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Accuracy and repeatability estimation in micromachining using an enhanced artificial vision algorithm for controlling the screen LED positioning on a LCD screen

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Abstract

Study of micromachining systems have become an important area of interest over the last decades. Within this issue, the closed-loop positioning systems play an important role when high machining precision should be fulfilled. In this proceeding, the vision control system of a demonstrator used in a former research workytpooo is improved in order to achieve better accuracy and repeatability results on the micro-machine tool. In this demonstrator an improved camera objective is mounted so that it jointly moves with a XY micromachine platform. The aim of the camera is to capture the image of a given LED, which is turned on a 326 ppi smartphone in order to serve as a coordinate position of the cutting tool path. The current study differs from a former camera-screen research in using an enhanced algorithm which is capable to work out the position of two lighted LEDs, which are uniquely detached by a LED gap, thus improving the resolution of the closed-loop control system. The developed artificial vision algorithm uses an advanced filtering method to detect and improve the light intensity and shape form of the captured image of the lighted LED. Having obtained the estimated position of the LED within the machining limits of the smartphone screen, the closed loop system is tested by a Back Step Test in order to evaluate the precision and repeatability of the micromachine tool. A significant accuracy improvement in micromachining positioning systems has been assessed, thus illustrating the viability of the enhanced artificial vision algorithm.

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

1. Introduction

The development of micromachining systems is considered an interesting issue of interest within manufacturing processes. Research on this systems have been focused on studying the cutting tool strategy, cutting parameters, workpiece material and cutting tool errors [1-3]. The positioning control of a micro-machine tool (MMT) are mainly based on closed-loop systems. Even though the current electronic devices mounted in closed loop systems provides robust position control, they are considered expensive in low-cost micro-machine tools applications. Other methods are based on the development of positioning algorithms that analyse a pattern shown in a photo image [4]. Within this approach, Montes et al. [5] developed an improvement on the control system, whereby a LCD screen was used as a reference system, with refreshed images as regards the type of machining operation.

2. Methodology

In a former research work, the authors obtained the precision and repeatability errors in a MMT prototype when different and sequential images were taken from a camera opposite-mounted in front of a LCD smartphone screen, as seen in the model shown in Fig. 1 [6].

The control system consisted of displaying an image according to a given target tool path on the LCD screen and capturing the target position by the camera. Thus, the AVA processes the captured image in order to produce the necessary movements of the MMT axes, which jointly move with the camera.

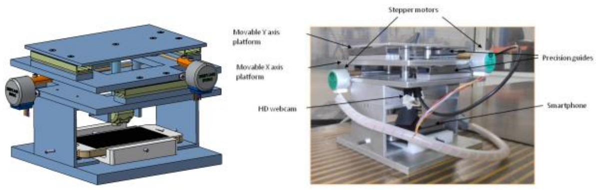

Figure 1. 3D model and the final MMT demonstrator used in the study.

The control tool path shown on the smartphone screen was based on a pattern of lighted LEDs in red colour on a black background. Each lighted LEDs pattern represented a set of possible target positions for a cutting operation (i.e. a micro drilling operation). The Artificial Vision Algorithm was developed on the basis of considering a gap of ten not illuminated LEDs between two consecutive lighted LEDs, on a control position template represented on the smartphone screen. The type of camera used along the study and the algorithm did not let us to use a closed distance between lighted LEDs, because the image was not sharp enough. In this study, an Artificial Vision Algorithm was developed in VBA in order to filter and magnified the image of a lighted LED on the smartphone screen. Due to the limitation of the camera resolution, the captured image of the lighted LED was not sharp enough and only a set of pixels was obtained as the representation of a lighted LED. Moreover, it is assumed that the smartphone image distance between two lighted control LEDs was known (i.e. 0.7791 mm is the screen gap between two consecutive lighted LEDs in a 326 ppi screen), the aspect ratio controlled by the artificial vision algorithm could be assessed:

$$\overline{G}_{k+1,k} = \frac{\text{Gap distance}}{\overline{d}_{k+1,k}} \qquad (1)$$

where $\overline{d}_{k+1,k}$ was the average difference between the centre of mass coordinates of two consecutive lighted LEDs within the same captured image. The AVA allowed us to work out the measured distance in pixel-image coordinate units and turned it into µm units by means of the known value of $\overline{d}_{k+1,k}$.

2.1. Enhanced AVA

With the enhanced AVA, the lighted LEDs have been processed in both, a 3×3 gap pattern (i.e. two LEDs gap between lighted LEDs) and a 2×2 gap pattern. The enhanced *AVA* has been implemented by means of the LABView application installed in a laptop. The laptop has been connected to a NI-USB-6001 data acquisition card, which generates logic outputs treated by a pre-amplification power stage. Finally, the necessary feedback for controlling the position of the workpiece is given by the USB Webcam connected to the laptop. The laptop sends the 3×3 and 2×2 image lighted LEDs pattern so that it is shown by the smartphone screen. Fig. 2 shows the above mentioned electronic device scheme.

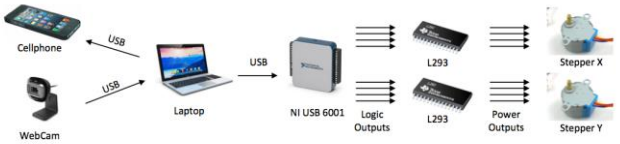

Figure 2. Electronic device scheme used for controlling the machine axis position

When the smartphone shows a 3×3 gap pattern and the camera captures an image of the pattern the laptop initiate an image treatment process (ITP) and the centre of mass calculation of each lighted LED on the pattern.

Figure 3. Image Treatment Process scheme

The ITP consists of conducting the following steps):

1. Original Image: Image Capture of the smartphone LCD through the webcam.
2. Color Plane Extraction 1: From the original RGB format image the extraction is performed through a RGB-Red Plane format.
3. Image Mask 1: Whereby a mask is applied to the image in order to scan only a 5x5 pixels mesh, which are placed in the middle of the original image. With this mask blurred vision errors are avoided on the image borders.
4. Threshold 1: The threshold pixels from the original image are rectified to override a possible pixel border raise due to a wrong focus adjustment in the camera.
5. Adv. Morphology 1 (Small Objects Removal): Noise removal into the image.
6. Adv. Morphology 2 (Border Objects Removal): Removal of possible trimmed pixel into the edge of the mask.
7. Particle Analysis 1: Calculation of the centers of mass of the overall pixels in the treated 5x5 matrix image.

An example of the final filtered and enhanced image obtained by the ITP is shown in Fig. 3.

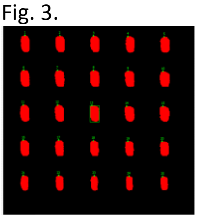

Figure 3. 5x5 matrix enhanced image of a 3×3 gap pattern

3. Experimental example and result analysis

Two tests were performed over 3×3 and 2×2 gap pattern using both the AVA implemented in VBA and Labview. The experimental study has been carried out on the MMT demonstrator shown in Fig. 1, which mounts a webcam (Trust©1280×1024 pixel) and an Iphone 5S. Two stepper motors (ST28, 12V, 280 mA) moves two precision guides (IKO© BSR2080 50mm stroke), each connected to one ball screw/nut (M3). The smartphone LCD screen has a definition of 1136×640 pixels. Both stepper motors are controlled by the digital signal outputs of a low cost NI-USB-6001 data acquisition card. The output signal of the NI-USB-6001 are treated by a pre-amplification power stage composed of two L293 H bridge.

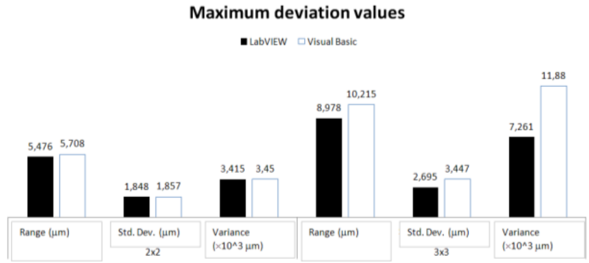

Figure 4. Maximum deviation values comparation between Labview and VBA implementation of the AVA algorithm.

As seen in Fig. 4 the results offered for the 2×2 pattern are considered quite similar. Meanwhile the results for the 3×3 pattern offers significant lower values for the range and for the variance, which means lower dispersion of results.

5. Conclusions

The results of the actual research demonstrate that the programed method develop using Labview + AVA algorithm vs VBA can be used in order to increase the complete system performance and stability. Moreover, has been The modification of the gap distance between the camera to the LCD screen and distance between two illuminated leds (3 or 2 vs 10 in the previous research study) achieved a decreased of the aspect ratio (µm/pixel) and thus, a positioning accuracy improvement. The uncertainty related to positioning accuracy has decreased from 1,522µm to 0,26 µm.

The next steps are the implementation of an end-effector (laser) and verify the real positioning accuracy against the theoretical one. Due to the dimensions an electronic microscope will be used for the verification.

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