, positioning, feedback control

1. Introduction

A multi-axis positioning system is essential to ensure desktop manufacturing which enables savings in energy, space, and resources. A three degree-of-freedom (3-DOF) inchworm which obtains submicron accuracy along a large working range (50 mm x 50 mm) is developed [1]. The inchworm consists of piezoelectric actuators (piezos) and electromagnets. The non-excited electromagnets sequentially move by the deformation of the piezos, and the inchworm realizes linear and rotational displacement.

Precise position measurement is an essential part of error compensation. In previous works, optical displacement sensors were used to measure the position of the inchworm [2]. The measurement range of the sensors however was much smaller than the working range of the inchworm. Some sophisticated measuring systems using laser interferometry can measure the position with nanometer resolution [3, 4].

This paper deals with the position measurement of a 3-DOF inchworm using a camera vision system. After the structure of an inchworm and a camera vision system are described, the camera vision system measures the trajectory of the inchworm. Then the resolution of the measurement system is evaluated.

2. 3-DOF inchworm

A 3-DOF inchworm consists three stacked piezos and three electromagnets as shown in Figure 1. An equilateral triangle is formed with three piezos. The piezo is 20 mm long, and the cross section is 5 mm x 5 mm. It extends 17.4 μm by the applied voltage of 150 V_{DC}. Electromagnets are attached to the vertices of the triangle. One electromagnet is not excited, and the others are excited. The electromagnetic force of an electromagnet is approximately 5 N at 10 V_{DC}. The non-excited electromagnet which is a free electromagnet moves by the deformation of two connected piezos. After one electromagnet moves, another electromagnet is free and moves. In short, one of the three electromagnets is free and moves by the extension or contraction of the connected piezos. The control signals are generated by a computer and applied to the piezos and electromagnets through amplifiers. One control cycle is 1 s.

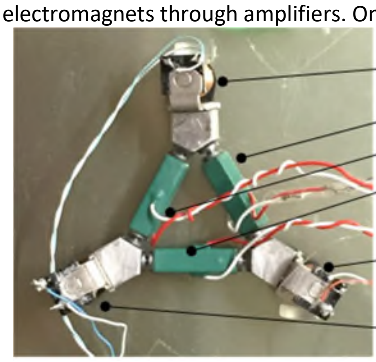


Figure 1. 3-DOF inchworm

3. Camera vision system

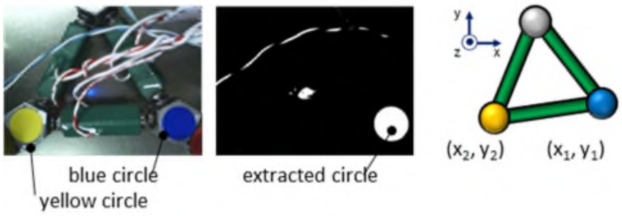
A USB camera (2048 x 1536 effective pixels) is used. Although the framerate of the camera is 15 fps (frames per second), images of the inchworm are captured by a computer every 2 s. Since the observed area of the vision system is 60 mm x 45 mm, the resolution is about 30 μm. The captured images are processed by a computer (CPU: Intel Core i5-2400, clock: 3.10 GHz, memory 8 GB). Different color circular marks 8.0 mm in diameter are affixed to the electromagnets. The experiment is conducted in a room where lighting conditions are not controlled. The circles are found by using circular Hough transform of Matlab. The radius and the x, y coordinates of the circles are calculated. The processing time is approximately 1 s.

Figure 2 shows an example of the image processing. The blue circle in Figure 2a is extracted as shown in Figure 2b, and the central position is determined. The position of the inchworm is calculated after one control cycle is completed. As the central positions of the two circles are (x_1, y_1) and (x_2, y_2) as shown in Figure 2c, the position (x, y) and orientation (θ) of the inchworm are calculated by the followings.

$$x = \frac{x_1 + x_2}{2} \quad (1)$$

$$y = \frac{y_1 + y_2}{2} \quad (2)$$

$$\theta = \tan^{-1}\frac{y_1 - y_2}{x_1 - x_2} \quad (3)$$



(a) original image (b) processed image (c) coordinate

Figure 2. images and coordinate of vision system

4. Experimental results

4.1. Displacement measurement of the inchworm

While the inchworm linearly moves in y-direction, the trajectory is obtained by the proposed system. The voltage applied to piezos is 90 V, which determines the displacement of the inchworm for one control cycle. After one control cycle is completed, the camera vision system obtains the position and orientation of the inchworm. The results are shown in Figure 3. The inchworm moves 500 μm in y-direction within 50 cycles (approximately 100 s). The inchworm also changes its position in x-direction and angle in θ-direction. Fluctuations in the y-displacement data result from the camera vision system, since the displacement per cycle is approximately 10 μm. Although there is not traceable measurement system in the rotational displacement of the inchworm, the position and orientation are measured.

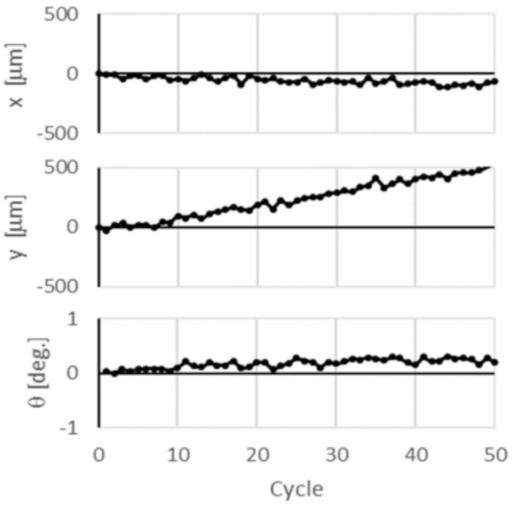


Figure 3. position and orientation of inchworm measured by camera vision system

4.2. Evaluation of camera vision system

In the experiment, optical and mechanical disturbances affect the resolution of the position measurement. Fluctuations in the position measurement is large compared with the theoretical displacement of the inchworm. Therefore, the position of the stationary inchworm is measured, while the inchworm keeps its position.

Figure 4 shows raw data and moving averaged data in x- and y-direction. The resolution of the position measurement of the stationary inchworm is about 30 μm. The moving average is calculated by adding 128 data and dividing the sum by the total number of the data (128). The number of data is determined in order to obtain 5 μm resolution.

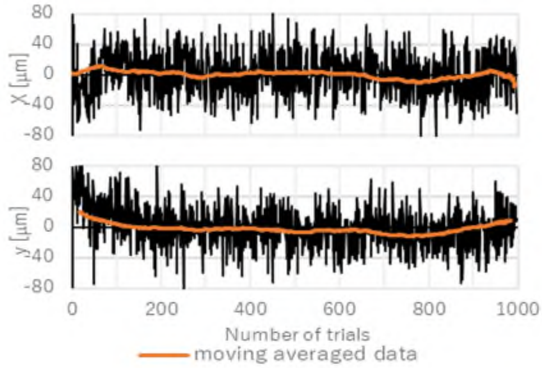
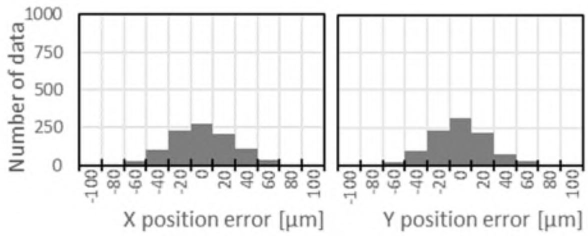
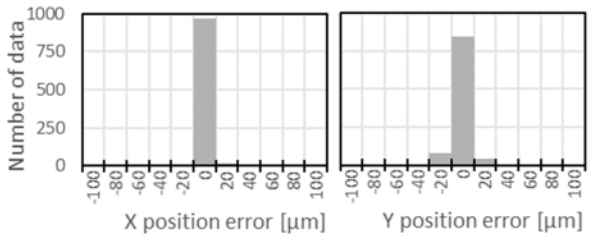


Figure 4. position of the stationary inchworm measured by camera vision system

Figure 5 shows histograms obtained from Figure 4, and each histogram contains 1000 data. Figure 5(a) shows histograms of the raw data. The standard deviations for x- and y-direction are 27.2 μm and 26.6 μm, respectively. Figure 5(b) is obtained by the moving average calculation. The standard deviations for x- and y- direction are 4.6 μm and 5.7 μm, respectively.



a) raw data



b) moving averaged data

Figure 5. histogram obtained with a stationary inchworm

5. Summary

This paper described the position measurement of an inchworm with a vision system. The system could measure the position and orientation of the inchworm. The resolution of the system was approximately 5 μm.

In future works, a high performance computer is introduced in order to reduce measurement time. A high resolution camera is used in order to improve the resolution. The position and orientation of the inchworm measured by the proposed system are used to compensate the motion of the inchworm.

References

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