Machine Vision Based Automatic Measurement Algorithm of Concentricity for Large Size Mechanical Parts

Jae Hong Shim[1] **and Tae Hyeon Nam**[2]

[1] Department of Mechatronics Engineering, Korea Polytechnic University, Siheung-city, Gyeonggi-do, 15073, Republic of Korea
[2] Department of Mechatronics Engineering, Graduate School, Korea Polytechnic University, Siheung-city, Gyeonggi-do, 15073, Republic of Korea

Abstract. In this paper, we proposed an algorithm of automatic measurement of concentricity for large size mechanical parts using machine vision technology. The proposed measuring method consists of the pre-processing and the measuring process. In the pre-processing process, we proposed a method for improving the image quality for accurate calculation. And in the measuring process, we proposed an efficient algorithm of concentricity measurement. Through a series of experiments, the proposed algorithm showed successfully the effectiveness of automatic measurement of concentricity for large size mechanical parts without using any additional measuring equipment.

1. Introduction

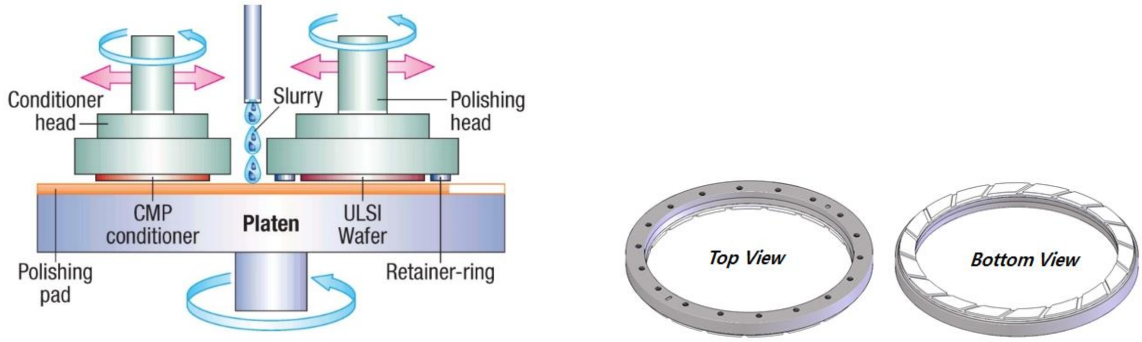
For machining, production and quality inspection of circular parts such as ring gauge, crank shaft and bore holes of automobile, retainer ring parts at semiconductor polishing process, the concentricity is very important considerations for quality control. Usually, manual dial indicator and three-dimensional measuring instrument have been used for measuring the concentricity of mechanical parts. However, if the measuring accuracy of the above instruments is μm or less, they are expensive equipment. In this paper we proposed an image-based algorithm for concentricity measurements as an inexpensive equipment [1-3].

In this paper, we obtained a concentricity of the circle by finding the center of the circle from any two points on the arc of a target circle based on the proposed algorithm proposed. In the preprocessing process, outline of the circle or the circle arc is obtained to specify two points on the arc through image processing. Through a series of experiments, the proposed algorithm showed successfully the effectiveness of automatic measurement of concentricity for large size mechanical parts without using any additional measuring equipment.

2. Pre-processing process of the input image

In this paper, we measured the concentricity of the retainer ring in CMP(Chemical-mechanical polishing) equipment for semiconductor wafer polishing as shown in figure 1.

In order to measure the concentricity of the circle of the retainer ring, it requires two points of inner circle and outer circle of the retainer ring. As the diameter of the outer circle of the retainer ring is about 360 mm, it is difficult to observe full circle within an image frame. Therefore, it should be observed in part for accurate measurement of the concentricity of large size mechanical parts as the retainer ring as shown in figure 2.



(a) (b)

Figure 1. (a) Head device of the CMP (b) retainer ring.

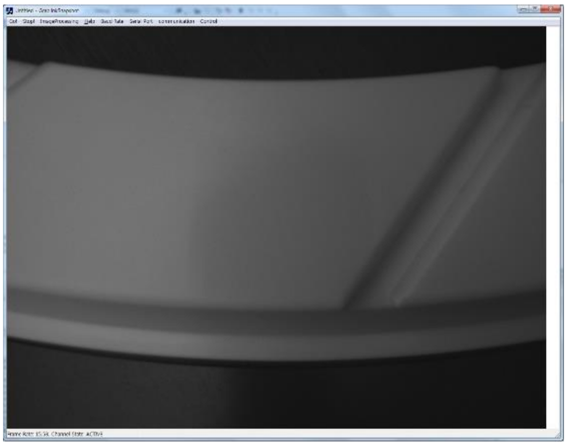


Figure 2. Image of section of a retainer ring.

Firstly, the object to be detected is set as a region of interest and binary operation is carried out to remove a portion other than the region of interest [4]. As the color of the objects in the image is white and the rest of image frame is black, we set the value of binary threshold as 250. When it check the binary image, clear image of circle can't be obtained because of pattern of the object surface, the influence of external interference as solar or illumination and shadows as shown in figure 3. And it is difficult to detect the correct border (edge) of the object as partly occurrence of holes.

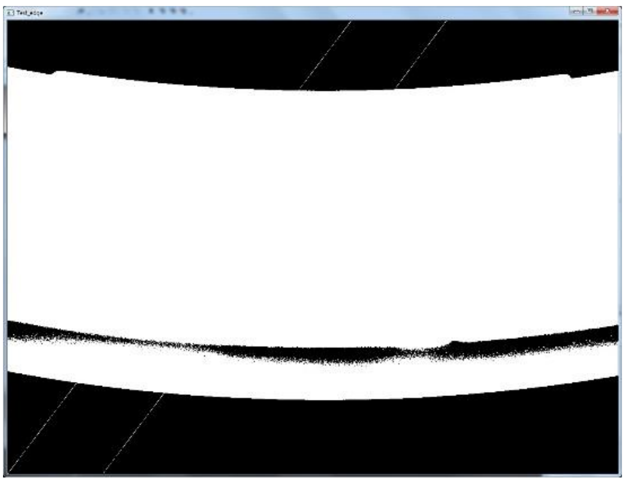


Figure 3. Firstly obtained image with noise and external influence.

The morphology technique was applied to decrease the effects of noise and holes [5-7]. As a result, the improved image was obtained as shown in figure 4.

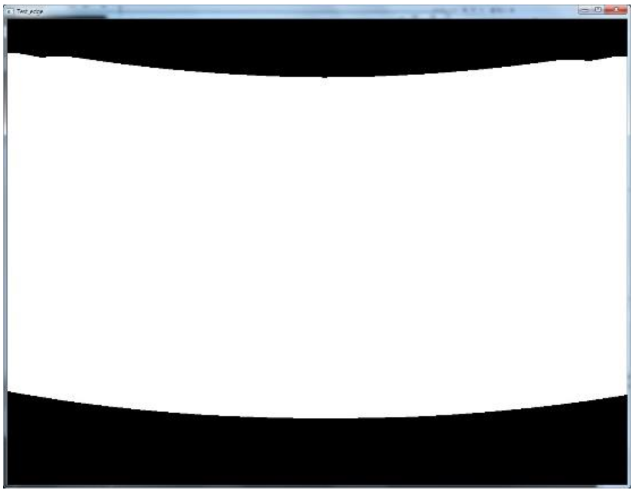


Figure 4. Improved image by using the morphology technique.

In order to obtain any two points of the inner circle and the outer circle of the object to be measured, the edge of image corresponding to the inner and the outer circles had to be extracted. We used the canny edge algorithm for edge detection. Particularly, the retainer ring has the material characteristics that it has engraved surface pattern and so its color image is relatively evenly distributed. Canny edge detection algorithm was selected as it has better performance of edge detection than the other edge detectors and can remove all the edges associated with the gray matter of the original image. Firstly, the Sobel mask is applied as (1):

$$\nabla \mathrm{f} = \begin{bmatrix} \frac{\partial f}{\partial x} & \frac{\partial f}{\partial y} \end{bmatrix} \tag{1}$$

where f is an two dimensional image.

And then, non-maximum suppression process is carried out to select a local maxima value. In order to obtain any two points of the inner circle and the outer circle of the object to be measured, the edge of image corresponding to the inner and the outer circles had to be extracted. Despite the pre-processing in the image, any part with non-edge may be detected. So it needs to remove these non-maximum. As a result, clean edge of the inner and outer circles of the target object was obtained as shown in figure 5.

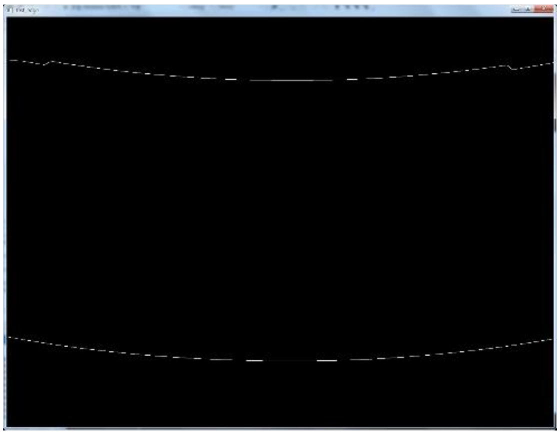


Figure 5. Edge image obtained by using the Canny edge detection algorithm.

3. Concentricity measurement algorithm

In this paper, since the diameter of a large size parts such as a retainer ring has close to 400 mm, we proposes a method of finding the center of the circle utilizing the similar triangle ratio about only a portion of the original image. Now, in order to measure the concentricity of a circular object, any two points are selected from the above edge detected image. As shown in figure 6, two y axis straight lines are drew to intervals of 200 pixels in the image and obtained the cross points of the coordinates between the y axis straight line and the edge of the circle in figure 5.

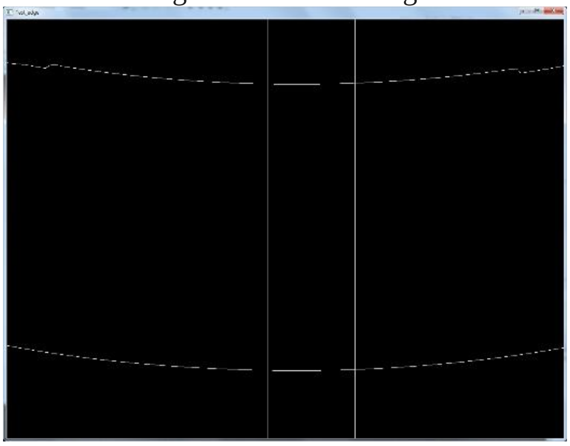


Figure 6. Cross points between two y axis straight lines and the edge detected.

Figure 7 represents the above mentioned method for finding the center of a circle.

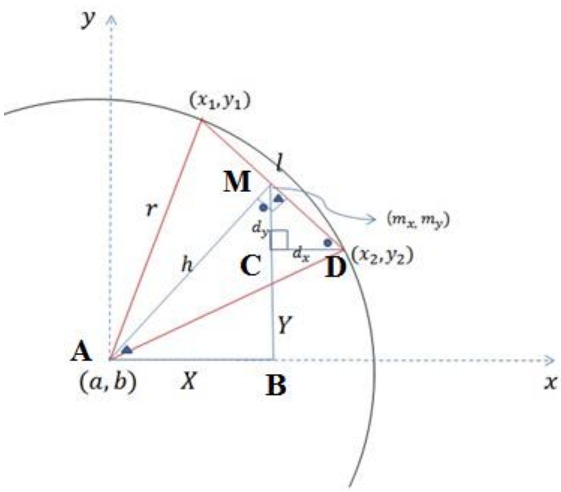


Figure 7. Schematic method of finding the center point of a circle using two points on the arc.

In order to obtain the center point (a, b), it should be find the center of the arc (m_x , m_y) and vectors X, Y. If radius of the circle is constant, △**MAB** and △**DMC** has the relation of similar triangles. Therefore, X and Y is obtained from (2) and (3), the center point a and b is found from (4) and (5):

$$\mathrm{X} = \frac{2\, d_y\, h}{l} \tag{2}$$

$$\mathrm{Y} = \frac{2\, d_x\, h}{l} \tag{3}$$

$$a = m_x \pm X \quad (4)$$

$$b = m_y \pm Y \quad (5)$$

4. Experimental results and discussion

In order to compare the accuracy of concentricity measurement with the proposed method, we measured concentricity of the retainer ring used in the experiment by using the high-precision contact-type three-dimensional measuring instrument of Roncorder EC 5100, and the measured concentricity was about 0.004mm. Using the proposed algorithm, the concentricity of the same retainer ring was measured as about 0.00903mm in case of using a camera having a resolution of 1280 pixels and its error range was 0.005mm. In case of using a camera having a resolution of 2560 pixels, the measured concentricity was approximately 0.00415 mm and its error range was 0.0001 mm. Table 1 shows the experimental results.

Table 1. Experimentally measured concentricity of a retainer ring by using the proposed algorithm.

Number of iteration	In case of using a camera with 1280 Pixels	In case of using a camera with 2560 Pixels
1	0.00903mm	0.004152mm
2	0.00903mm	0.004152mm
3	0.00903mm	0.007019mm
4	0.00903mm	0.004152mm
5	0.00715mm	0.004152mm
6	0.00903mm	0.005107mm
7	0.00903mm	0.004152mm
8	0.00903mm	0.004152mm
9	0.00903mm	0.004152mm
10	0.00903mm	0.004152mm

5. Conclusions

In this paper, we proposed an algorithm of concentricity measurement of large size mechanical parts by using the image sensor. Through a series of experiments, the proposed algorithm showed similar measuring accuracy compared with a high-precision contact-type three-dimensional measuring instrument(CMM). In addition, the proposed algorithm was capable of high-speed measurement within an average 0.1 seconds. Actually compared with the manual indicator or the three-dimensional measuring devices, the proposed machine vision-based concentricity measurement device is cheap and can be supported by a fast and precise measurement effect.

Acknowledgments

This paper was supported by Gyeonggi-do and Siheung-city under Industry-University Convergence Campus Outcome Utilization Project, a provincial government financial support program, Korea.

References

[1] Huh G M and Moon H Y 2003 The development of automatic measurement algorithm of concentricity and roundness using image processing technique *J. Control, Robotics and Systems* **9** **3** pp 227-235

[2] Zhang T Y and Suen C Y 1984 A fast parallel algorithm for thinning digital patterns *Communications of the ACM* **27** **3** pp 236-239

[3] Xie Y, Pang H, Wang C and Xaio S 2009 Small components concentricity measuring based on machine vision *Int. Symp. on Intelligent Information Systems and Applications* pp 522-525

[4] Shi B H and Wei Y H 2014 Detection method of optical fiber connector internal parts based on machine vision *Applied Mechanics and Materials* **568** pp 483-488

[5] Leta F R, Feliciano F F, Souza I L and Cataldo E 2006 Discussing accuracy in an automatic measurement system using computer vision techniques *ABCM Symposium Series in Mechatronics* **2** pp 645-652

[6] Chen M C 2002 Roundness measurements for discontinuous perimeters via machine visions *Computers in Industry* **47** pp 185-197

[7] Shankar N G and Zhong Z W 2005 Defect detection on semiconductor wafer surfaces *Microelectronic Engineering* **77** pp 337-346