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Evaluation of roundness error for cylindrical surfaces using vision system

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ABSTRACT

The roundness of cylindrical surfaces is mainly measured using two methods; contact and non-contact. Contact method of evaluation is widely used in industries. But nowadays the demand for the non-contact method is increasing. The roundness measuring instruments are mainly used by the automobile and manufacturing industries. This paper deals with the development of non-contact measuring instrument using machine vision to measure dimension and form error which are affordable to Indian industries and educational institutions.
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1. Introduction

Today the demand for higher accuracy and precision on the measurement of mechanical parts on size, form and position is increasing. In order to minimize manufacturing cost and time, dimensional and form tolerance inspection need to be done during the production of parts which in turn help in the correction of tolerance error and roundness deviation at that stage of the process itself [1]. To find roundness using non-contact method, Ganesha Udupa et al. developed an optical method on the basis of Confocal Scanning Optical Microscope [2]. Research works are carried out in the field of developing cost-effective instruments for automated measurement of roundness error by a non-contact method using a vision system [3]. Jia Liu et al. shows how we can accurately measure the shape of the taper holes in sub miniature parts with the help of photo-centric microscopes and CCD cameras [4]. Meng Fanwu et al. used a maximum inscribed circle method for finding the roundness error for internal bore. A more reliable and efficient algorithm has been developed, which gives a precise solution for the maximum inscribed circle without any error in a linearising way in optical methods [5]. A. Mohamed et al. developed a computer algorithm to find the roundness deviation by the non-contact method using image processing [6]. In this project, an attempt has been made to measure dimension and roundness error by the vision system using image processing technique

2. Measurement of roundness error (O)

For the automobile and manufacturing industries, roundness property is highly expected form for circular workpieces. Turning process is a method in which most of the circular shaped workpieces are made. In this manufacturing process roundness deviation can be formed due to non-alignment of jaw and chuck, angular error, inadequate lubricant, rotational imperfection or by deformed machine parts etc.

For finding the roundness error there are four internationally defined methods which include Maximum Inscribed Circle (MIC), Minimum Circumscribed Circle (MCC), Least Squares Circle (LSC) and Minimum Zone Circles (MZC). Roundness error by Minimum Zone Circle (MZC) is evaluated by including all the points and making two reference circles; one inscribed circle which is drawn inside and one circumscribed circle which is drawn outside the profile [7] as shown in Fig. 1 and is found out by determining the minimum radial separation of two circles (Fig. 2).

The Roundness Error (ΔZ), can be expressed as

$$\Delta Z = R\max - R\min \tag{1}$$

In the Eq. (1), ΔZ is the roundness error, R max is the maximum distance between the measured profile and minimum zone circle (MZC) and R min is the distance between the measured profile and the MZC.

Standard Equation of the circle is given by,

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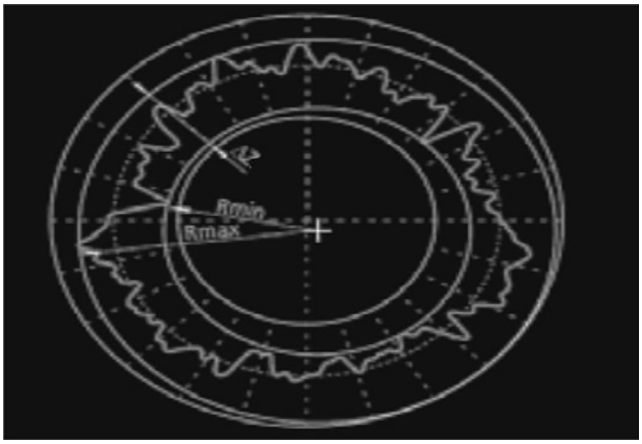

Fig. 1. Roundness profile.

$$(X-h)^2+(Y-k)^2=R \tag{2}$$

In the Eq. (2), h and k are the 'x' and 'y' coordinates of the center of the circle.

For every measured point the distance between point and circle center,

$$Ri=(Xi-h)^2+(Yi-k)^2 \tag{3}$$

3. Experimental setup

For evaluation of roundness error using a vision system, both the software are hardware part are integrated together. A platform is designed to keep the hardware components for the experiment (Fig. 3).

3.1. Setting up the test-rig

The test rig is set up with components which include aerostat bearing to have a frictionless non-contact rotation of the spindle. The use of aerostat bearing helps to reduce the mechanical wear and tear, unlike the conventional rolling element bearings. For achieving precise accurate rotary motion. A 4-bar pressure is being supplied to the aerostat bearing from an external source. A collet is used for holding the sample on the air spindle. For rotating the aerostat bearing a PK244-01AA Oriental stepper motor is used, which provides high torque, low noise, low vibration and has 1.80 resolution. Gears are used to transform motion from stepper motor to aerostat bearing. The stepper motor is controlled by Arduino Uno, which upon receiving the command from the computer, rotates the motor by 10 degrees. For the image processing techniques, a camera of 20 megapixels is used and kept horizontally focused on the sample which is mounted on the collet.

Fig. 3. Plug gage.

In this setup, nine samples of diameter 10 mm, 12 mm, 14 mm, 16 mm, 20 mm, 22 mm, 24 mm and 26 mm are used for the inspection process.

3.2. Image processing

After the image is taken and it is converted into HSV (Hue Saturation Value) and a mask is applied to remove the background and highlight the object. Then the resultant image is converted into grayscale and canny edge detection is applied to find the edges of the object. Then a rectangle bounding box is drawn to enclose the object. The width of the object in pixels is obtained.

Initially, the system doesn't know the conversion rate between pixel and microns. So, to get the measurements of the object in microns we need to calibrate the system. For the calibration, we are using a 20 mm h7 plug gage as shown in Fig. 4. We keep the plug gage and run the system, it rotates the plug gage 10 degrees for 36 times and the average of the width in pixels is equated to 20 mm. and the conversion rate is stored. Once the system is cali-

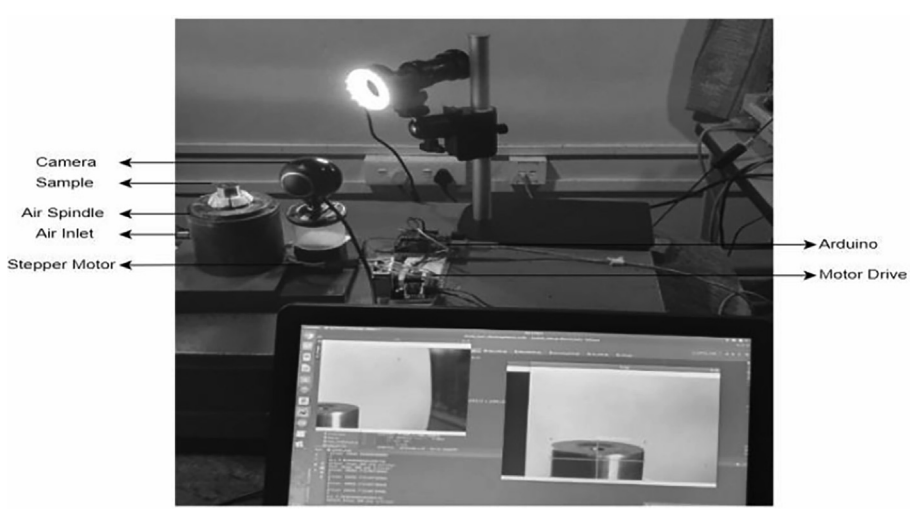

Fig. 2. Experimental setup.

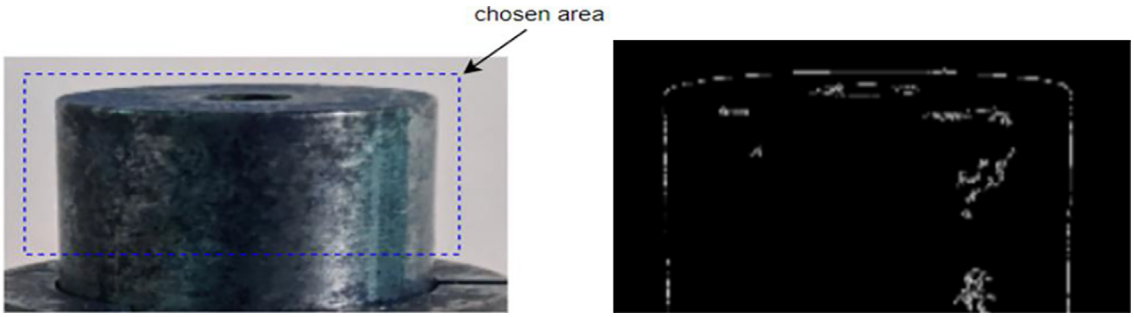

Fig. 4. (a) Chosen area for edge detection; (b) image after edge detection.

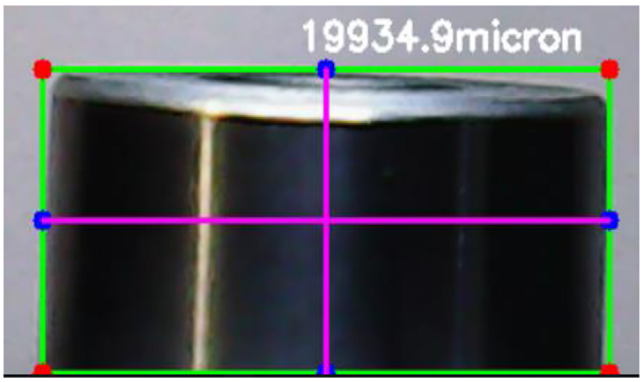

Fig. 5. Length (diameter) of sample 20 mm at 30 degrees.

brated, we can keep the object which has to be tested and the process is repeated but this time the width in pixels is converted to microns using the conversion rate automatically.

As shown in Fig we have sample which was chosen to do edge detection.

3.3. Section heading

In this process, data acquisition is achieved automatically. The sample is kept on the collet component is rotated by the air spindle. 36 images are taken in one rotation. Images of the sample were captured using a camera which is positioned horizontal and straight to the axis of In this experiment, for every 10-degree rotation, one image is captured.

Automatic measurement of dimension and form error of cylindrical object by a non-contact method using a vision system particularly vision system is a challenging task. To achieve accuracy and precision to the level of contact method we need better lighting condition for image processing.

4. Results

The experiment is successfully carried out using in-house manufactured nine samples of diameter 10 mm, 12 mm, 14 mm, 16 mm, 20 mm, 22 mm, 24 mm and 26 mm. The dimension of the sample is acquired using Image processing technique (Fig. 5). Here the length of the sample is equal to the diameter of the sample (Fig. 6).

For employing Minimum Zone Circle (MZC) method we have to convert diameter (length) of the sample at every 10 degrees to the radius. Table 1 shows the conversion of diameter to the radius of the sample 12 mm (Fig. 7).

Roundness error (O) calculation of the sample of 12 mm diameter using Minimum Zone Circle (MZC) is given below

O = Maximum Radius – Minimum Radius

= (6199.1–5996.55) μm

= 202.55 μm

Similarly, the roundness error calculation is done for all other samples in house is shown in Table 2.

After getting the result using non-contact method comparison was done using contact method using the same sample.

5. Conclusion and future works

In this paper, an attempt has been made to measure dimension and roundness error by the vision system using image processing technique. The main drawback of image processing technique is the edge detected changes with the illumination. To always obtain a proper edge detection, the illumination should be fixed. To achieve this we will be keeping the whole experimental setup in an enclosure and the lighting will be fixed in such a way that there are no shadows and reflections (Table 3).

The future work will be to evaluate form error without rotating the air spindle. This can be done by moving the object x-y table and focusing the camera from the top at the edge of the specimen and finding the radial variation of the object at various angles.

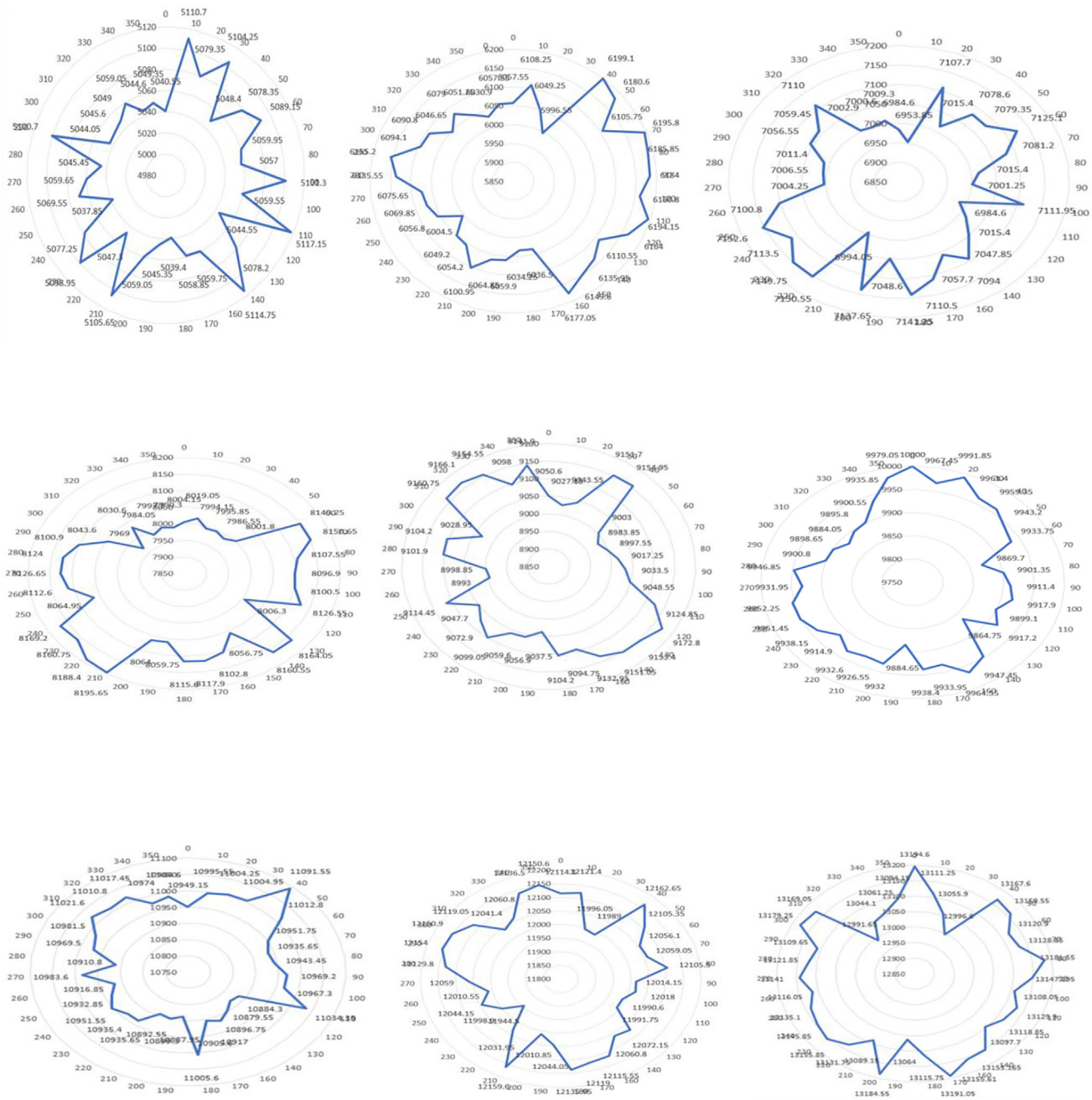

Fig. 6. Roundness profile of the samples.

Table 1
Length (diameter) of sample 12 mm at different degrees (●Only half of the sample measurements are shown).

Degree	Column A (t)	Column B (t)
0	12115.1	6057.55
10	12216.5	6108.25
20	12098.5	6049.25
30	11993.1	5996.55
40	12398.2	6199.1
50	12361.2	6180.6
60	12211.5	6105.75
70	12391.6	6195.8
80	12371.7	6185.85
90	12,368	6184
100	12321.6	6160.8
110	12388.3	6194.15
120	12,328	6164
130	12221.1	6110.55
140	12271.9	6135.95
150	12299.2	6149.6
160	12354.1	6177.05
170	12,073	6036.5
180	12068.5	6034.25

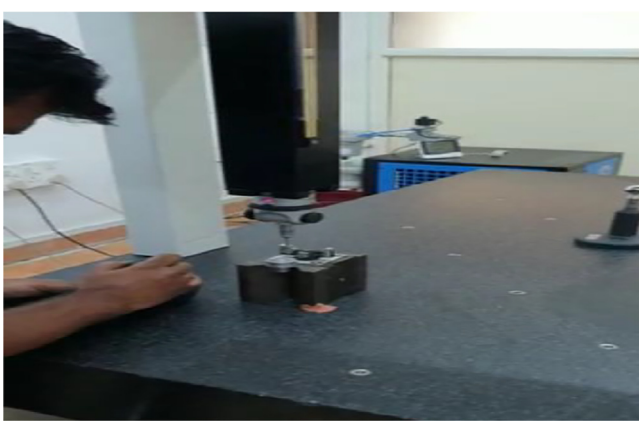

Fig. 7. Finding the radial deviation using CMM.

Table 2
Roundness error of samples by non-contact method.

Degree	Column A (t)	Column B (t)
1	10	77.3 μm
2	12	200.55 μm
3	14	196.75 μm
4	16	224.65 μm
5	18	188.95 μm
6	20	132.25 μm
7	22	210 μm
8	24	213.1 μm
9	26	200.95 μm

Table 3
Roundness error from CMM.

Degree	Column A (t)	Column B (t)
1	10	7.6 μm
2	12	14.6 μm
3	14	3 μm
4	16	12.7 μm
5	18	5.8 μm
6	20	5.4 μm
7	22	5.7 μm
8	24	3.7 μm
9	26	7.6 μm

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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