Development of Noncontact Coordinate Measuring Machine implementing High Precision Optics and Precision Image Processing Algorithms of Subpixel Accuracy

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1. Introduction

The noncontact coordinate measurement technology has been considered as one of very important tools for the automation of inspection of the parts and products in industry. As the size of the parts and products becomes smaller and more precise, such as semiconductor, the needs for precision dimensional measurement with high accuracy and high precision has been increased. In this paper, a noncontact coordinate measuring machine has been developed; high precision optics head, precision motion stage, and the software of image processing algorithm. The optics head consists of high magnification optics units and illumination units, and the precision motion stage has been designed such that accurate scanning is obtained for the measurement objects. Auto focus imaging principle is implemented such as optimum focused image is captured by the proposed image focus measurement function, where optimum focusing distance is calculated and the optimally focused image is captured at the displaced capturing location. One of the key feature of the developed system is the precise and intelligent image processing algorithm for analysis of the measurement data. A new and precise image processing algorithm has been developed with subpixel accuracy. The developed image processing technique includes: various fine edge detection techniques, several feature scanning techniques. The developed system can be applied to various measurement/inspection processes in many practical application.

2. Precision Image Processing Algorithms

2.1. Auto Focusing

In vision inspection system, the focused image is required for precise detection. The defocused image inherently have distorted information of object, and aggravate the efficiency of edge detector. Thus the focus position providing the sharpest image must be calculated in advance. The optimum focusing position can be calculated by the image focus measurement function(IFMF), which is defined as in eq(1)

$$F(i,j) = \sum_{x=i-N}^{i+N} \sum_{y=j-N}^{j+N} ML(x,y) \quad \text{for} \quad ML(x,y) \geq T_1 \tag{1}$$

where ML(Modified Laplacian) has the form as

$$ML(x,y) = | 2I(x,y) - I(x-step,y) - I(x+step,y) |$$
$$+ | 2I(x,y) - I(x,y-step) - I(x,y+step) |$$
$$T_1 = Threshold$$

$I(x,y)$ is the gray value at x,y in image

In the developed system, sequential images are captured at the displaced capturing locations, and the IFMF finds the focused image. Fig.1 shows the sequential images and IFMF evaluation.

2.2 Edge Detection with Subpixel Accurcy

In an Area of Interest(AOI), edge detection is usually performed in the normal direction to the edge, where the AOI can be defined by the user. Fig.2 shows an AOI and edge search direction for line and circle feature scanning. After setting the AOI and the search direction, edge detection is performed with the Laplacian-Gaussian operator, funding the Zero Crossing. The Laplacian-Gaussian operator is defined as in eq(2)

$$\nabla^2 G(x,y) = \frac{1}{\pi\sigma^4}\left(1 - \frac{x^2+y^2}{2\sigma^2}\right)\exp\left(-\frac{x^2+y^2}{2\sigma^2}\right) \quad (2)$$

where σ is space constant.

At the zero-crossing location, the intensity can be modeled as the polynomial form as in eq(3)

$$F(r) = k_0 + k_1 r + k_2 r^2 + k_3 r^3 \quad (3)$$

where r is the coordinates of edge search direction

With the polynomial equation F(r), we can divide the pixel into 5~10. With the divided pixels, the edge detection is performed again and we can find the edge point with subpixel accuracy.
In this paper, various edge detectors with subpixel accuracy have been developed such as common edge detector ,closest edge detector and first edge detector. Common edge detector determines the best or strongest edge in the AOI; the first edge detector find the first edge of a given strength and direction that lies within the search region; and the closest edge detector locates the peak point on a curved edge in a given direction.

2.3 Feature scanning techniques

Developed system includes several feature scanning techniques such as line feature scanning, arc/circle feature scanning, and ellipse feature scanning. Feature scanning is composed of edge detection, feature analysis by Least Squares Technique for removal of noise or corrupted data. Fig.3 shows the procedure of circle feature scanning technique. When there exists noise in object, the result of feature scanning can be used to remove that noise or corrupted data. Fig. 4 shows the removal of noise or corrupted data and the result of re-analysis.
The measured Items such as point, line, circle and ellipse can be saved in the list type and the relationship between items can be calculated by the developed operation software. Fig.5 shows the developed operation software, which includes image I/O, motion control, auto focusing algorithm, etc.

3. Measurement System

The developed measuring machine consists of the optical part with CCD camera, camera controller, illumination, motion part for motorized wide range scanning, and software part for operating measurement system.
The image frame grabber is implemented for capturing CCD camera image, and a light controller is also used for the illumination control. The whole optical image processing are performed under Windows based image analysis and light control software developed.
For scanning wide range, a precision X-Y stage has been designed using linear scale, AC servo motor,. Z axis motion part also has been designed for the focus adjustment. The motion control is operated by the Windows based motion control software developed. Fig.6 shows the noncontact coordinate measuring machine developed.

4. Results and conclusion

The developed coordinate measuring machine has been applied to various features such as distance of lines and radius of circle of precise grid. The measurement process has repeated 10 times, and the result is shown in Fig. 7, demonstrating the performance.

The conclusion is as follows.

(1) A noncontact coordinate measuring machine has been developed, giving measurement feature with subpixel accuracy upto a few micrometer resolution.
(2) For scanning wide range of object, precision XY stage, Z axis motion part have been designed, and the measurement region can be easily selected by user-interactive software developed
(3) An auto focus technique has been implemented. The optimal focus position of CCD camera has been found very much effective in practical measurement application..
(4) Various edge detectors and several feature scanning techniques have been developed. These

tools can be used in many inspection applications with high efficiency.

Reference

1. Andres Huertas, Gerard Medioni, “Detection of Intensity Changes with Subpixel Accuracy using Laplacian-Gaussian Masks”, IEEE Trans. On Pattern Analysis and Machine Intelligence, Vol. Pami-8, No. 5, September 1986.
2. Eric Krotkov, “Focusing”, International Journal of Computer Vision, 1, 223-237, 1987

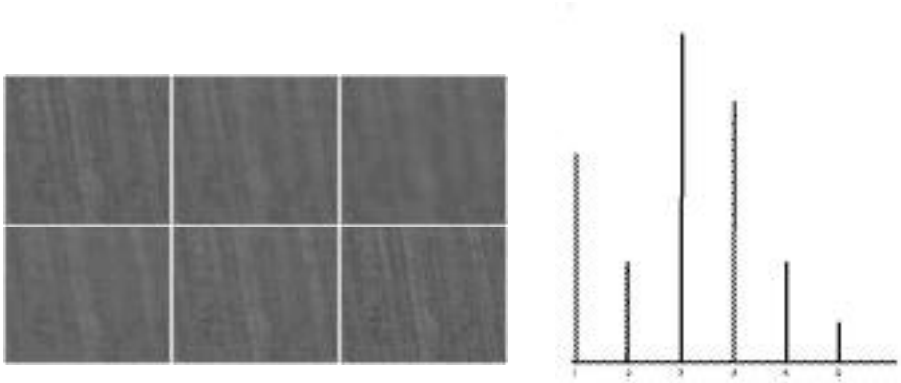


Fig.1 Sequential images with 100um step and result of IFMF

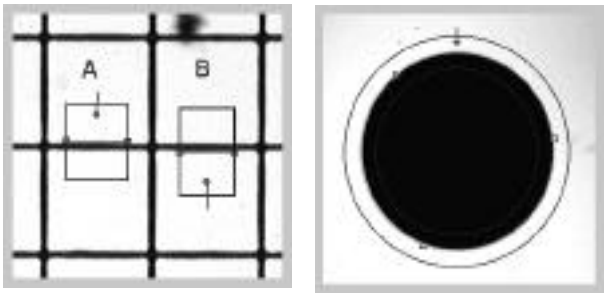
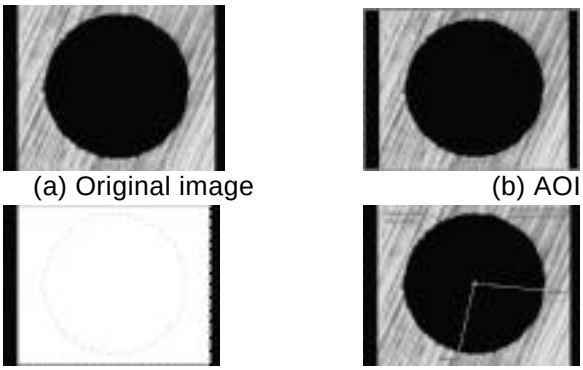


Fig.2 AOI and edge search direction for line and scanning technique



(a) Original image (b) AOI

(c) Edge detection (d) Result of analysis

Fig.3 Procedure of circle feature scanning technique

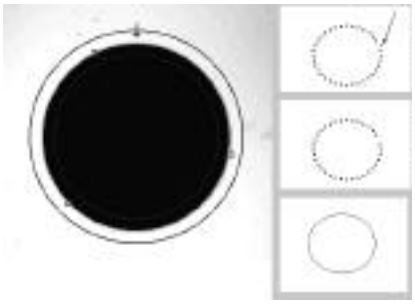


Fig.4 Removal of noise or corrupted data

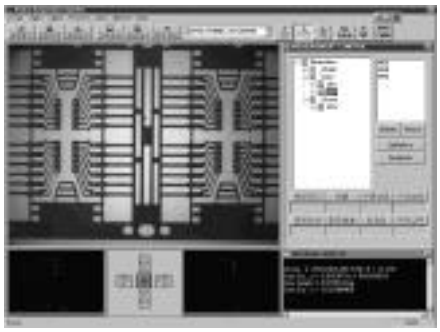


Fig.5 Operation software

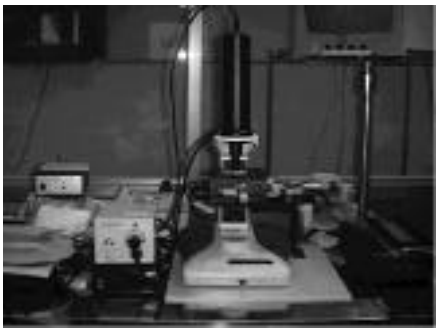


Fig.6 Developed coordinate measuring machine

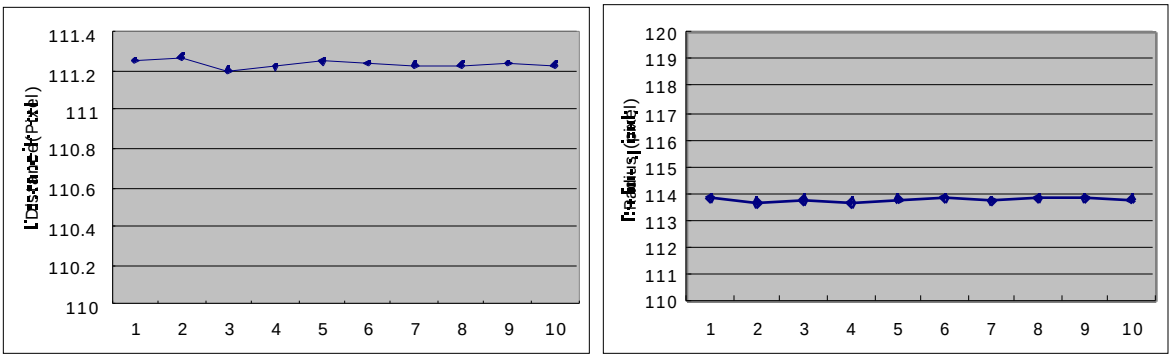


Fig.7 The result of line and circle analysis