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Automated Restoration Measurement Analysis of Image Grayscale Imaging Sequence Based on Triangle Shape

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ABSTRACT

Image grayscale imaging technology has a wide range of applications in modern image processing, such as medical imaging, remote sensing, security monitoring, etc. However, in certain application scenarios, due to limitations of imaging equipment or external factors, images may experience distortion or damage, affecting their quality and accuracy in subsequent processing. This article studies an automatic restoration measurement and analysis method for image grayscale imaging sequences based on triangles. This method uses triangles to segment the image, and achieves automatic image restoration and measurement by grayscale imaging of the segmented triangles. This article verifies the feasibility and effectiveness of this method through experiments.

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1. Introduction

CT technology, namely computer-fault scanning technique [1]. It is a new discipline with an intersecting edge generated by the combination of modern nuclear physics and imaging technology theory. It has developed into an important field of non-destructive testing in recent years [2]. Based on the CT imaging measurement method, it is one of the most potential non-contact measurement technologies and has been widely applied in medicine and industry. Due to its non-destructive, it is often applied to non-destructive testing and measurement dimensions of objects, and can deal with the internal structure of objects detection measure [3].In biomedicine, the standard CT imaging technology is applied to detect and analyse microscopic imaging processing, histological section analysis, cancer cell recognition, visceral size measurement and shape detection, and tumor property determination [4]. In the industrial field: CT imaging technology is often used in non-destructive testing of key parts and components, measurement of geometric quantity of small size parts, metallographic analysis, automatic identification of assembly line parts, 3D shape detection of precision complex parts such as microelectronic devices, on-line measurement of size of large workpiece (such as measuring the length, width, diameter of steel wire online on steel rolling production line), and safety inspection of airport exit and entry and so on [5]. Unlike other imaging, industrial CT imaging will inevitably have the point diffusion effect introduced by the industrial CT system in the filtering process, and the noise introduced by data acquisition, image reconstruction, and volume effect are caused by the thickness of the scanning layer [6].

2. State of the Art

At present, a serious problem that affects the three-dimensional measurement of CT sequence slice imaging is that the spatial resolution of the pixels in the fault is far higher than the spatial resolution between the faults; that is, the slice inner pixel is not consistent with the spatial resolution of axis direction, which makes the edge data of the interlayer slice incomplete, resulting in the low accuracy and large error of the three-dimensional measurement based on the sequence imaging [7]. Two methods usually equate the spatial resolution of the horizontal and the axes: One way is to control the CT scanning spacing; the scanning interval between adjacent faults is reduced until the resolution is equal to the resolution within the slice [8]. However, as the accuracy of the detector is upgraded and the accuracy of the ray source is improved, the quality of the imaging reconstruction is also getting higher and higher. That is, the spatial resolution in the slice imaging is getting higher and higher, which makes it difficult to realize the inter-fault resolution equal to the internal resolution of the slice in physics, and the general CT scanning system is unable to achieve such a high resolution [9]. In addition, reducing the interval between scanning layers means increasing the number of scanning slices, which will greatly increase the cost of scanning. Therefore, this method does not have great engineering application value [10]. Another way is to carry out interpolating operations on the existing tomographic images by using the imaging processing method and interpolating the edge of the fault to get the data information of the middle slice [11]. After interpolation, the number of tomography is increased, equivalent to the increase in the number of scanning times. This is a commonly used method in the world at present [12]. The research on high-precision interpolation methods of fault slice imaging has become one of the most important questions of scholars in the world [13].

3. Methodology

3.1. The Algorithm of the Platform Body Summation

The steps of the platform body summation are as follows: first, the sub-pixel edge of each CT slice image is extracted by the Zernike moment edge extraction algorithm. The eight neighbourhood tracking is used, and then the polynomial fitting is performed on the edges of each layer. Then, the equal angle interval sampling is carried out on the fitting curve, with the same phase angle as the matching condition, and the interlayer point matching is carried out by formfitting the edge point of each layer [14]. The intermediate edge points are obtained by interlayer interpolation algorithm, and the top point of the workpiece is estimated by extrapolation. Finally, the workpiece volume is calculated by using the platform body summation algorithm. Figure 1 is the step flow chart of the summation [15].

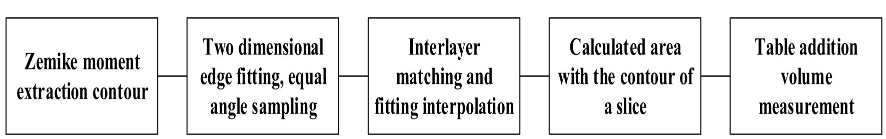

Figure 1. Table addition flow chart

At present, due to the high cost of using industrial CT scans, sometimes only one cross-section scan can cost thousands of yuan, and the scanning speed is not ideal. Therefore, in the actual workpiece scanning and inspection process using the industrial CT system, in order to reduce the detection cost, and also to improve the efficiency of three-dimensional scanning detection, when the workpiece is subjected to continuous slice three-dimensional scanning, the slice thickness and the interlayer distance are usually set far less than the pixel width of CT slice imaging, that is, the resolution of interlayer imaging perpendicular to the slice direction is about an order of magnitude lower than the inner resolution of the slice two-dimensional imaging, and the data information of the middle layer is missing, so the accuracy of the three dimensional measurement is far from the requirement of the high precision measurement.

In order to solve the problem of insufficient accuracy of three-dimensional measurement due to lack of resolution between layers, the method of inter-layer polynomial fitting is used in this paper. The principle of fitting method has been described in detail in Chapter 3 of the previous article. As shown in Figure 2 below, it is the method of three-dimensional schematic in s paper. The solid line circle represents the edge of the slice image after extraction, the axial curve in the diagram is the edge coordinates of the middle layer obtained after matching the edge points with the same phase angle in each layer and fitting and interpolation. The data of the middle layer is as shown in the dotted line, $\triangle\theta$ is the phase angle interval taken.

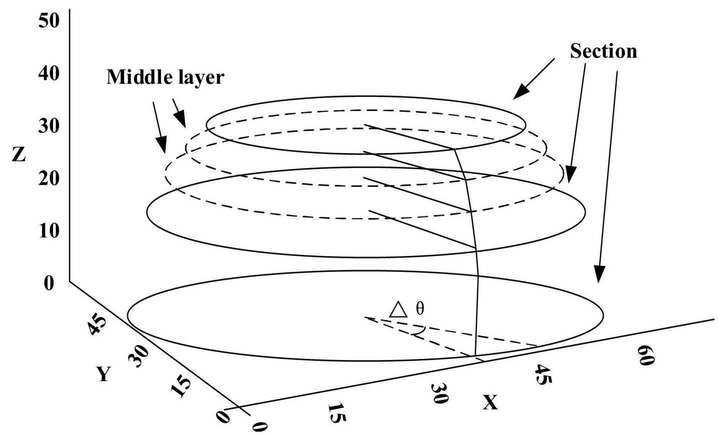

Figure 2. Three-dimensional schematic diagram of interlayer interpolation

According to the algorithm of the platform body summation, after the interlayer edge fitting is interpolated to get the edge points of the middle layer, each edge point of the same intermediate slice is taken out to get the interpolation slice in the middle layer, and then the volume is added to each slice by the algorithm of the platform body. According to the table body volume formula (3), it can be seen that the slice imaging area needs to be measured before calculating the volume of the platform body, the triangle area summation method is used in this paper. First, the target slice image edge after extracting is equivalent to the N edge form composed of N edge points, then a fixed vertex is found in the edge, and the vertex is connected to two adjacent edges of each side to form a small triangle. N small triangles can be found in turn and these small triangles are pieced together to be equal to the previous N edges. Then, each small triangle area is calculated in the formula 1 in the plane.

$$S = \sqrt{p(p-a)(p-b)(p-c)} \tag{1}$$

Among them, *a, b and c* are the sides of the triangle and $p = (a+b+c)/2$ is half perimeter. Finally, the area of the small triangle is added, that is, the area of the edge is drawn from the following formula.

$$S = \sum_{i=0}^{N} S_i \tag{2}$$

The volume formula of the platform body is as follows

$$V = \frac{1}{3}h(S_1 + \sqrt{S_1 S_2} + S_2) \qquad (3)$$

S_1 is the upper floor space of the platform body and S_2 is the Lower floor space, and h is the height. Assuming that the workpiece is interpolated with equal thickness to obtain the K layer data, and then the K-1 intermediate platform body can be obtained, thus the total volume is the cumulative volume of each intermediate platform body. That is

$$V = \sum_{i=1}^{K-1} V_i \qquad (4)$$

In order to improve the signal to noise ratio of the imaging, the thickness of the scanning slice is often not infinite in CT scan, but has a certain thickness. When the workpiece is not a straight tube shape, this will result in a certain degree of volume effect in the CT imaging after reconstruction.

In practice, the axial edge of the top of a lot of workpiece changes very violently (such as ball workpiece), all the top information of the work piece is often included in the top slice. In CT scan testing, there are usually two kinds of scanning conditions on the top of the workpiece, as shown in Figure 3, that is, the top slice is just scanned to the top part, and the top part of the workpiece is not scanned because of the non-integer relationship between the interval and the height of the workpiece.

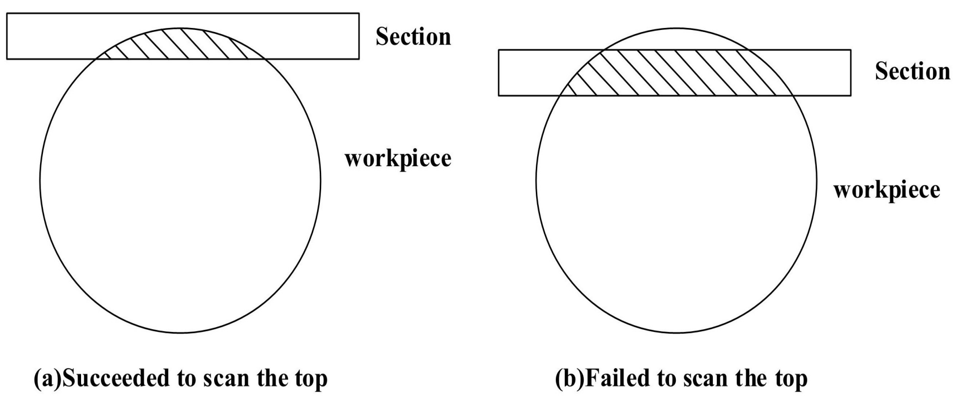

Figure 3. Scanning mode of work piece

When the edge of the workpiece is a non-vertical line, no matter which kind of scanning is above, the image obtained after the reconstruction will have a strong volume effect. Usually, the 3D measurement algorithm based on sequence imaging treats the imaging as an infinite thin slice with only two-dimensional information, and then the edge detection algorithm is used to carry out the three-dimensional measurement after extracting the imaging edge. For edge detection with stronger volume effect imaging, it is usually only to find the equivalent edge position, which makes the tip information of the tip shape to be lost and eventually leads to an incomplete axial edge in the three-dimensional measure of the sequence imaging. Also, due to the failure to scan the top part of the workpiece, an incomplete axial edge will appear in the three-dimensional measurement.

In view of the problem of lack of top part in the above two cases, in this paper, by combining external interpolation of the fitting curve of the axial edge of the workpiece and the tangent of

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the interpolating curve, this algorithm automatically determines whether the workpiece to be tested is a spire, and the vertex position of the workpiece is estimated by the fitting curve of the interlayer edge, which solves the problem of the lack of top part in the actual measurement. In this experiment, the automatic vertex is estimated for two spires of the conical and hemispherical parts.

When the above first case occurs, the grey edge and the workpiece edge similarity method is used to approximately represent the actual workpiece volume contained in the top slice, which is used to supplement the missing top of the workpiece in the simple inter-layer interpolation fitting. According to the principle of CT system imaging, in the two-dimensional slice imaging, the grey value of the imaging is related to the density and thickness of the object to be measured, and the internal shape of the object to be measured can be described by the grey scale. Similarly, the edge of the grayscale curve can be used in the slice to be equivalent to the edge change of the object to be measured.

When the second case occurs, the extrapolation of the inter-layer grayscale curve is used to automatically predict the vertices of un-scanned artifacts. As shown in FIG. 4 below, taking a hemispherical workpiece as an example, after describing interlayer fitting and interpolation an edge group formed by two coplanar interlayer fitting edges of an phase angle è and another phase angleð+è is used to automatically predict the diagram method of vertexes. The black dots in the figure indicate the edge points on the original slice image, and the point o is the sphere center of the hemisphere workpiece. By determining whether the tangent lines at the edge points of the uppermost slice of the two-layer edge fitting curve are intersected as shown in the figure, it is judged whether or not the automatic tip point prediction is performed. If the two tangents have intersections, then automatic vertex prediction is performed and the vertex s is obtained. The main steps are as follows: First, take a set of coplanar inter-layer edge fitting curves, find the tangent at the top point of tangency respectively, and determine whether the two tangents have an intersection or not, if there are intersection points, the edge points of the top slice and the bottom slice are taken as end points; then extrapolate the original layer edge fitting curve, the intersection point of the two extrapolation curves is considered as a temporary vertex under the phase angle; then, the same method is used to find the temporary vertices under the remaining phase angles. Finally, all the temporary vertices are averaged, which is regarded as the expected vertex s of the object to be measured.

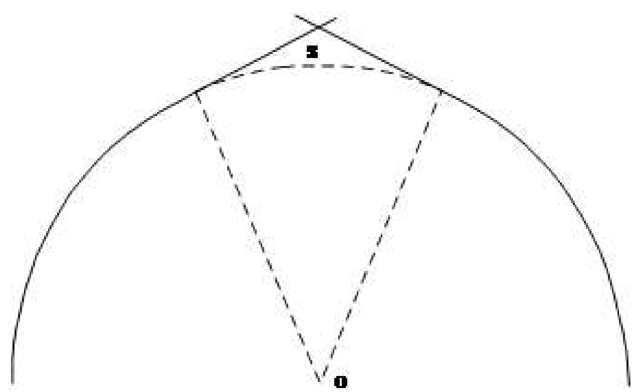


Figure 4. Schematic diagram of automatic top prediction

3.2. Rotational Integration Algorithm and Lumen Volume Measurement Algorithm

The steps of the rotational integration method are as follows: Firstly, the subpixel edge of each CT slice imaging is extracted by the Zemike moment edge extraction algorithm, and the polynomial fitting for each layer is performed. And the eight-neighborhood method is used to track the edge to form the closed edge curve and the curve is fitted with equal angle interval sampling. Then, according to the overlapping of the projection edges of each layer, the topology of each layer is determined and the optimal axis of rotation is found. For the edge points of different slice layers, the interlayer points are matched with the same phase as matching conditions; the polynomial fitting method is used to fit the edge points of each matching group, and the top point of the workpiece is estimated by extrapolation; finally, the interval between the edges of the layers is rotated by one phase angle interval to perform volume integration, and each rotation integral volume is added to calculate the workpiece volume.

According to the different shapes of the workpieces, the degree of deviation of the edges of each slice obtained by the scanning is not the same, so the method of three-dimensional measurement is also different. Usually, the processing method is to project the edges of each layer in the vertical direction. According to the difference in the coincidence of the projection edges, the correlation between the edges in each layer slice is determined, and different measurement strategies are selected. When the adjacent two slice edges are projected without intersection, it is usually considered that the two layer edges are not related to the topology structure and there is no need for inter-layer matching interpolation in the middle. When the adjacent two slice edges are projected, there is an intersection but the centroid point is not in the intersection, it is usually considered that there is a certain relationship between the two layers of the edge in the topology structure. The specific measurement strategies require the introduction of certain prior knowledge, which is not discussed in detail here. In the third case, there are intersections between the projections of the adjacent two slice edges, and the edge centroid points are within the intersection. In this case, the two edges are considered as having a close topological relationship, and the centroid point of each slice edge is found out, the matching interpolation is carried out according to the criterion of the phase equal between the centroid and the edge point.

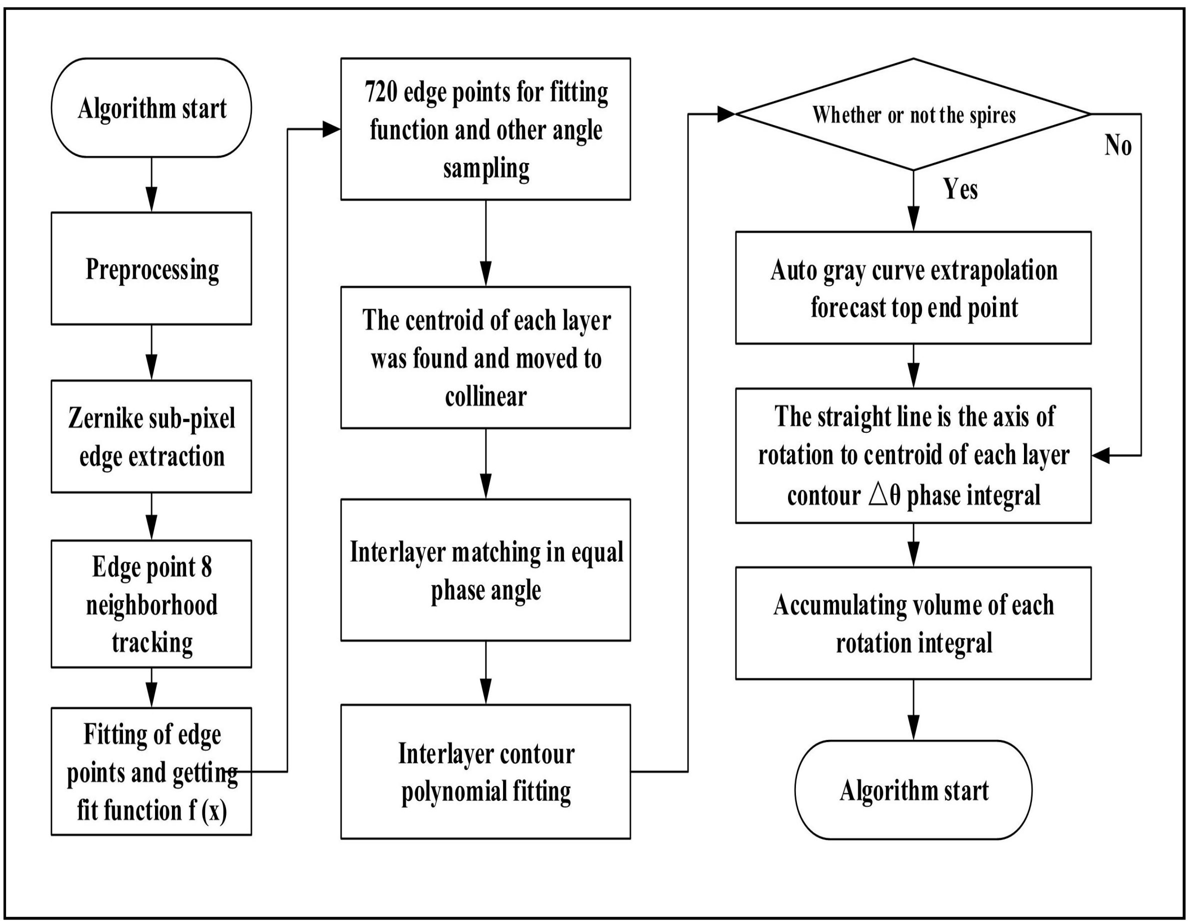


Figure 5. Flow chart of rotation integral algorithm

Although the edge centroid points between layers are not on a straight line, when the layers are matched, the phases of the edge points of each layer are calculated within the slice, so the matching of the edge points between layers can still be performed according to the principle of equal phase, then the rotation integral of the matching interlayer edge points is carried out. For the sake of convenience, the axis of rotation is selected as a vertical sliced straight line over the centroid point of the first layer, if the workpiece is a spire; the vertical sliced line over the vertex of the workpiece is selected. The rotational integration algorithm based on the CT imaging 3D measurement is shown in Figure 5.

Industrial CT as an important means of non-destructive testing, a very important advantage in engineering applications is that, under the premise of not destroying the integrity of the surface of the object to be detected, the inside of the object can be seen and the internal information of the object can be grasped, that is, it is irreplaceable in the measurement of the high precision of the volume of the cavity. In practical engineering applications, many workpieces have internal cavities or voids that are not directly visible. The volume of these cavities is often required to be measured and controlled with a high degree of accuracy, but the accuracy of the outer surface volume is not high. As a common automobile engine, as shown in Figure 4.27, the moment of inertia of the engine is controlled by the resonance of the inner cavity gas, and then the starting effect of the engine is controlled, therefore, the volume of the inner cavity of the engine needs to be accurately controlled and measured.

4. Result Analysis and Discussion

According to the above introduction, the steps of the platform body summation are area accumulation and then volume accumulation layer by layer. First, the edge of each layer obtained by scanning is edge-fitted, and then the stratified area of the data is calculated. In this paper, polynomials are used to fit the edge of each layer, and then the fitting function is sampled. The number of sampling points in each layer is 720, and the sampling phase angle interval is $\Delta\theta = 2\pi / 720$. The local imaging of the fitting of the edges of the bottom slice of the cylinder is shown in figure 6.

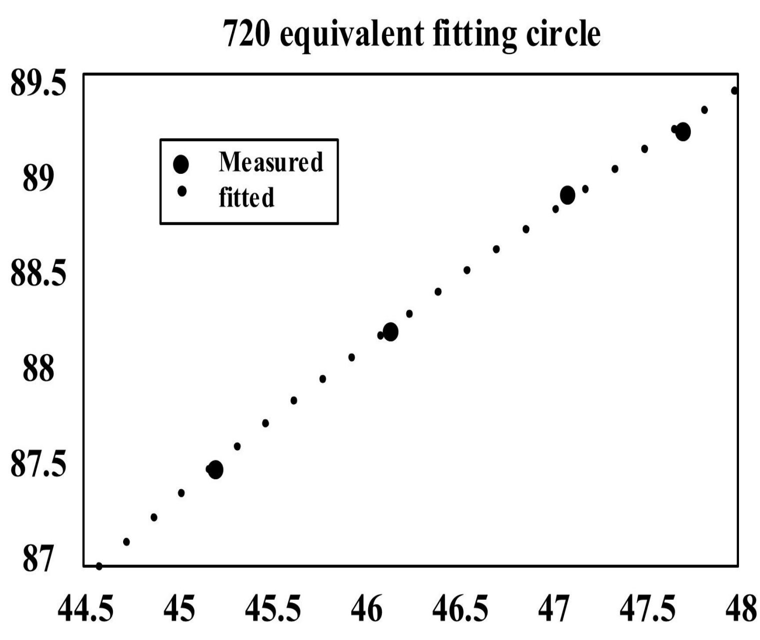


Figure 6. Zernike local edge contour and fitting rear contour

The following figure 7 describes the area measurement error of each slice edge of each workpiece in order to observe the variation trend of the measurement error of each workpiece.

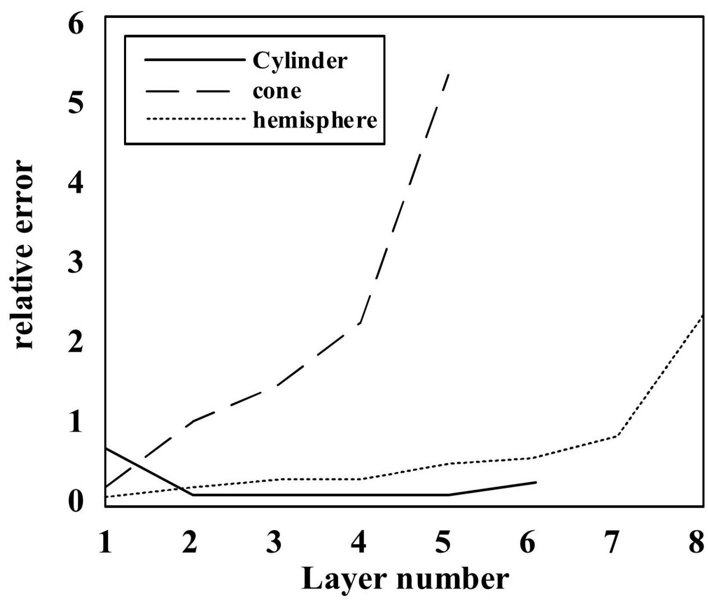


Figure 7. Error change curve

From Figure 7, it can be seen that the measurement error of each layer area of the cylindrical workpiece is basically stable and there is no large fluctuation; the error of each layer area of the conical workpiece is as follows: with the increase of the layer number, the trend from the bottom slice to the top slice is gradually increasing. The slope of the error curve is consistent with the change of the slope of the conical axis curve; the measurement error of each layer of the hemisphere workpiece shows a trend of non-linear increase from the bottom up with the increase of the layer number. The slope of the error curve is consistent with the change in the slope of the conical axis curve.

Because the measurement method used is completely consistent, it can be known that the difference in the measurement result is caused by the different shapes of the workpiece, that is, it is caused by the different axial change edge of the workpiece. The analysis shows that the measurement error of the top slice area of two spires of the cone and hemispheres is greater than that of the bottom slice. Because the top slice area of the measured workpiece is less than the bottom layer and the edge extraction algorithm is the same, the measure deviation is the same level, which causes the relative error of the measure of the top area to be greater than the bottom. The error curve is consistent with the change curve of the interlayer axial edge (Figure 8).

Because the method in the literature only realizes the measurement of simulation imaging, this method proposed in this paper is used to carry out volume measurement on the simulation model of cylinder, cone and hemisphere, which are equal to the actual workpieces in the text. For example, figure 8 and 9 are the error comparison between the results of this algorithm and the experimental results of the document algorithm measure, the curve of error change when measuring the area of each layer is described in Figure 9. It can be seen from the figure that the algorithm is obviously superior to the algorithm proposed in the literature, and it is easy to find that the measurement error of the two algorithms varies with the shape of the workpiece, but the variation trend of the measurement of the slice area of each layer is the same. For the measurement of cylindrical workpieces, the error of each layer of the two algorithms remains basically unchanged, while for the measurement of the conical and hemispherical shaped spires, with the increase of the layer number, the measurement error is all improved.

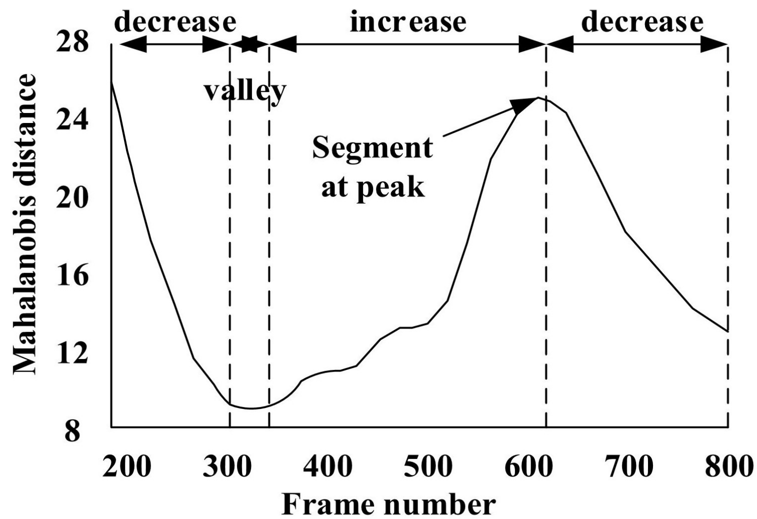


Figure 8. The change of average Mahalanobis distance

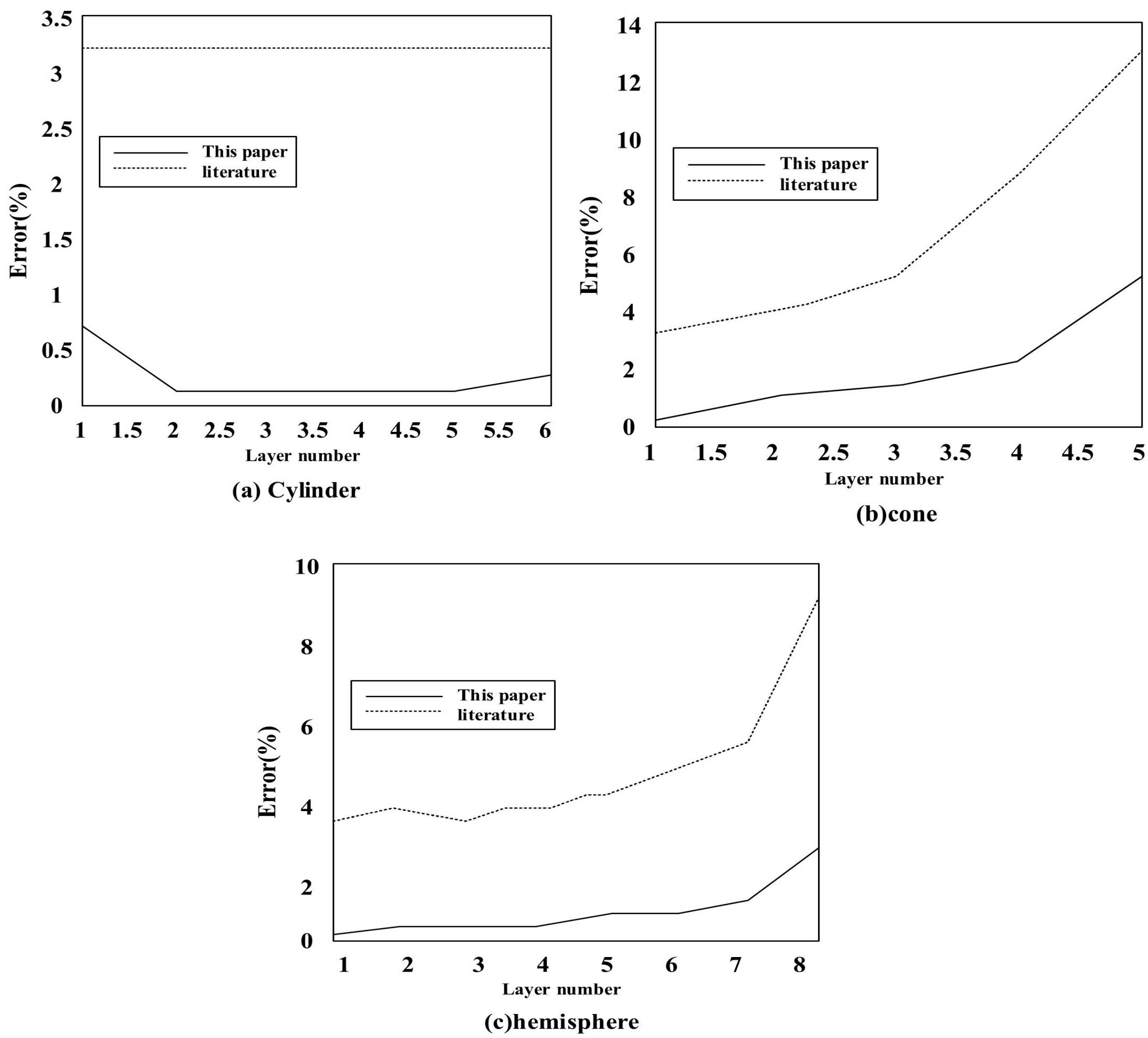


Figure 9. Comparison of the area measurement errors between this method and the literature method

Figure 9 is a histogram of the volume measurement error for the three workpieces in the algorithm and the volume measurement algorithm in the literature, and the normalized comparison of the measurement error of two algorithms.

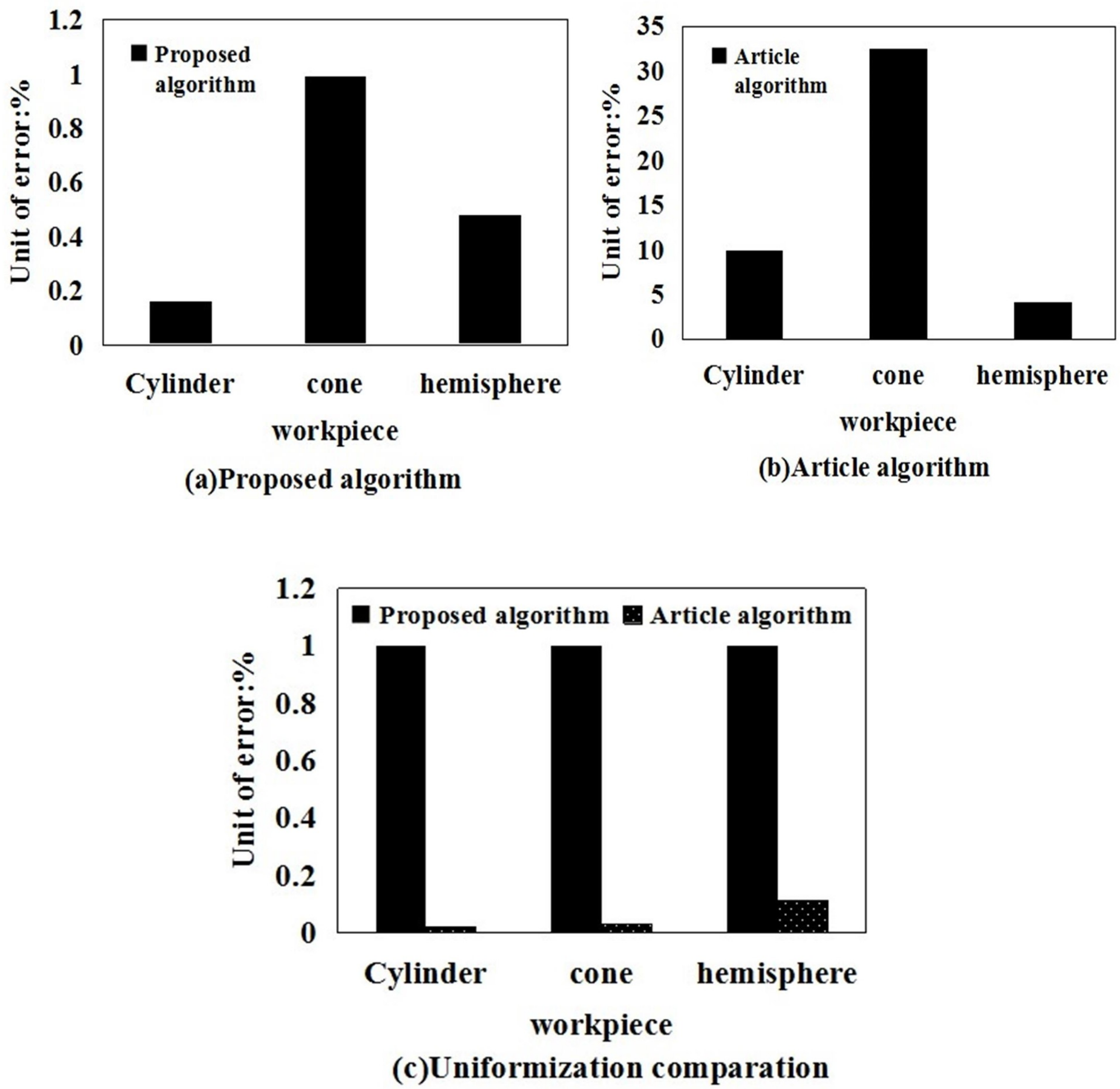
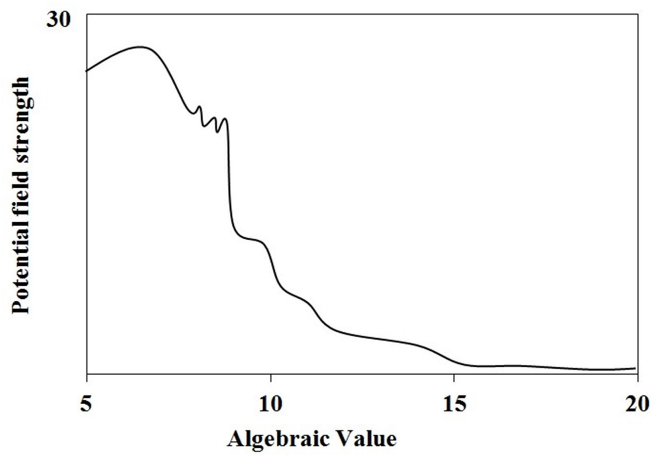
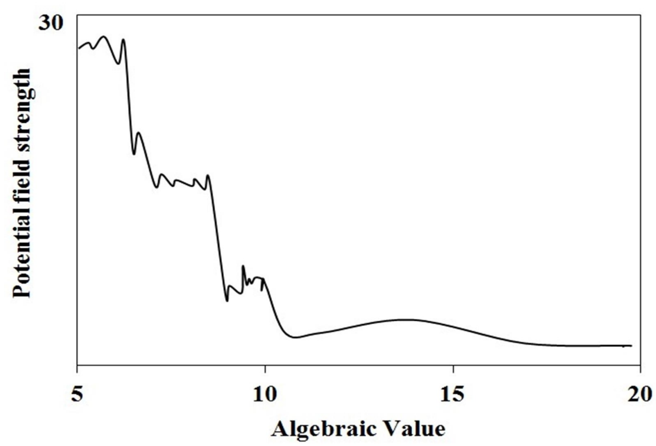


Figure 10. Volume measurement error (per unit:%)

As can be seen from Figure 10, the volumetric measurement errors of the literature method for simulated cylindrical, conical and hemispherical models are 9.85%, 32.452%, and 4.191%, respectively. The accuracy of the measurement is far from being able to meet the engineering application requirements. In this paper, the volume error of the actual CT imaging measure is better than 1%, and it can fully meet the requirements of the actual engineering accuracy. As shown in Fig. 10(b), the document volume measurement errors are in the order of cone>cylindrical>hemisphere, this is because the document volumetric measurement formula is a method for replenishing the high-height cylinder. The half-top volume of the cylinder is larger than the half-top volume of the hemisphere. Therefore, the cylinder error is slightly greater than the hemispherical error. In addition, the convergence of the algorithm in this paper is shown in the figure below. It can be seen that the algorithm runs more stable.



First experiment



Second experiments

Figure 11. Convergence test of the algorithm

For the same measurement objects as the bench accumulation methods described above: standard steel cylindrical, conical, and hemispherical workpieces are subjected to the volume measurement experiment by using the rotational integration method. After the interlayer matching, whether the workpiece is the tip shape or not is judged by whether the tangent of the interlayer edge curve has the intersection point, if it is, the automatic vertex prediction is carried out and the method is same as the platform body summation, which will not be described here.

5. Conclusion

Aiming at the problem that the shortage of the Directional resolution of Slice imaging Z of industrial CT that led to the low accuracy of three-dimensional measurement, two 3D volume measure algorithms based on sub-pixel Zernike moments edge detection and polynomial fitting are proposed: the platform body summation method and rotation integral method, the actual workpiece volume measurement experiment is carried out and the measurement result is better than 1%, which meets the requirement of high accuracy in practical engineering application. A three-dimensional volume measurement algorithm based on interlayer sub-pixel fitting and edge rotation integration is proposed, the volume obtained by rotating the interlayer fitting edge for a certain angle is used to replace the volume of workpiece under a phase angle interval. Through the experiment of scanning imaging the same practical workpiece, it is proved that the algorithm is better than the platform body summation algorithm in the measure accuracy, and the more complex the axial edge change of workpiece is, the more accurate the measure is, when the degree of nonlinearity is stronger. The causes of measurement error in volume measurement method of the platform body summation method and rotation integral method are analyzed in detail, and according to the different shapes of experimental measure object, the applicability of two algorithms to the shape of the workpiece is analyzed. For the problem of measuring the volume of inner cavity often occurs in practical application, taking the actual inner cavity workpiece as the measure object, cavity volume measurement experiment is carried out, and the experimental results are better than 0.61%, and the causes of measurement error are analyzed.

References

[1] Vogl, T. J., Schaefer, P., Lehnert, T., Nour-Eldin, N. E. A., Eichler, K., Kerl, J. M., Scholtz, J. E., Naguib, N. N. N., Wichmann, J. L., Hammerstingl, R. M., Zangos, S., Gruber-Rouh, T. (2016). Intraprocedural blood volume measurement using C-arm CT as a predictor for treatment response of malignant liver tumours undergoing repetitive transarterial chemoembolization (TACE). *European Radiology, 26*(3), 755-763.

[2] Henschke, C. I., Yankelevitz, D. F., Yip, R., Reeves, A. P., Farooqi, A., Kattan, M. W. (2016). Tumor volume measurement error using computed tomography imaging in a phase II clinical trial in lung cancer. *Journal of Medical Imaging, 3*(3), 035505.

[3] Reis, H. Ç., Bayram, B., ªeker, D. Z. (2016). A semiautomatic segmentation approach to biometric measurement of the talus bone of sedentary women and ballerinas using CT images. *Asian Biomedicine, 10*(5), 455-459.

[4] Wotherspoon, A. D., Burgin, S. (2016). Lizard testes volume measurements: Are they always underpinned by the correct assumptions? *European Journal of Anatomy, 11*(3), 163-167.

[5] Huttin, O., Voilliot, D., Mandry, D., Juilliere, Y., Selton-Suty, C. (2016). All you need to know about the tricuspid valve: Tricuspid valve imaging and tricuspid regurgitation analysis. *Archives of Cardiovascular Diseases, 109*(1), 67-80.

[6] Clanton, T. O., Ho, C. P., Williams, B. T., Backus, J. D., Dornan, G. J., LaPrade, R. F. (2016). Magnetic resonance imaging characterization of individual ankle syndesmosis structures in asymptomatic and surgically treated cohorts. *Knee Surgery, Sports Traumatology, Arthroscopy, 24*(7), 2089-2102.

[7] Chae, S. H., Moon, H. M., Chung, Y., Kim, S., Park, R. W. (2016). Automatic lung segmentation for large-scale medical image management. *Multimedia Tools & Applications, 75*(23), 15347-15363.

[8] Bawaneh, M. J., Obeidat, A. A. (2016). A secure robust gray scale image steganography using image segmentation. *Journal of Information Security, 7*(3), 152-164.

[9] Winklhofer, S., Lambert, J. W., Sun, Y., Anderson, S. W. (2016). Pelvic beam-hardening artifacts in dual-energy CT image reconstructions: Occurrence and impact on image quality. *AJR American Journal of Roentgenology, 208*(1), 1.

[10] Zhang, P., Lu, S., Li, J., Zhang, C., Zhang, Y. (2017). Multi-component segmentation of X-ray computed tomography (CT) image using multi-Otsu thresholding algorithm and scanning electron microscopy. *Energy Exploration & Exploitation, 35*(3), 281-294.

[11] Zhang, Y., Yue, Y., Yang, G., Liu, Y., Zhu, Y. (2017). A method of increasing precision for hand bone models reconstruction of CT images. *Journal of Computer-Aided Design and Computer Graphics, 29*(10), 1802-1806.

[12] Pan, T., Martin, R. M., Luo, D. (2017). New prospective 4D-CT for mitigating the effects of irregular respiratory motion. *Physics in Medicine & Biology, 62*(15), N350.

[13] Wi, J. M., Sung, K. H., Chi, M. (2017). Orbital volume restoration rate after orbital fracture: A CT-based orbital volume measurement for evaluation of orbital wall reconstructive effect. *Eye, 31*(5), 713.

[14] Shafiq-Ul-Hassan, M., Zhang, G. G., Latifi, K., Ullah, G., Hunt, D. C., Din, S. U. (2017). Intrinsic dependencies of CT radiomic features on voxel size and number of gray levels. *Medical Physics, 44*(3), 1050.

[15] Sec, S. E. C. (2017). Statistical analysis of feature extraction for CT brain image using reduced gray level run length method. *Journal of Advanced Research in Dynamical & Control Systems, 9*(2), 60-66.