Study on Method of Extracting Circle of Complex Objects Based on 3D Scanning

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Abstract. This paper proposes a method for extracting information about circular holes for complex objects with cylindrical apertures which base on special 3D scanning platform. After scanning the object, the point cloud is sliced after fitting the plane using the eigenvalue method. Aiming at the slice data, a point cloud segmentation extraction algorithm is proposed. The experimental results show that the system can effectively control the aperture extraction error and broaden the types of detectable parameters.

1. Introduction

In terms of object workpiece, there is often a large amount of information about the aperture to be detected, as well as other aspects. However, much detection needs can not be met because of the existing limitations which are confined to two approaches, namely, the use of manual or two-dimensional image acquisition for processing. In order to ensure the quality control of products [1], it is inevitable to harness three-dimensional scanning technology.

Three-dimensional scanning technology is defined to be a high-tech method integrating light, machine, electricity and computer technology. It can quickly catch the three-dimensional structure of objects in three-dimensional space, featuring with faster speed, higher precision, and a wide range of acquiring the density of point cloud [2], thus involved widely in the application in the industrial field.

It is dictated that the original samples acquired at the initial period in the three-dimensional technology is merely used to record the spatial three-dimensional coordinates of each sampling point, between which there is no topological relationship. Furthermore, with the continuous development of 3D scanning technology and the increasing enhancement of data precision, there is multiple challenges ahead for data processing. For this reason, this paper puts forward how to extract circular aperture from complex point cloud data. According to the surface shape of the object, a reasonable solution is designed to quickly and accurately obtain the information about the aperture of the object.

2. System platform

The point cloud data is a set of discrete points in the dimensional space of the object. For a simple structure object, the point cloud can be sliced in a certain direction to obtain the aperture and its relevant parameter information. For an object with a complicated external structure such as a cylinder, a specific method is required to score its relevant parameters. The system used in this paper is composed of a CCD industrial camera, an optical projector, and a computer.

Fig 1. System platform

After obtaining the point cloud information, the point cloud is first visualized, the plane is set by manually selecting the plane point, and then the plane is fitted to obtain the relevant parameter information of the plane. The completion of fitting the plane leads to the next step of processing the point cloud slices along the direction of the plane to extract the two-dimensional aperture information of the point cloud. Ultimately, the contour data of the two-dimensional direction is detected by using the Hough algorithm, the result through which can be the source of parameter for obtaining the relevant parameters of each circle.

3. Aperture extraction

3.1. Eigenvalue method matching point cloud plane
It is common to use the least square method to match the plane when processing the point cloud. The least square method to match the plane is arguably demonstrated under the condition that the data error exists only on one of the directions, considering that the point cloud data may have errors in the three directions of x,y and z, this paper in particular takes eigenvalue method to match the plane[3].

3.2. Point cloud slices
During the scanning process, for larger objects, the scanning device cannot scan the entire picture of the object at one time, resulting in the mess of three-dimensional data. As to point cloud slicing technology, it can transform spatial discrete points into point cloud slices, and integrate a certain range of data into a smaller range, thereby transforming the problem of processing three-dimensional data into the problem of processing two-dimensional data, that is, performing dimensionality reduction processing[4], reducing the scope of data search, making some problems easily to be resolved to some extent.

Point cloud slicing is a kind of data segmentation by using a plane with a certain interval in the selected direction, and the segmented data is the outline of the point cloud data on the plane [5]. Considering that the density of the point cloud is fixed, it is impossible to secure complete outline data in the context of intersecting the point cloud and the plane to make the point cloud data totally in line with the plane parameters. For this reason, it is imperative to calculate the density of the point cloud, and slice the point cloud with the usage of data in a certain range, that is, the data between the planes at a certain interval, thereby obtaining a composite outline. While the density of point cloud can be roughly calculated as:

$$\frac{\sum_{i=0}^{n}\sum_{k=0}^{m} d_i^k}{m \times n} \tag{1}$$

The thickness of the slice can be determined by a certain multiple of the point cloud density, i.e.:

$$\mathbf{\delta = x\rho} \tag{2}$$

3.3. Circle extracted from the point cloud slices
Since the circle is secured by using the Hough transformation in this paper, which needs to map the

data to the parameter space during the circle detection process. In order to reduce the calculation steps and facilitate the mapping of parameters, the data is simplified and translated for discarding a large amount of redundant data and guaranteeing the overall data in the first quadrant. After the rough calculation of the circle parameters, the least squares method is used to fit the data before the simplification.

If the actual spatial point is converted to the polar coordinate system, then these points on the circle will be concentrated in a point set, and that is the formula of the circle. The actual space point is transferred to the formula under the polar coordinate system. It is as follows:

$$\begin{cases} x = x_0 + r\cos\theta \\ y = y_0 + r\sin\theta \end{cases} \qquad (3)$$

The flow chart of the method for extracting circles using the Hough transform in the two-dimensional data projected by the point cloud slice is shown in Figure 2:
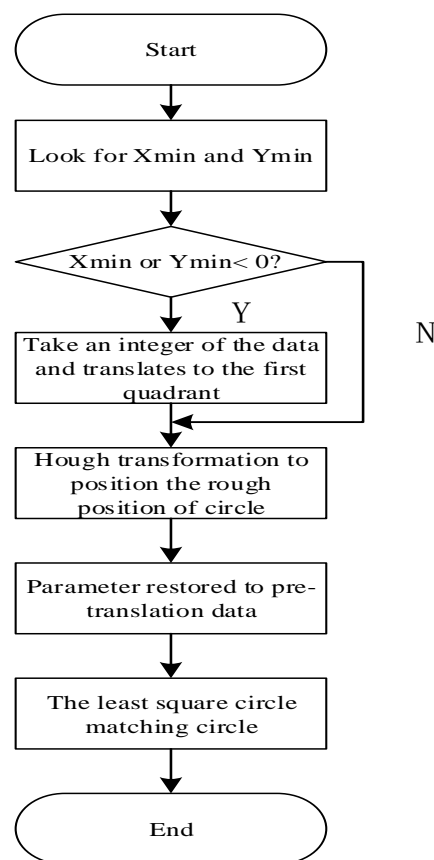

Fig 2. Circle extracted from slices

The cylinder slice is processed to obtain the center radius as shown in Fig 3(a). Then, according to the obtained estimated value, it is accurately calculated, that is, the data in the original data conforms to the set range is calculated, As shown in Figure 3 (b).
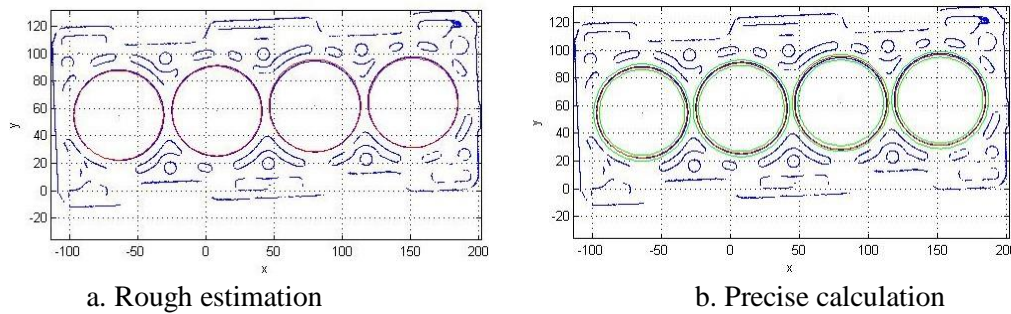
a. Rough estimation   b. Precise calculation

Fig 3. Rough estimation

4. Result and analysis of the experiment

4.1. Plane matching
Set the 3D plane to

$$\frac{1}{2}x + \frac{1}{2}y + \frac{\sqrt{2}}{2}z = 1 \tag{4}$$

Add an abnormal point to it, as shown in Figure 4.

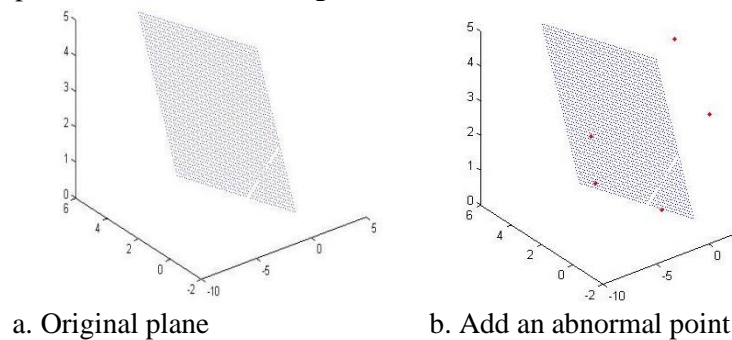a. Original plane   b. Add an abnormal point

Fig 4. Test plane

If an abnormal point is selected in the process of selecting a plane point, a different algorithm is used to simulate the above data, and the following results can be obtained.

Table 1. Plane fitting test

		A	B	C	D	average error
Set parameters		0.500000	0.500000	0.707108	1.00000	
No abnormal point added	The least square method	0.499999	0.499999	0.707107	1.00000	7.5×10^{-7}
	Eigenvalue method	0.500000	0.500000	0.707107	1.00000	2.5×10^{-7}
Abnormal point added	The least square method	0.504009	0.507007	0.723264	1.03432	1.54×10^{-2}
	Eigenvalue method	0.501409	0.504382	0.702984	1.02997	9.97×10^{-3}

Through the above experiments, it can be known that when there is no abnormal point in the data, the results of plane fitting using the least squares method and the eigenvalue method, respectively, are not much different, and the errors are within the acceptable range. When abnormal points are added to the plane, a more accurate value can be obtained using the plane fitting method of the eigenvalue method.

4.2. Circle extraction
After processing the point cloud data, the extracted circle parameters are compared with the actual

errors. In this paper, a single round object, a plurality of round objects, and a test for the second scanned object are tested and compared in sequence.

At the beginning, the precision of the method is tested to extract circle in the point cloud data. The 3D point cloud model used in this test is the point cloud model generated by the model generator. The test point cloud file and test results are shown in Figure 5 and Table 2.
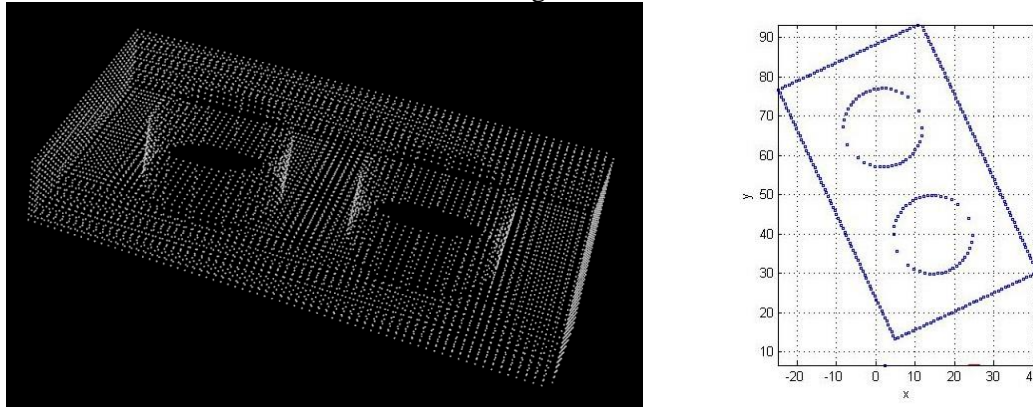

Fig 5. Point cloud model

Table 2. Extraction test of point cloud model

	Diameter 1 (mm)	Diameter 2 (mm)
Setting value	20.0000	20.0000
Rough calculation	19	19
Precise calculation	20.0008	20.0018
Accurate calculation error	0.0008	0.0018

The object is scanned by a three-dimensional scanning platform, and the multi-aperture complex object is scanned and extracted. The test results are shown in Table 3. The scanning accuracy of the three-dimensional scanner used in this paper is ±0.1~0.01mm.
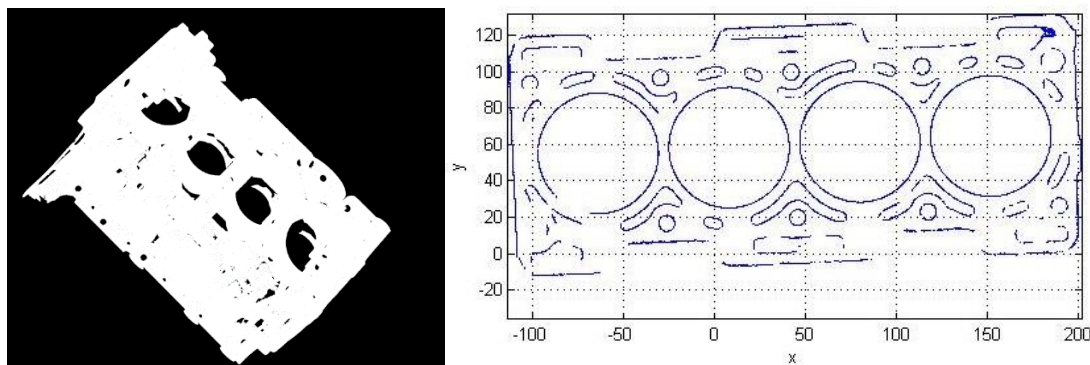

Fig 6. Scanning model

Table 3. Extraction of scanning model

	Radius 1 (mm)	Radius 2 (mm)	Radius 3 (mm)	Radius 4 (mm)
Measuring value	66.2800	66.2700	66.2700	66.2700
Rough calculation	64	65	65	66
Precise calculation	66.2655	66.2373	66.2414	66.2410
Error	0.0145	0.0327	0.0286	0.0290
Error rate	0.0219%	0.0493%	0.0432%	0.0437%

It can be seen from the above test data that under the premise of ensuring the accuracy of the point cloud, the aperture extraction error of the object is within 0.04 mm, and the error range can be controlled within 0.05%.Looking at the literature in recent years, Wang Kai et al.[6] used traditional machine vision to detect the size of the circular hole, within 0.039mm of the measurement accuracy. Zhang Junyong et al. [7] used binocular vision to scan the object to generate feature point cloud and extract related information,only with 0.277mm of the worst error and less 0.06% of the relative error of the linear contour measurement of the workpiece. The methods used in this paper basically meet the detection requirements and increase the types of parameters to be detected.

5. Conclusion
This paper presents a method of extracting the aperture of a complex object satisfying certain conditions by using a three-dimensional scanner, which demonstrates that the accuracy of the aperture extraction can reach the micrometer error level when the point cloud data has no error after excising many experiments. When the accuracy of 3D scanning is sufficient, the error of the method can be controlled within ±0.05mm and the error is 0.06%, which is of great research significance.

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