Three-Dimensional Reconstruction of Continuous Tomographic ICT Images of Defective SRM

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Abstract. As an advanced technology for non-destructive testing of defective SRM, industrial computed tomography can visually show the structure of the SRM's transverse section. 3D reconstruction of continuous tomographic images technology can convert the 2D images obtained into 3D visualization models, thus accurately determine the size and distribution of internal defects in the SRM, etc. Study the main technical methods of 3D reconstruction, it mainly includes 2D images denoising, edge detection and gray-scale image segmentation. Project, accumulate and render the pre-processed 2D images to obtain the 3D model, and then smooth the surface of the 3D model, the end result is a clear reconstruction model. The reconstructed 3D model can provide efficacious data support for SRM non-destructive testing, making the testing results more real and effective.

1. Introduction

During the long-term storage and on-duty work of solid rocket motor (SRM), due to environment, load and other factors, the SRM will produce different degrees of defects and damage. These defects are most likely to expand under the SRM operating conditions, causing the SRM become invalid and even exploded. For a long time, due to the lack of advance detection technology, in order to ensure safety, engineers had to eliminate some defective motors but work fine, resulting in a great waste of resources. So, it is of great strategic significance to evaluate and predict the performance of defective SRM. Industrial Computed Tomography (ICT) as an advanced technical means for non-destructive testing of SRM, the ICT images obtained from the scan can reflect the structure of the propellant grains in the slice. In medicine, doctors mainly use the medical knowledge and experience to judge the structure of slice images to achieve the purpose of diagnosis. However, this method relies on the personal experience of the doctor, for engineers, they often do not have the relevant knowledge to directly analyze the ICT images, therefore, it is difficult to make an effective analysis of the overall performance of the SRM with only 2D images. This makes the 2D images inverse 3D model become a more effective way to solve this engineering problem. This technology can visualize the internal structure of the SRM, allowing researchers to directly analyze and process the 3D model they have built [1, 2, 3]. Since the 3D reconstruction is a process from discrete to continuous, it will inevitably result in the loss of some information. The problem that arises from this is the contour mismatch between layers, so the accuracy of the reconstructed model will also be affected. The most direct way to improve the accuracy of models is to reduce the scanning interval. However, when the resolution of the existing
ICT machine is not enough to scan the slice at a smaller interval, it is particularly important to choose an appropriate reconstruction method.

2. Reconstruction method
In the current research, the method used are mainly divided into surface rendering and volume rendering. The advantage of the surface rendering method is that the model generation speed is fast, but this method only reconstructs the surface of the measured object, and cannot obtain data information inside the object. The volume rendering method can be used to display the internal structure of the object, but this method requires a large amount of information in the calculation process, so the model generation speed is low [4].

2.1. Surface rendering
In the process of 3D reconstruction by surface rendering method, firstly, the image is processed for noise filtering and edge detection, and then the detected edge information is subjected to inter-layer interpolation processing, thereby splicing to obtain the object surface and smoothing the surface, finally, rendering to get a 3D surface model. The main process is shown in Figure 1. Typical surface rendering algorithms mainly include Connected Contour, Cuberille, Marching Cube and Dividing Cube [6].

![Figure 1. The main process of surface rendering method](image)

2.2. Volume rendering
The central idea of volume rendering is to first analyze the transparency and brightness of the voxels, and then calculate the emission, reflection and transmission of light through the voxels to obtain a projected image. Typical volume rendering algorithms include Ray-Casting, Splatting and Shear-Wap [7]. Voxels represent the properties of a point in space, such as color, density, opacity, etc. In the actual calculation process, the voxel can be simplified into a cube, as shown in Figure 2.

![Figure 2. Volume data and voxel](image)

3. Reconstruction process and result analysis

3.1. Image denoising
There are often a lot of noises in the two-dimensional images directly generated by ICT machine. Therefore, image denoising must be performed before image processing. The main purpose of image denoising is to improve the accuracy of the reconstructed model. The methods commonly used for processing are Disk filtering, Gaussian filtering, Average filtering, and Median filtering. During the
denoising process, care must be taken not to destroy the edge information of the image, otherwise the edge information cannot be effectively extracted. The processing results of four different methods are shown in Figure 3. In the figure, a indicates the Disk filtering, b indicates the Gaussian filtering, and c indicates the Average filtering and d indicates the Median filtering.

![Figure 3. Denoising effect of different methods](image)

As can be seen from the figure, different filtering methods have significant differences when filtering images. Disk filtering caused a blurred visual effect after processing, and also filtered some valid information in the image; Gaussian filtering and Average filtering produce clearer images, but during the processing process, the edges of some details are damaged, which will affect subsequent analysis; compared with the above three methods, Median filtering not only can effectively filter noise, but also has a better retention of image edge information.

3.2. Edge detection
The main principle of edge detection is to determine the gray level change rate of pixel information in a certain area of the image through algorithms. The change law of the direction derivative near the edge has obvious characteristics compared to other areas, so that the edge information of the image is obtained. The edge detection operators mainly include Roberts operator, Sobel operator, Prewitt operator, Approxcanny operator, Log operator and Canny operator. The test results of different operators are shown in Figure 4, and the test results are analyzed and compared in the following.

![Figure 4. Test results obtained by different operators](image)
In the figure, a indicates Roberts operator, b indicates Sobel operator, c indicates Prewitt operator, d indicates Approxcanny operator, e indicates Log operator, and f indicates Canny operator. From the test results in the figure, the results obtained by different operators are quite different. Roberts operator can get relatively thin edges, but the information is seriously lacking, resulting in discontinued edges; Sobel operator and Prewitt operator get continuous results, but it is easy to produce false edges; Approxcanny operator and Log operator have better continuity, but they are more sensitive to noise and cannot effectively identify noise; compared with other operators, the Canny operator obtains a clearer, complete and smooth edge, and can effectively recognize the noise contained in the image.

3.3. Gray-scale image segmentation
Image segmentation is one of the basic problems of image processing and computer vision. Segmentation is usually used for further analysis and recognition of images. The purpose of segmentation is to separate the target area and background area of the image, so as to further reduce the interference of background factors and improve the quality of image reconstruction. During the research, it was found that the selection of the threshold has a great impact on the results obtained. Figure 5 shows the effect of choosing inappropriate thresholds on the segmentation results. In the figure, a and b respectively show two cases where the threshold is too large and too small. When the threshold is selected too large, it is easy to overwhelm the contained defects and the SRM case is likely to affect the results; however, when the threshold is selected too small, it is easy to confuse some areas inside the grain with the background. Therefore, an appropriate threshold value needs to be selected to obtain an ideal segmentation result. Figure 6 shows that the histogram threshold method is used to determine the threshold, and the obtained threshold is used for image segmentation. A clear segmentation result can be observed from the figure.

![Figure 5](image5.png)

**Figure 5.** Segmentation result of inappropriate threshold

![Figure 6](image6.png)

**Figure 6.** Histogram threshold segmentation results
3.4. Reconstruction results display

The 3D model is obtained after rendering the 2D image processed as described above. But some noise is inevitably retained in the volume data, which causes the surface of the reconstructed model to be not smooth enough. Therefore, the surface of the model needs to be smoothed, and more realistic results can be obtained after the smoothing, as shown in Figure 7.

![Figure 7. Reconstruction model](image)

Sectioning the generated model can facilitate the feature extraction and classification of defects. The sectioning method is to find the intersection of the anatomical section and each slice in the 3D model according to the given section, divide the slice into two different regions through the intersection line, and redraw the segmented model to get the desired section model. Figure 8 shows the results of cutting along.

![Figure 8. The results of cutting along](image)

The Volume rendering image is essentially a linear superposition of the color values and transparency of the sampling points on the ray. If different color values are assigned to different structures, the opacity of the model can be adjusted when rendering, and then the internal structure and relative position can be observed. As shown in Figure 9.

![Figure 9. Reconstruction model](image)
4. Summary
This paper studies the application of continuous tomographic ICT image 3D reconstruction technology in the non-destructive testing of defective SRM, and makes the following conclusions:
1. Briefly analyzed the basic ideas of surface rendering and volume rendering in 3D reconstruction, and explain the advantages and disadvantages of each method;
2. The effects of four different denoising algorithms are explained in comparison, and the effect of the median filtering algorithm is the most ideal;
3. Analyzed the effect of six different operators on image edge detection, and conclude that the effect of Canny operator is more clear than several other operators;
4. Analyzed the effect of threshold selection on gray-scale segmentation, and use the histogram threshold to obtain better segmentation results;
5. The results obtained in this paper can use the numerical simulation method to simulate the combustion and flow process of SRM, thereby getting some indicators to reflect the working performance of SRM.

5. References
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