

Optimization Scheme of Measuring Accuracy of Bearing Seat Size Based on Machine Vision

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ABSTRACT

At present, the size measurement of industrial workpieces is mainly manual measurement and CMM measurement, which cannot meet the requirements of high precision, high efficiency and low error rate in industrial production at the same time. In order to solve the above problems, this paper uses monocular vision technology to propose an optimization scheme of workpiece size measurement accuracy based on machine vision, which takes the height and declination Angle between the camera lens and the workpiece as variables. Firstly, the image was captured by camera calibration correction, and morphological methods such as gray-scale, denoising, expansion and corrosion were used for image pre-processing. Secondly, features were extracted using double-threshold canny edge detection algorithm and connected domain algorithm. Finally, the bearing seat size was measured using the minimum external rectangle algorithm. The experiment shows that the higher the distance between the camera lens and the stage, the larger the error is when the image information can be collected completely. The greater the Angle between the center of the camera lens and the center of the workpiece, the greater the error; The device not only meets the precision requirements, but also has the advantages of fast response speed, which can meet the needs of industrial applications.

KEYWORDS

CMM Measurement; Optimization Scheme of Measuring Accuracy; Camera Calibration; Connected Domain Algorithm

1. INTRODUCTION

The bearing seat part of CNC machine tool is one of the main parts of connecting the shaft and the machine tool. It is the support and bearing system of the machine tool feed system after loading the bearing, which reduces the wear of the moving parts and improves the stability and working accuracy of the machine tool. However, in the production process, due to material, measurement technology and process reasons, resulting in the production of bearing seat size and the required size deviation, resulting in the accuracy of the feed system is out of whack, and even lead to bearing or screw damage. In order to solve the impact of poor bearing housing, in addition to improving the process, more efficient and high-precision measurement methods should be used[1].

With the rapid development of industrial production and manufacturing, the demand for high-precision and high-efficiency dimensional measurement is growing. Traditional manual measurement and CMM measurement can't meet the accuracy requirements and efficiency requirements of modern industrial production lines. Therefore, as a non-contact measurement method, machine vision dimension measurement has gradually become a hot research direction in the field of industrial

automation. In recent years, Bo JIAO et al.[2] proposed a subpixel level measurement method of flange size based on machine vision. After image processing, this method uses improved Zernike moment subpixel edge detection algorithm to reposition the flange edge. Ruxin ZHEN et al.[3] uses the saddle point method to locate the workpiece through binocular vision technology, and finally uses the plane vector to determine the size of the workpiece. In the image contour measurement method based on subpixel edge detection model proposed by Haoran RAN et al.[4], a subpixel detection model is established by mathematical method to calculate the pixel circumference of the contour curve. In the study of the algorithm for solving the maximum image tangent circle proposed by Wei LI et al.[5], the idea of image corrosion is used to remove edges layer by layer to solve the maximum image tangent circle. Liangyu LEI et al.[6] put forward the method of accurately measuring bearing edge points by using polynomial interpolation in the bearing inner and outer diameter measurement system, and optimized the technical route of edge acquisition. Although the above method can improve the measurement accuracy, it is more complicated and difficult to achieve in actual industrial production.

The bearing seat of CNC machine tool studied in this paper is used to support and allow machine tool parts (spindle, slider and other rotating parts) to move, and its dimensional accuracy is related to the stability and life of the machine tool. In order to improve the measuring accuracy, this paper proposes an optimization scheme for measuring the measuring accuracy of the bearing seat of CNC machine tool based on machine vision. Under different measuring schemes, the edge is extracted by image preprocessing, Canny edge detection and connected domain algorithm, and the maximum inner circle size of the bearing seat is measured by the minimum external rectangle algorithm. The measured position of the bearing seat is shown in Figure 1:

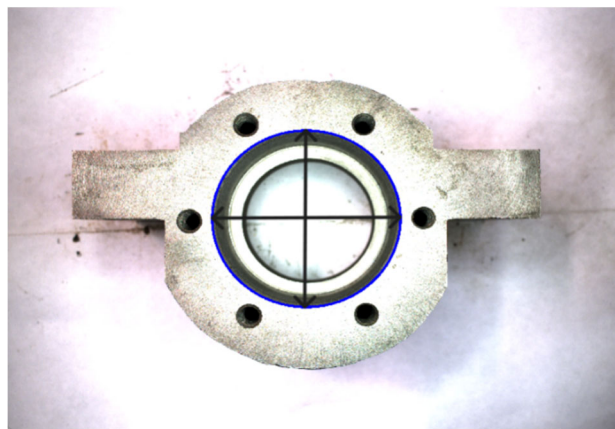


Figure 1 Diagram of maximum inner circle of bearing seat

2. EXPERIMENTAL SCHEME AND MEASUREMENT SYSTE

2.1. Experimental scheme

In the measurement process, the focal length of the camera and the declination Angle between the center of the camera lens and the center of the bearing seat have a great influence on the measurement accuracy[7]. In order to adapt to the industrial production site and improve the measuring accuracy of the bearing seat, the height of the camera lens from the bearing seat (that is, the focal length of the camera) and the declination Angle between the center of the camera lens and the center of the bearing seat were selected as variables, and the measuring accuracy optimization scheme was designed:

(1)The height of the camera lens distance from the stage is a variable, and the height is respectively 305mm; 355mm; 405mm.

(2)The Angle between the center of the camera lens and the center of the bearing seat is a variable.

In the optimization scheme, scheme (1) when the height of the camera lens from the stage is 305mm, the image collected by the camera can include the whole bearing seat, and then increase the height by 16.4%; Solution (2) Because the declination Angle between the center of the camera lens and the center of the bearing seat is difficult to accurately control, it is set to gradually increase the declination Angle in the same direction.

2.2. System composition

In the experiment, monocular vision technology was used to establish the size measurement device of the bearing seat, which mainly included the industrial COMS color camera -- Hikang camera, optical lens, LED ring light source, computer and camera bracket[8]. The image acquisition device is shown in Figure 2:

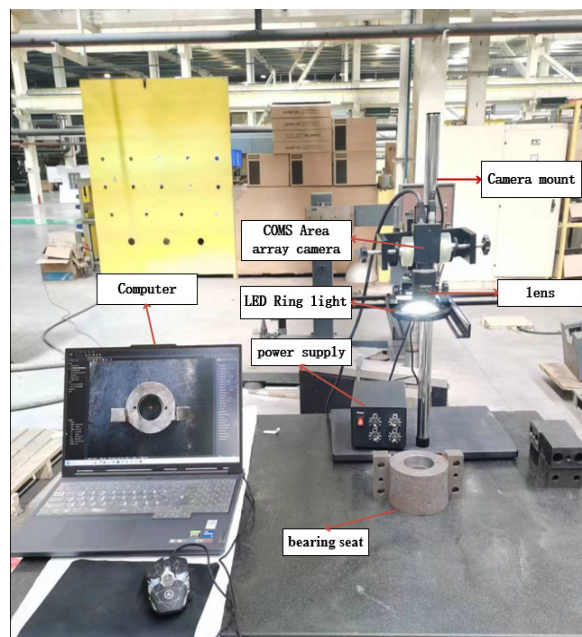


Figure 1 Image acquisition device

In order to capture high-quality images, Haikang camera model MV-CH120-10GC was selected in the experiment, with 12 million pixels and 4096*3000 resolution, respectively. Lens is optimized for machine vision light source and chip design, focal length is 16mm, can manually adjust the focal length and aperture; The light source provides a suitable lighting environment for image acquisition and reduces the interference of natural light[9]. The image processing is based on C++ using opencv open source algorithm.

2.3. Overall Process

2.3.1. Camera calibration

Before image acquisition, camera calibration should be carried out to calculate camera parameters, map pixel coordinates of space points to world coordinates, and eliminate the impact of image distortion on measurement accuracy through image correction algorithm. The accuracy of calibration results directly affects the accuracy of measurement installation [10].

Select the calibration plate, use the camera to capture calibration pictures, ensure that the focal length and exposure of the calibration pictures captured by the camera and the bearing seat images captured do not change, and shoot 15~20 calibration pictures. Use MATLA's calibration tool to open the calibration picture, set the calibration plate size and distortion parameters, and then calibrate. The calibration device is shown in Figure 3:

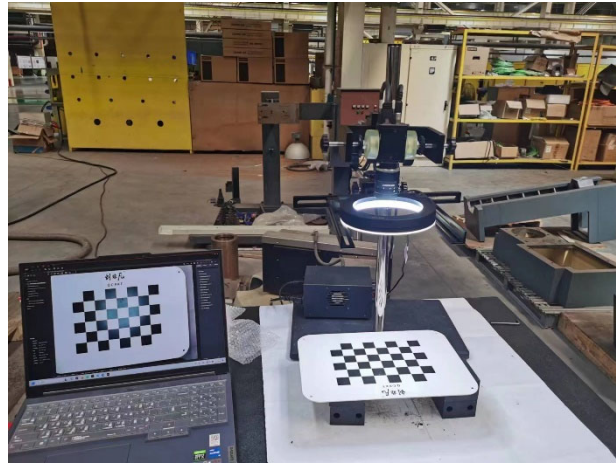


Figure 3 Calibration device

The calibration image will produce calibration error, and the camera parameters can be used when the calibration error is less than 0.5. Since this experiment requires precision measurement at different focal lengths, three times of calibration are required, and the calibration results are shown in Table 1:

Table 1 Camera parameters

H/mm	DM		IPM		CE
305	$-6.1232e - 04$	360.4896	0	$2.0494e + 03$	0.43
	$3.5397e - 06$	0	360.4568	$1.5404e + 03$	
		0	0	1	
355	-0.1279	$4.9437e + 03$	0	$2.0670e + 03$	0.32
	0.2169	0	$4.9450e + 03$	$1.4783e + 03$	
		0	0	1	
405	$-3.0433e - 04$	271.5863	0	$2.0341e + 03$	0.32
	$1.7820e - 06$	0	271.4519	$1.4970e + 03$	
		0	0	1	

Note: (The following tables are shared)

H: Height;

DM: Distortion matrix;

IPM: Internal parameter matrix;

CE: Calibration error;

2.3.2. Measurement process

The measurement process is shown in Figure 4:

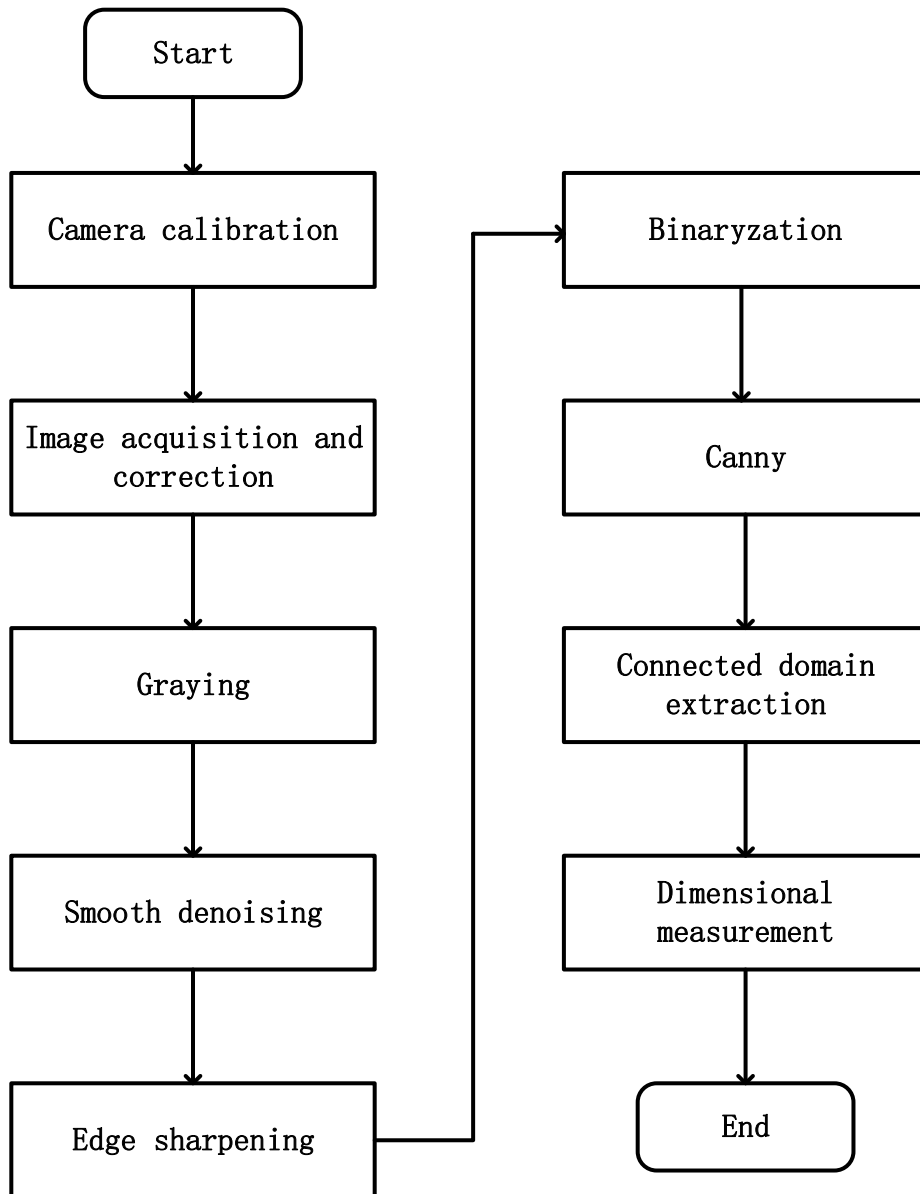


Figure 4 Measurement flow chart

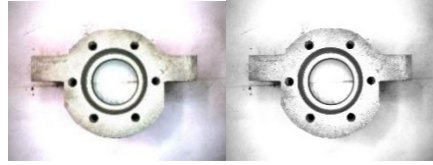
The specific operations in the figure are as follows: 1) First, the bearing seat image is collected and corrected according to camera parameters; 2) The image is processed by grayscale, median filter, Gaussian filter, mean filter, edge sharpening and binarization; 3) Use canny edge detection and connected domain algorithm to extract edge contour; 4) Finally, the maximum aperture size of the bearing seat is measured by the minimum external rectangle algorithm;

3. IMAGE PROCESSING

In the process of image acquisition, there will be interference from the external environment, which will affect the image quality. The main purpose of image processing is to reduce this impact, simplify the data to the maximum extent, and enhance the effective information.

3.1. Graying

The image collected by the camera is a color three-channel image, which contains too much information, and the graying of the image can change the three-channel into a single channel to improve the computing speed. In Figure 5, (a) is the original image, and (b) is the grayscale image.



(a)Master drawing (b)Gray level map

Figure 5 Comparison before and after gray-scale processing

3.2. Filter denoising

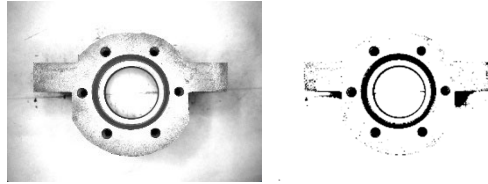
In the process of image acquisition, salt and pepper noise, Gaussian noise and particle noise are produced not only by the equipment itself, but also by environmental factors, and the median filter, Gaussian filter and average filter can effectively remove the above noise. Therefore, this experiment conducted median filtering, Gaussian filtering and mean filtering for the same image successively, and the effect of image filtering was shown in Figure 6:



Figure 6 Image filtering effect

3.3. Edge extraction

Smoothing the de-noising process will weaken some feature values while reducing various noise interferences. Therefore, this experiment enhances edge feature information through edge sharpening and binarization processing to make edge detection more accurate. The effect of edge sharpening and binarization is shown in Figure 7:



(a)Edge sharpening effect (b)binaryzation

Figure 7 Image enhancement

As can be seen from Figure 7, edge feature information is enhanced, which is conducive to edge extraction. Among many edge detection operators, Canny operator is a multi-stage optimization operator, which has the characteristics of low error rate and optimal positioning[11]. Canny edge detection algorithm was selected for edge detection in this experiment, and the effect is shown in Figure 8:



Figure 8 Canny edge detection

As can be seen from the figure above, the edge of the largest inner circle can be well detected. Then the connected domain algorithm was used to extract the edge contour and fit the circle, and the fitting effect was shown in Figure 9:

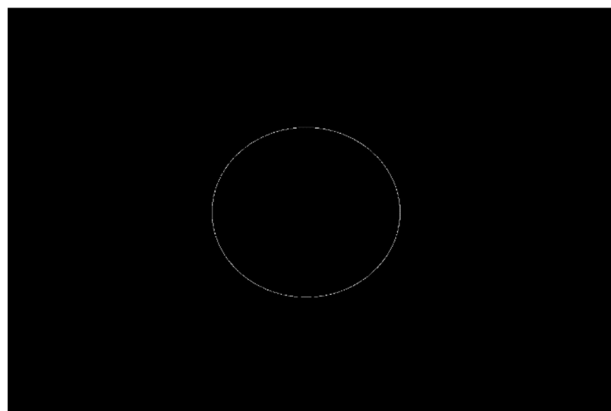


Figure 9 Circle fitting effect diagram

The connected domain algorithm refers to the region composed of adjacent pixels with the same pixel value in the image. How it works: 1) Put all non-0 pixels into a set C; 2) Randomly select a pixel in

set C as the seed pixel, and start to spread and label it according to the adjacency relationship until it can no longer spread; 3) Delete the spread pixels from set C ; 4) If set $C \neq \emptyset$, return to operation ;4) and set $C = \emptyset$, then the connected domain algorithm ends (\emptyset stands for empty set) [12]

4. DIMENSIONAL MEASUREMENT

The minimum external rectangle is a classical geometric calculation method, the core idea is to find the minimum rectangle that surrounds the set of points, and the length and width of the rectangle can be rotated arbitrarily, so it can also be called a rotating rectangle. It is widely used in image recognition, image processing, machine vision and other fields[13].

The basic idea of the minimum external rectangle is as follows: 1) According to the point set extracted from the connected domain, find the point containing the x coordinate or y coordinate as the maximum value, and then calculate the initial length and width of the rectangle; 2) Take the center of this point set as the center of the rectangle, constantly rotating and updating the optimal rectangle. 3) Find the optimal external rectangle by comparing the rectangular area.

Based on the minimum external rectangle, calculate the ratio of pixels to the true size:

$$Ratio = \frac{d_{max} + d_{min}}{real_{max} + real_{min}} \quad (1)$$

where d_{max} and d_{min} represent the maximum and minimum pixels respectively; $real_{max}$ and $real_{min}$ indicate the maximum and minimum real sizes respectively.

Suppose the center $p_1(x_1, y_1)$ of the connected domain and the center $p_2(x_2, y_2)$ of the camera lens produce an *offset*, and the deflection Angle is θ , then:

$$offset = \frac{\sqrt{(x_2 - x_1)^2 - (y_2 - y_1)^2}}{Ratio} \quad (2)$$

$$\theta = \arctan \frac{offset}{real_1 - real_2} \quad (3)$$

where $real_1 - real_2$ indicates the distance between the camera lens and the measuring surface of the bearing seat.

According to the principle of the minimum external rectangle algorithm, the length and width of the minimum external rectangle is the maximum and minimum value of the measured size, and then the measured value can be obtained according to the following formula:

$$ce_{max} = \frac{d_{max}}{Ratio} \quad (4)$$

$$ce_{min} = \frac{d_{min}}{Ratio} \quad (5)$$

where ce_{max} , ce_{min} represent the maximum and minimum measurement values respectively.

Error formula is as follows:

$$gap_{max} = real_{max} - ce_{max} \quad (6)$$

$$gap_{min} = real_{min} - ce_{min} \quad (7)$$

where gap_{max} and gap_{min} are the maximum and minimum error respectively.

5. DATA ANALYSIS

In this experiment, the measurement data of the CMM is used as the real size of the bearing seat of the CNC machine tool. The source of the bearing seat and the measuring site of the CMM are shown in figure 10:



(a) Bearing seat source (b) Three coordinate measurement site

Figure 10 Data sources

Three bearing seats were selected in this experiment, and the measurement data of the CMM are shown in Table 2:

Table 2 Coordinate measurement data

WP/mm	Min/mm	Msx/mm
1	62.012	62.032
2	61.984	62.021
3	62.004	62.017

Note: (The following tables are shared)

WP: WorkPiece;

Min: Minimum of measurement;

Max: Measure the largest point;

AE: Average error;

ER: Error ratio;

DA: Deflection Angle;

5.1. The height of the camera lens from the stage is a variable

When the height of the camera lens from the stage is a variable, the measurement data is as follows:

Table 3 Measuring data of bearing seat 1 at different heights

H/mm	Min/mm	Max/mm	AE/mm	ER
305	61.997262	62.046741	0.014740	0.0238%
355	61.992139	62.051861	0.019861	0.032%
405	61.986740	62.057260	0.025260	0.0407%

Table 4 Measuring data of bearing seat 2 at different heights

H/mm	Min/mm	Max/mm	AE/mm	ER
305	61.977767	62.027231	0.006232	0.0101%
355	61.97262	62.032382	0.011381	0.0184%
405	61.967211	62.037789	0.016789	0.0271%

Table 5 Measuring data of bearing seat 3 at different heights

H/mm	Min/mm	Max/mm	AE/mm	ER
305	61.985626	62.035374	0.018374	0.0296%
355	61.980529	62.040471	0.023471	0.0379%
405	61.975126	62.045874	0.028874	0.0466%

The line chart of measurement data of each bearing seat at different heights is shown in figure 11:

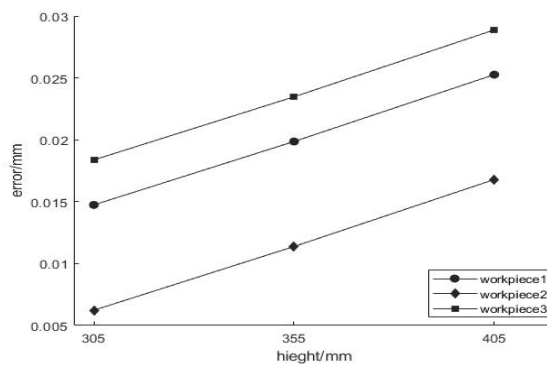


Figure 11 Line chart of measurement data of each bearing seat at different heights

In summary, under the condition that other conditions remain unchanged, the higher the distance between the camera lens and the stage, the greater the measurement error.

5.2. The Angle between the center of the camera lens and the center of the workpiece is a variable

When the Angle between the center of the camera lens and the center of the bearing seat is a variable, the measurement data is as follows:

Table 6 Measuring data of bearing seat 1 at different deflection angles at 305mm

DA/°	Min/mm	Max/mm	AE/mm	ER
0.8	61.997262	62.046741	0.014740	0.0238%
6.3	61.848825	61.947783	0.123696	0.1994%
9.26	61.799346	61.898304	0.173175	0.2792%

Table 7 Measuring data of bearing seat 2 at different deflection angles at 305mm

DA/°	Min/mm	Max/mm	AE/mm	ER
0.18	61.977767	62.027231	0.006232	0.0101%
6.3	61.680986	61.878840	0.222587	0.359%
8.8	61.631523	61.779913	0.296782	0.4787%

Table 8 Measuring data of bearing seat 3 at different deflection angles at 305mm

DA/°	Min/mm	Max/mm	AE/mm	ER
0.37	61.985626	62.035374	0.018374	0.0296%
6.44	61.736888	61.886131	0.198991	0.3209%
8.87	61.736888	61.786635	0.248738	0.4011%

In this experiment, the Angle between the center of the camera lens and the center of the bearing seat is difficult to be accurately controlled, so it is set to gradually increase the declination Angle in the same direction. The test data line chart of different declination angles of each bearing seat at the same height is shown below:

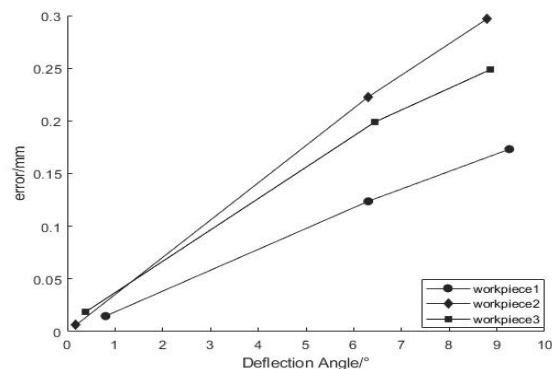


Figure 12 Line chart of measurement data at different declination angles at 305mm

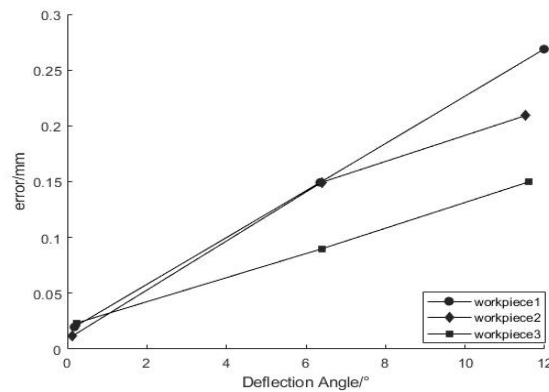


Figure 13 Line chart of measurement data at different declination angles at 355mm

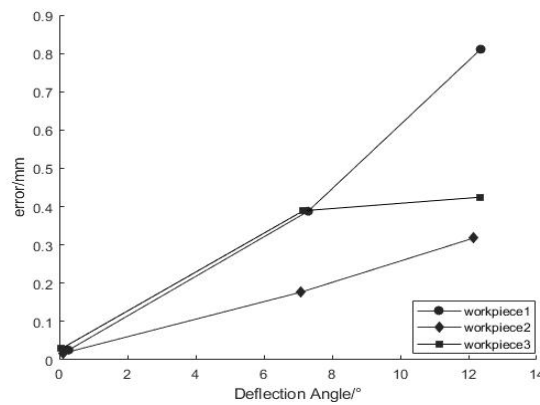


Figure 14 Line chart of measurement data at different declination angles at 405mm

To sum up, no matter the height of the camera lens from the stage is 305mm, 355mm, or 405mm, the same conclusion can be reached, that is, as the declination Angle between the center of the camera lens and the center of the bearing seat gradually increases, its error also gradually increases.

5.3. Error analysis

The reason for the different error ratio of each bearing seat in the same case is that in addition to the different size of the bearing seat itself, there are defects such as markings, sand and pores on its surface.

6. CONCLUSION

In view of the fact that the current measurement methods of bearing seat for key parts of CNC machine tools cannot simultaneously meet the requirements of high precision, high efficiency and low error rate in industrial production[10], this paper proposes an optimization scheme of bearing seat size measurement based on monocular vision technology.

The experimental results show that the higher the distance between the camera lens and the stage, the larger the error is when the image information can be collected completely. The greater the Angle between the camera lens and the center of the bearing seat, the greater the error. In this experiment, when the height from the camera lens to the stage is 305mm and the Angle between the camera lens and the center of the bearing seat is 0.18° , the measurement accuracy reaches the highest. Compared

with the measurement data of the CMM, the error generated by the measurement data is 0.006232mm, the error ratio is 0.0101%, and the response time of the experimental device is less than 4s. The CMM needs about 30s, and the device has no fatigue state, which meets the requirements of high precision, high efficiency and low error rate in industrial production.

ACKNOWLEDGEMENTS

Zigong City Science and technology Bureau school-local cooperation project: Development of aviation five-axis bridge gantry processing equipment(self-study[2022]43).

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