Steering knuckle diameter measurement based on optical 3D scanning*

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To achieve accurate measurements, the creating a fitting hole for internal diameter (CFHID) measurement method and the establishing multi-sectional curve for external diameter (EMCED) measurement method are proposed in this paper, which are based on computer vision principle and three-dimensional (3D) reconstruction. The methods are able to highlight the 3D characteristics of the scanned object and to achieve the accurate measurement of 3D data. It can create favorable conditions for realizing the reverse design and 3D reconstruction of scanned object. These methods can also be applied to dangerous work environment or the occasion that traditional contact measurement can not meet the demands, and they can improve the security in measurement.

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Some researches on the diameter measurement methods have been reported. Wang et al[1] proposed a handheld tree's diameter at breast height measurement system based on a linear laser diode and a low-cost complementary metal-oxide semiconductor (CMOS) image sensor. Long et al[2] proposed the abdominal aortic aneurysm imaging with three-dimensional (3D) ultrasound 3D-based maximum diameter measurement. Wu et al[3] proposed a new technology of building up defect measuring system for inner micro pipe. Yu et al[4] proposed a non-contact diameter measurement system by using a linear array CCD as light source for target detection. Bartosz Gapinski et al[5] proposed a measurement of diameter and roundness on incomplete outline of element with three-lobbing deviation. Chen et al[6] proposed an optical multi-directional shaft hole diameter measurement method, but it is complex and difficult to achieve the measurement of large diameter hole. Zhang et al[7] proposed a precise measurement method of the applanated diameter in the ocular cornea with the optical probe. Sun et al[8] proposed a shaft diameter measurement using a digital image. Lin et al[9] proposed a lens sag and diameter measurement of large-size micro lenses using sub-pixel algorithm and optical interferometer, but it can not be used for the measurement of the large objects.

The measurement methods above can only measure the single parameter diameter, but can not achieve a comprehensive measurement of multiple dimensions. In this paper, a new method using optical 3D scanning is proposed for measuring the automobile steering knuckle based on previous work[10-12], and it can obtain the key data, such as the steering shaft inside and outside data.

In this paper, the measurement of the steering knuckle is based on the optical 3D scanning. The photo of steering knuckle is shown in Fig.1, and the 3D optical photo scanner used in this paper is shown in Fig.2.

After scanning and detecting the steering knuckle, the scanned point clouds are imported into 3D processing software based on the principle of binocular vision system, and then the software Geomagic Studio is used to register together a complete 3D image accurately with different angles of point clouds. After splicing and processing the point clouds, a complete 3D image of steering knuckle is obtained as shown in Fig.3.

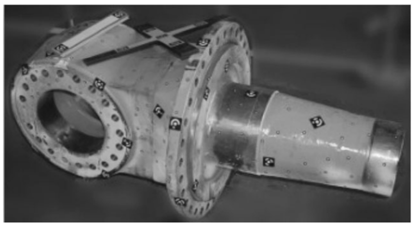

Fig.1 Steering knuckle in automobile

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Fig.2 3D optical photo scanner

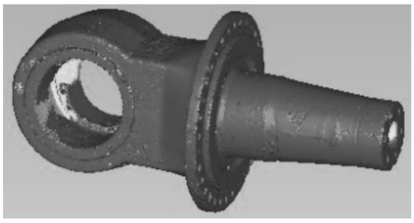

Fig.3 A complete 3D image of the steering knuckle

The diameter measurement methods can be divided into contact and non-contact ones. There are some common methods in contact diameter measurement, such as three line method, which requires direct contact with the workpiece. It has low precision and inconvenient operation, and it is easy to cause deformation and pollution of the workpiece. In this paper, the creating a fitting hole for internal diameter (CFHID) measurement method and the establishing multi-sectional curve for external diameter (EMCED) measurement method are proposed, which are both non-contact measurement methods without moving the workpiece. Their precision is high, and they can reduce the labor intensity of operating workers and improve the work efficiency.

Curve fitting refers to a data processing method using continuous curve approximatively to describe the function relation among the coordinates of discrete points on the plane[13]. The key problem of curve fitting is the choice of the objective function which can directly affect the calculation accuracy of the curve parameters and computational complexity in the process of fitting.

The CFHID measurement method described here refers to using the principle of curve fitting in the cylindrical object unknown radius data to create a circle and adjust the radius to meet the requirement of coincidence between the actual object radius and the fitting radius. Therefore, it can get the radius data in the measured object. Known from the geometric theory, it is essential to need at least three points not in a straight line to determine a circular curve. The method for determining the center is shown as follows.

As shown in Fig.4, the coordinates of three points on circular curve are $A(x_1, y_1)$, $B(x_2, y_2)$ and $C(x_3, y_3)$, respectively. The coordinate of the circle center and the circle radius can be calculated as

$$\begin{cases} x = \frac{1}{2}\left[x_2 + x_3 + (y_2 - y_3)\cot r\right] \\ y = \frac{1}{2}\left[y_2 + y_3 + (x_3 - x_2)\cot r\right] \end{cases}, \tag{1}$$

$$R = S_{BC}/2\sin r , \tag{2}$$

where x and y are the abscissa and ordinate of the center of the circle, respectively, R is the radius of the circle, r is the angle between line AB and line AC, and S_{BC} is the length of line BC.

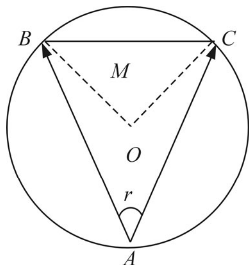

Fig.4 Three points on a circle

As shown in Fig.4, draw a vertical line from the center of a circle O to the line BC, and then the foot point M must be the midpoint of line BC. So we can get

$$x_M = \frac{1}{2}(x_2 + x_3) , \tag{3}$$

$$y_M = \frac{1}{2}(y_2 + y_3) , \tag{4}$$

$$S_{OM} = S_{BM}\cot r = \frac{1}{2}S_{BC}\cot r , \tag{5}$$

where x_M and y_M are the abscissa and ordinate of the center of the circle, respectively, and S_{OM}, S_{BM} and S_{BC} are the lengths of the lines OM, BM and BC respectively. Then we can get

$$x = \frac{1}{2}(x_2 + x_3) + \frac{1}{2}S_{BC}\cot r\cos(\alpha_{BC} + \pi/2) = \frac{1}{2}(x_2 + x_3) - \frac{1}{2}S_{BC}\sin\alpha_{BC}\cot r = \frac{1}{2}[x_2 + x_3 + (y_2 - y_3)\cot r] , \tag{6}$$

$$y = \frac{1}{2}(y_2 + y_3) + \frac{1}{2}S_{BC}\cot r\sin(\alpha_{BC} + \pi/2) = \frac{1}{2}[y_2 + y_3 + (x_3 - x_2)\cot r] , \tag{7}$$

where α_{BC} is the angle between the line BC and the Y axis in the coordinate system.

It can be derived that as long as the three points A, B and C are arranged clockwise, Eqs.(1) and (2) are suitable. x is obtained from Eq.(6) as a abscissa of the circle center, and y is obtained from Eq.(7) as a ordinate of the circle center. Therefore, Eqs.(1) and (2) are the general formulae for calculating the circle center coordinate using three points of the circle.

The center position can be obtained based on the calculation process above, and it can lay the foundation for the following work in the 3D image processing software. Next, the position of circle center is fitted in the Geomagic Studio software, and the circle diameter is obtained.

In a column object as shown in Fig.5, find three points which are not in a straight line, and make marks. Create circular model using curve fitting and calculate the position of the circle center. It is the circle center under the axis in Fig.5. Find the position of the circle center in the scan data, and fit a circular hole for creating a fitting axis. At the same time, we can adjust the radius to meet the requirement of coincidence between the object radius and the fitting radius, and then we can get the actual radius of the measured object.

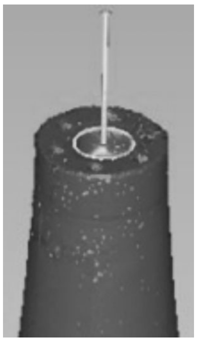

Fig.5 Illustration of fitting the hole for a column object

In an unknown circle, it is very difficult to accurately calculate the diameter, because it is difficult to determine which one is the diameter of the circle among the chords. Aiming at this problem, this paper proposes an EMCED measurement method.

As shown in Fig.6, three points are selected on the circular plane in the measured cylindrical object, and thus a plane perpendicular to X axis and parallel to the plane composed with Y axis and Z axis is established.

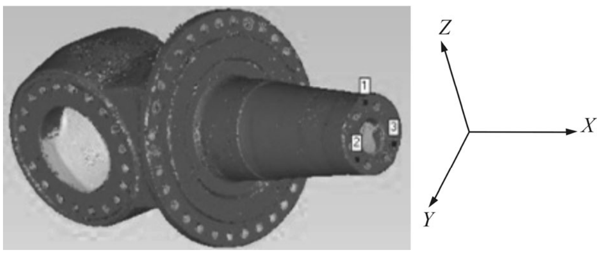

Fig.6 Illustration of selecting three points and establishing a plane

The cylindrical cross section is also parallel to the plane composed with Y axis and Z axis. Multi-section curve is established to intercept the cylindrical cross section using the Geomagic Studio software. More surfaces are intercepted, and the shorter the distance among the curved surfaces is, the more accurate the diameter measurement data is. The drawing after the interception is shown in Fig.7.

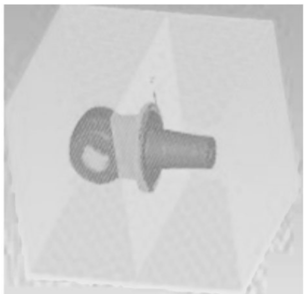

Fig.7 Columns-shaped cross section obtained by multiple surface interception

After intercepting the cylindrical plane, the section curve needs to be generated. After calculation, the section curve diagram is shown in Fig.8.

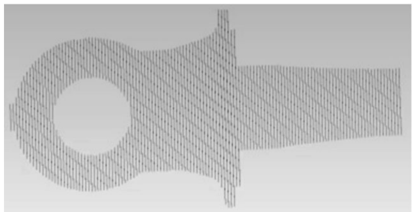

Fig.8 Section curve diagram after intercepting the cylindrical plane

Rotate the workpiece angle in the section curve diagram, and make it match the side elevation. If we select two points in small graph, the error will be relatively large. So we enlarge the measured cylindrical plane to a certain extent, and determine two points in diameter line of the measured column. The enlarged drawing of the measured cylindrical section curve in the right of knuckle is shown in Fig.9. Select two endpoints 1 and 2 similar to a segment in Fig.9 and use the function of measuring distance in Geomagic Studio software to measure the distance between the two points, and then it is the diameter of the cylindrical section circle.

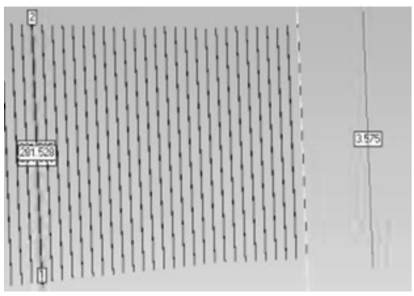

Fig.9 Enlarged drawing of the measured cylindrical section curve

In order to prove the stability of the measurement method and the accuracy of measurement results, we measure the internal and external diameters of steering knuckle by CFHID and EMCED measurement methods, respectively. The measurement results are shown in Tab.1.

Tab.1 Comparison of the measured results and actual values

	1	2	3	4	5	Actual value (mm)
Internal diameter (mm)	112.0	112.2	111.9	112.1	112.0	112.1
External diameter (mm)	254.6	254.7	254.8	254.5	254.8	254.7

It can be obtained from Tab.1 that the average internal and external diameters of steering knuckle are 112.04 mm and 254.68 mm, and their variances are 0.005 67 and 0.013 6, respectively. Therefore, the proposed methods for measuring the internal and external diameters in this paper both have very high precision, and can overcome the disadvantages of the contact measurement method.

For accurately measuring the workpiece diameter in practice, the CFHID and the EMCED measurement methods are proposed in this paper. The methods use the precise 3D scanning technology to obtain 3D data of steering knuckle from each view, and import them to the computer software to register together and form a complete steering knuckle image. The two kinds of new methods have the characteristics of non-contact measurement, higher precision and reducing the labor intensity of workers, and they can greatly protect the workpiece and improve the efficiency. The proposed 3D vision measurement methods can obtain full information of the workpiece and thus obtain more measurement parameters. Therefore, it is easy to evaluate and improve the quality of workpiece. The methods are suitable for accurate measurement of the diameter of column equipment.

References

[1] Wang D., Li T., Wang J. L., Fan L. and Liu J. H., Sensors & Transducers **172**, 111 (2014).

[2] A. Long, L. Rouet, A. Debreuve, R. Ardon, C. Barbe, J. P. Becquemin and E. Allaire, Ultrasound in Medicine & Biology **39**, 1325 (2013).

[3] WU Bin, SHAO Zhen-yu and ZHANG Yun-hao, Journal of Optoelectronics · Laser **25**, 293 (2014). (in Chinese)

[4] YU Zhi-jing, LIU Yue-lin and ZHUGE Jing-jing, Transducer and Microsystem Technologies **33**, 120 (2014). (in Chinese)

[5] Bartosz Gapinski and Michal Wieczorowski, Procedia Engineering **69**, 247 (2014).

[6] CHEN Hao, ZHU Ji-gui, XIE Hong-bo and WANG Zhong, Journal of Mechanical Engineering **49**, 16 (2013). (in Chinese)

[7] ZHANG Xue-yong, LU Rong-sheng, LI Ping and MA Jian-guo, Optoelectronics Letters **7**, 294 (2011).

[8] Qiucheng Sun, Yueqian Hou, Qingchang Tan and Chunjing Li, Optics and Lasers in Engineering **55**, 183 (2014).

[9] Shir-Kuan Lin and Shih-Wei Yang, Optics and Laser Technology **57**, 293 (2014).

[10] Limei Song, Xiaoxiao Dong, Jiangtao Xi, Yanguang Yu and Chaokui Yang, Optics & Laser Technology **45**, 319 (2013).

[11] Limei Song, Yulan Chang, Zongyan Li, Pengqiang Wang, Guangxin Xing and Jiangtao Xi, Optics Express **22**, 13641 (2014).

[12] Limei Song, Changman Chen, Zhuo Chen, Jiangtao Xi and Yanguang Yu, Optoelectronics Letters **9**, 143 (2013).

[13] Nathan R. Jager and Timothy J. Fox, Methods in Ecology and Evolution **4**, 789 (2013).