The development of inclination measurement by using the imaging based autofocus method

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Abstract

The path scanning methods frequently use in the large area inspection. The inspection accuracy is easy affected by the inclination of the inspection target when the inspection area is too large (length > 100 mm). It will result to the defocus of captured image and enlarge the inspection results. In conventional, the additional sensor or focus associated device is used to maintain the focus status of lens during the inspection or measurement. In usually, the additional devices are expensive and it doesn’t suit each application. In this paper, the imaging base autofocus method was used to measure the 2 dimensional inclinations. And this paper presents a numerical method to compensate the scanning path. It can decrease the defocus status during scanning or measurement. The presented method based on the existed 3 axis optical inspection system, it didn’t need additional device or component. It will improve the inspection accuracy and doesn’t increase the system cost.

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Selection and/or peer-review under responsibility of the Organising Committee of the ICOPEN 2011 conference

PCAS: 06.20.Dk, 07.05.Pj

Keywords: ballscrew contact angle, digital projection method;

1. Introduction

In recent 20 years, the development of automatic optical inspection system risen very fast. The large area scan was frequently used because the field of view (FOV) of a single imaging sensor is small. The large area scan is easy influenced by the target inclination. If the target is inclination, the captured image will be defocus in some position. It will result in the measurement errors. In general, the target surface is flat and the measurement system only needs to consider the inclination. In this paper, the autofocus method is used to measure the inclination. The surface of test target was assumed is flat. And the defocus will not occur when the target is horizontal.

The autofocus methods are frequently used on the image capture application, ex. camera, video camera and microscopy etc. The autofocus also can be used to measure the height and 3D profile besides associate the user to obtain focus image. For example, the confocal microscopy uses the autofocus method to scanning the sub-micro 3D profile.

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Autofocus sensors are used for an automatic accurate adjustment of the right image position [1]. There are several position setups and techniques used for the task. The various solutions are quite different in its performance and complexity of the technical realization. The main performance criteria of focus sensors are 1. accuracy, 2. dynamic range, 3. speed. The principles which are mostly used are as follows. 1. astigmatic sensor, 2. confocal sensor, 3. chromatic confocal sensor, 4. prism sensor, 5. triangulation and 6. software-based image processing systems. All above sensors used the optical principle. The software-based imaging processing system is most frequently used because most autofocus sensors were used on the imaging system. The imaging system usually owns an imaging processing system which can capture, record, process and analysis the images. It implements the focus procedure by compare the image contrast and recorded the lens position. But its performance was limited by the computing performance and imaging sensors performance. Therefore, its focus speed is lower than the above method. But it does not need any additional device and component, its cost is lower. In recent years, the FPGA development is very fast. Some imaging system uses the FPGA to pre-process image before the image system read image. It can decrease the computing loading of imaging system and improve the focus performance. The above most methods need additional optical system which will increase cost and need additional space to setup besides the software-based imaging processing system. Therefore, the conventional imaging system doesn’t use them only when they need high focus speed and accuracy.

Moreover, the imaging system can add the focus function by add additional sensor such as capacitance sensor, inductance sensor, LVDT etc. Because the sensors are able to measure the distance between the lens and measurement target, the imaging system can maintain focus status by maintain the distance to constant. But the additional sensor means the additional requirement of cost and space. In recent years, the development of autofocus system is continuing proposed [2][3]. But it not suits this paper, this paper need low cost technique. Therefore, this paper presents an inclination measurement method and a compensate technique. They are based on the imaging system and no other device need be added.

2. System structure and methods

![Schematic diagram of system structure.](image)

2.1. System structure

The presented autofocus and compensation methods are base on a 3 axis imaging system. The system includes a 3-axes motorized stage, a telecentric lens (0.8 X ~ 4.5 X), red light LED light source. The movement range of x axis, y axis and z axis are 600 mm, 500 mm and 200 mm separately. Its driven system combines the ballscrew, DC servo motor and rotation encoder (count = 10,000). The pitch of ballscrew of x axis and y axis is 10 mm and z axis is 4 mm. The 3-axis stage was controlled by the personal computer through the motion card. The resolution of 3 axes are 1 μm, 1 μm and 0.4 μm. But the accuracy of 3 axes are about 10 μm. In this paper, the variation of our telecentric lens magnification is continuous. Therefore, the focus position is not fixed for different magnification. In
order to decrease the influence of magnification variation, a reference plate was used to calibrate the magnification before autofocus. Therefore, the magnification is almost the same for test in different times.

In general, the telecentric lens has large imaging depth. But the imaging depth of the magnification variation type telecentric lens is small. Therefore, the autofocus function is important.

2.2. Autofocus method

During the autofocus procedure, the lens usually was moved to near the focus position in the first, and then the lens was moved a fixed range, ex. 0.2 mm. During the fixed range movement, the image captured system and PC continuously capture image and record the stage position. And the focus position usually is within this fixed range. If the focus position is not in the fixed range, the system will never find the focus position. In general, the movement range is \( \ell \), the captured interval is \( dz \), then the captured times is \( n = \ell / dz \). In ideal, to find the position of the largest image contrast can carry out the focus position because the contrast is highest when the lens is focus. But many factors will affect focus result, they include the accuracy and repeatability of stage, the simultaneous performance between imaging captured system and PC, noise of imaging sensor. Therefore, this paper combines the discrete image capture method [4] and curve fitting method [5][6]. The discrete image capture method means the image captured system capture the image in the fixed position or fixed interval. During capture, the stage is static. After capture, the stage moves to the next position. And the system repeats the movement and capture until the focus procedure is finish. Because the timer of PC is not very accurate and the stage is continuously move during the focus procedure, the imaging contrast and stage position are not mapping perfectly. It will result to some error, the repeatability of focus result is worse. Although using the discrete captured method will spend much time, but it can make sure the imaging contrast and stage position are mapping almost perfectly.

Because the discrete captured method was used, some interpolation method was needed to improve the focus accuracy. In this paper, we select some point near the highest contrast and define the stage position is \( x \) axis, imaging contrast is \( y \) axis. Then using curve fitting methods to find the focus position of highest contrast. In this paper, the least square method for polynomial regression was used to curve fitting.

2.3. Inclination measurement

In this paper, the definition of plate inclination was defined as 2 rotations along the \( x \) axis and the \( y \) axis. The schematic diagram shows as Fig.2. Fig.2 (a) is the 3-dimensional graph and Fig.2 (b) is 2-dimensional graph. The positions of \( x \) and \( y \) axes of 4 points are known and the position of \( z \) axis can be obtain by autofocus. Consequently, the inclination can be obtained from the position of 4 points. The inclination \( \varepsilon_y \) is

\[
\varepsilon_y = \sin^{-1}\left(\frac{P_{2y} - P_{1y}}{P_{1x} - P_{2x}}\right)
\] (1)

And the inclination \( \varepsilon_x \) is

\[
\varepsilon_x = \sin^{-1}\left(\frac{P_{3x} - P_{4x}}{P_{3y} - P_{4y}}\right)
\] (2)

Where the \( P_{nx} \) is the \( x \) axis position of \( P_n \), \( P_{ny} \) is the \( y \) axis position of \( P_n \) and \( P_{nz} \) is the \( z \) axis position of \( P_n \).
2.4. Compensation of scanning path

\( P_n (x_n, y_n, z_n) \) is the scanning path in large area scan test and \( n \) is the scanning number. This paper used the homogeneous transformation [7] to transform the path. The homogeneous transformation usually used on the robot control and multi-axes machine center control. The original path refer to \((xyz)_0\). When the target is inclined, the path \( P_n (x_n, y_n, z_n) \) becomes respect to \((xyz)_0\'). Therefore, let the path transform to with \((xyz)_0\), the inclination will be compensated. If the test plane is horizontal, the coordinates \((xyz)_0\) and \((xyz)_0'\) are overlap. The pose matrix of the \((xyz)_0'\) with respect to world coordinate frame \((xyz)_0\) is

\[
\begin{bmatrix}
C_{\theta_y} & S_{\theta_y} & S_{\theta_x} & C_{\theta_x} & 0 \\
0 & C_{\theta_x} & -S_{\theta_x} & 0 \\
-S_{\theta_y} & C_{\theta_x} & S_{\theta_y} & 0 \\
0 & 0 & 0 & 1 \\
\end{bmatrix}
\]

The expression \( P_n' \) of Eq. (4) refer to \((xyz)_0'\). It expression with respect to \((xyz)_0\) is given by the following transformation:

\[
0P_n = 0A_0 0P_n'
\]

To transform all paths by Eq. 3 and Eq. 4, the compensation of scanning path is complete.

3. Experimental result

Some tests for focus curve and autofocus were shown in this extended abstract. Full test will show in final full paper.

3.1. Focus curve

The imaging depth is different for different magnification. In general, the imaging depth is large for low magnification and the incident light is large and easy to focus. Figure 3 shows the focus curve for different magnification. They were obtained by recorded the image contrast and z-axis position simultaneously. The imaging depth is short when the magnification is high. But the contrast is lower for high magnification because of the incident light is low. Moreover, the low incident light will result in the contrast enhance must be higher. It will result to the noise increment. And the contrast of image will become unstable even thought the stage is static. In principle, to compare the contrast can obtain the focus position. The position of highest contrast is focus position. In real, the records of contrast and z-axis position are not simultaneous. During the position record and image capture, a small delay time (<10 ms) is existed. Therefore, the recorded position is not the real position for each image. Fig. 4 shows the focus curve which was obtained by the discrete captured method. There are 3 sampling interval (0.005 mm, 0.01 mm and 0.02 mm) be used in this figure. Their focus curve is similar.
3.2. Autofocus results

Fig.5 shows the curve fitting result for 5 points and Fig.6 shows the curve fitting result for 7 points. Table 1 shows the curve fitting results by 5 different calculated point numbers. Their point data is the same, just number is not the same. Their results are also similar. Therefore, in further test the each test uses 7 point to curve fitting. The noise of imaging sensor will affect the stability contrast even though the stage is static. Increasing the capture time can decrease the noise, but it will increase the test time. Therefore, how to select the sampling interval, stage movement speed and CCD camera is very important. If the noise is large, the autofocus will easy fail. The inclination can not be accurately measured.
4. Conclusion

This paper establishes a compensation method for large area scan in the inclined tested target. And an autofocus method based on 3-axis imaging system was also developed in this paper. The autofocus tests were complemented. It shown the measurement accuracy is about 0.01 mm. The performance can be better if the stage and imaging sensor is changed to better. The proposed method is suitable for inclination varying range over 0.01 mm.

Acknowledgements

Grateful appreciation is given to the National Science Council of Taiwan for financial support under grant number (99-2622-E-492-003-CC3).

Reference