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Improved Artificial Vision Algorithm in a 2-DOF Positioning System operated under feedback control in micromachining

O. de Francisco Ortiz[1], H.T. Sánchez Reinoso[2], M. Estrems Amestoy[3], J. Carrero-Blanco[4]

[1,2,3,4] Dpto. de Ing. de Mat. y Fabricación, Univ. Politécnica de Cartagena, C/ Doctor Flemming s/n, Cartagena 30202, Spain

oscar.defrancisco.ortiz@gmail.com

Abstract

Research about micromachining systems have focused on the study of the machining strategy, the machining parameters and the errors of the cutting tool. In these systems, closed-loop positioning systems play a very important role in achieving the required accuracy. In this communication, the vision control system used in previous studies has been further improved by means of a novel artificial vision algorithm in order to achieve better results of precision and repeatability. In the experiments carried out in this study, a camera lens has been used, which jointly moves with the XY platform of the micro-machine tool, in order to capture an optimized image related to the location represented in the form of an illuminating series of LEDs on a 326ppi smartphone screen . This study differs from previous works by using an enhanced artificial vision algorithm method and the implementation of auto alignment process between the LCD and the camera, in order to reduce errors and achieve a significant improvement in the stability of the system. As a result it is obtained a significant precision and repeatability improvement.

Keywords: Machine tool; Precision; Position control; Accuracy; Micro-milling; Artificial vision.

1. Introduction

This paper presents an improved method for generating motion commands in a 2 degree-of-freedom (DOF) vision-based position control system. The digital camera lens, which jointly moves with the XY platform of the micro-machine tool, captures an optimized image by image processing relative to the location represented on the screen of a smartphone with 326ppi resolution by illuminating series of LEDs. In recent years different methods based on the development of positioning algorithms analyse a pattern shown in a photo image LCD screen [1]. In a further research Montes and Ziegert [2] developed an improvement on the control system, with refreshed images related to a given machining operation. Most recently, a vision algorithm for controlling the position in micromachining was implemented based on the detection of the colour intensity transition [3] thus showing uncertainty associated to the precision measurement procedure on the order of 0,26μm. This communication goes further to introduce an improvement of the Artificial Vision Algorithm (AVA) along with the implementation of the auto-alignment between the LCD and the camera in order to reduce the errors introduced in above mentioned study. As a result a more accurate and robust method is developed in order to provide an increase in the stability of the system.

2. Methodology

As seen in Fig 1. the control tool path shown on the smartphone screen is based on a pattern of lighted LEDs in red colour on a black background. Each lighted LEDs pattern represents a set of possible target positions for a cutting operation.

Note that one LED is selected as the origin of the reference positioning system.

The Artificial Vision Algorithm (AVA) can be summarised as follows:

1) Gap distance definition. The gap distance between the lighted LEDs is defined in order to get a minimum unit for controlling the displacements in the positioning system. For example, a LCD screen with 326ppi resolution, has a minimum gap between lighted LEDs of 77.91 μm.
2) Image magnification and mask building from a Region of Interest. Once the photo has been taken by the camera, all the lighted LEDs on the screen are magnified and turned into a set of pixels with different intensity levels according to a bitmap format. Since the whole image is reduced to a mask the image processing is accelerated. Note that the resolution of the HD Camera is higher than the one related to the screen.
3) Threshold and advanced morphology modules. They basically filters the color features and perform high level operations to remove small particles and obtain a fine point location by using LabVIEW. Afterwards, for a discrete-valued function related to the intensity grade of each pixel B(i,j), where *i* varies in pixels units over a horizontal array of pixels, with $i \in [1,m]$; the coordinates x_g and y_y of the center of mass of each set of pixels can be obtained as:

$$x_g = \frac{\sum_{i=1}^{n}\sum_{j=1}^{m} x_{i,j} \times B(i,j)}{\sum_{i=1}^{n}\sum_{j=1}^{m} B(i,j)} \quad (1)$$

$$y_g = \frac{\sum_{i=1}^{n}\sum_{j=1}^{m} y_{i,j} \times B(i,j)}{\sum_{i=1}^{n}\sum_{j=1}^{m} B(i,j)} \quad (2)$$

Average distance between axis displacements. This step consists of processing the image and calculate the average for each axis displacement. The average displacement depends on the differences between the x_g and y_g coordinates, worked out after and before the movement. Therefore, for two consecutive images related to a given axis displacement (k+1 and k) the average distances d_x and d_y can be achieved according to:

$$\overline{d_x} = \left| \frac{\sum_{i=1}^{n}(x_{g\,k+1,i} - x_{g\,k,i})}{n} \right| \qquad (3)$$

$$\overline{d_y} = \left| \frac{\sum_{i=1}^{n}(y_{g\,k+1,i} - y_{g\,k,i})}{n} \right| \qquad (4)$$

where *k* is the number of processed image; *i* and *j* are the number of row and columns of the matrix, respectively; and *n* and *m* are the overall number of evaluated rows and columns, respectively.

4) Aspect ratio between the LCD screen and the camera images. Assuming the above mentioned LCD image distance of 77.91 μm, the aspect ratio controlled by the artificial vision algorithm *G* is evaluated as:

$$\bar{d}_{pixel} = \sum_{k=1}^{k} d_{k+1,k} \qquad (5)$$

$$\bar{G} = \frac{\bar{d}}{Mesh} \times Gap\ distance \qquad (6)$$

where $\bar{d}$ is the average difference between the coordinates of the center of mass of two consecutive lighted LEDs within the same captured image. We calculate the mean value with all pixels in x and y axis. All $d_{k+1,k}$ values obtained, where *k* and *k+1* are denoted as the number of two consecutive pixels, respectively. Having measured *dx* and *dy*, the next step consists of transferring their coordinates from pixel image-units into metric units using the evaluated related aspect ratio of $\bar{G} = 729{,}407\ pixel/mm$.

The final step consists of activating the necessary stepper motors so as to make the micromachining axis achieve the target point coordinate on the smartphone screen.

2.1. Auto-Alignment

One of the most important error source to account for is associated to the alignment process of the screen. Since we used a smartphone screen located and fixed by two screws on the low bench. Nevertheless, the LCD (mobile phone) is not positioned exactly in the same position at each test thus resulting a misalignment between the display and the demonstrator.

Fig. 1 depicts an example of illuminated pixels that are shown in the images captured by the camera. These pixels create calibration lines that can be calculated so that the deviation of the LCD screen is obtained. As it is shown in Fig. 1, the auto-alignment process consists of constructing a mesh along the *x* and *y* axis are taken, based on the deviation evaluated from the camera image.

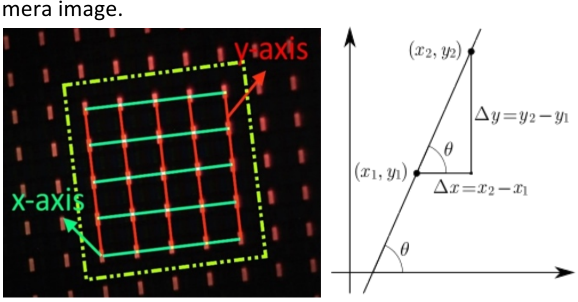

Figure 1. Software function diagram for auto-alignment

Therefore, five calibration lines are used for each axis to minimize the error so that the LCD screen deviation is obtained from the average of ten calibrated lines.

Finally, equation (9) is implement into the AVA in order to calculate the average slope from the x-axis and y-axis slope equations.

$$m_n = \frac{\Delta y_n}{\Delta x_n} \qquad m_m = \frac{\Delta y_m}{\Delta x_m} \qquad (7)$$

$$\bar{m}_x = \frac{\sum_{n=1}^{n} m_n}{n} \qquad \bar{m}_y = \frac{\sum_{m=1}^{m} m_m}{m} \qquad (8)$$

$$\bar{m} = \frac{\sum_{n=1}^{n} m_n + \sum_{m=1}^{m}\left(m_m - \frac{\pi}{2}\right)}{m+n} \qquad (9)$$

3. Experimental example and result analysis

Several tests were performed over 2x2 gap pattern using the updated AVA implemented in LabVIEW. The simulation consisted of testing a 5mm X-Y axes movements using 10 steps of 0,5mm each. Each travel has been repeated 30 times in both forward and backward directions, according to the VDI/DGQ 3441 standard.

Fig. 2 shows the results obtained in above mentioned simulation. It is noted that each line represents the average of the 30 repetitions at each direction.

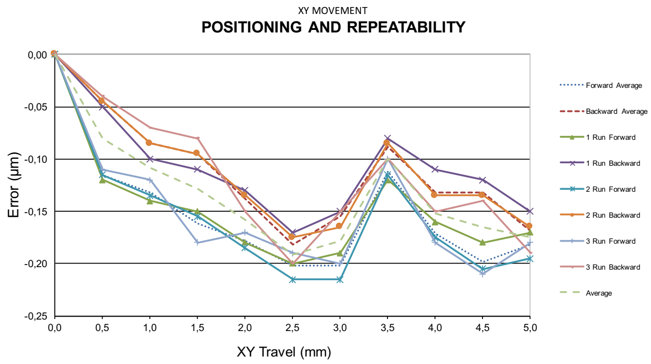

Figure 2. Test results

4. Conclusions

Position control of a Micro Machine Tool based on artificial image processing method with a screen-camera micro-positioner has been improved. The original artificial image processing method previously developed has been enhanced by means of a new step: the introduction of new image processing modules including an auto-alignment process which has reduced the errors introduced in previous studies. As a result it has been developed a more accurate and robust AVA which increase the stability of the system. As a consequence, a significant improvement for precision (0,22 μm) and repeatability (0,02 μm) have been achieved with respect to those obtained in previous research [3].

Future work will include the implementation of the global reference coordinate system using an auto-focus and mounting a laser end effector with collimator lens in the micromachining.

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