Abstract
The three-dimensional (3-d) reconstruction and visualization of serials of industrial computed tomography (ICT) images is an important research aspect for large objects nondestructive detection. In the course of 3-d reconstructions of the continuous equidistant ICT images, the contour lines of every tomogram are picked out and joint by triangles in serialized order. After the stereo images of the scanned objects are displayed, some special functions, including views from different angles and orientations, nondestructive measurement of 3-d parameters, will be carried out just by operating the computer mouse and keyboard. The inspectors can get more detailed structural information by the reconstructed images. So in this way the convenience and veracity of the nondestructive detection have been promoted.

Keywords: industrial computed tomography (ICT), three-dimensional (3-d) reconstruction, nondestructive detection

1 introduction

As one of the most efficient nondestructive detection and testing method, the Industrial Computed Tomography (ICT) gets more widely used. And some researches about it are attractive and hot. In high energy X-ray ICT system for large objects’ detection, a linear-array detector is commonly used and a tomogram is got. The tomogram is two-dimensional (2-d), so the information at one layer is limited. It’s difficult to achieve the dimensional information, such as geometric shape and dimensional size. In recent years, the research applying the three-dimensional (3-d) reconstruction and visualization of images to ICT is widely developed. The reconstructed dimensional image from serials of ICT images gives more information of the detected objects to inspectors. For it helps to qualitative analysis and even quantitative analysis sometime of the dimensional structure or existent lacunas by views from different angles and orientations, nondestructive measurement of 3-d parameters. At the same time the convenience and veracity of the nondestructive detection have been promoted.

In this paper, some method about 3-d reconstruction and visualization of continuous equidistant ICT images is developed. During the course the contour lines of every tomogram are picked out and joint by triangles in serialized order. Some functions as dimensional rotation and measurement are carried out by programming, which enables man-machine conversation convenient.
2 3-d reconstruction foundation

The grad information of every pixel, which stands for the dimensional positioning structure in one tomogram, is got by analyzing the relationship between the grey scale of single tomogram and spatial orientation vector grad. So the 3-d coordinate information for every pixel, that is the 3-d data of the ICT images, can be educed in this way. The dimensional information of continuous equidistant ICT images is processed and joint according to some algorithm. After all the 3-d parameters of the whole object are achieved and arranged in order, the stereo image is got and displayed on the screen. One difficulty of the job is to extract 3-d coordinate information from 2-d data, including proper threshold segmentation for CT images, extracting contour information of the object from different tomogram data. During the research, some automatic threshold segmentation methods are done, such as maximum entropy, double peak, histogram segmentation and so on. The result turns out the threshold segmentation based on histogram is more efficient and suitable for many different objects.

The 3-d reconstruction flow of ICT images begins from scanning the objects equidistantly and continuously, then taking and saving the data in order. Contours of every tomogram extracted by threshold segmentation are combined with the Z axis parameter, which converts the 2-d array to 3-d array. Then triangles are used to join the corresponding points in adjacent two tomograms in a specified direction. This forms the dimensional vector array and is fundamental to 3-d reconstruction.

3 3-d reconstruction results

The whole soft is composed of three functional modules: 3-d reconstruction, 3-d visualization and 3-d analysis. (1) In reconstruction module, the parameters of the object as scale factors of X,Y,Z axis, threshold segmentation, interpolation methods choice can be set; (2) In visualization module, some operations on reconstructed image can be implemented, including rotation, zooming, color changing; (3) In analysis module, aimed to get the inner structure images of objects is dealing with measurement, clipping operations. It enables inspectors to get some inner information nondestructively.

3.1 3-d reconstruction module

The function is to reconstruct the continuous equidistant CT tomograms to 3-d image. Image matrix is free style, 512 multiply 512 or 1024 multiply 1024 or other size will be all right. But matrix size of every tomogram for one object should be the same. It’s important that the X, Y, Z scale factor should be correctly set. For example if the pixel distance in X,Y directions is 0.1mm, while the counterpart of Z is 1mm, then Z scale factor is 10 times compared to that of X,Y. The difference should be taken into accounts. During the reconstruction, not all the scanned tomograms are needed. It’s for inspectors to decide how many tomograms to be reconstructed, and the only limitation is the tomogram number should no less than two. Figure 1 shows an example of photo and its 3-d reconstructed image of a plane turbine blade.
The reconstructed time is various for different objects. It mainly depends on the matrix size of tomograms. Under the same circumstances, the bigger the size, the more time is for reconstruction. For example, the time for seventy 512 multiply 512 tomograms of aero-engine blade is thirteen seconds, while that for thirty-six 1024 multiply 1024 of an engine casting is three minutes. Besides the simplification of objects contributes to reconstruction time. The more complex the object, the more time is for reconstruction. For the same matrix 512 multiply 512, reconstruction time for aero-engine blade is thirteen seconds while for air cleaner is seventy seconds.

3.2 3-d visualization module

In this module, the main function is to supply different views of the reconstructed image to inspectors. In some cases, objects should be rotated from one angle to another. In other cases, objects should be zoomed to show the detailed part or be changed to different color to adapt for different parallax. Figure 2 shows four images of an air cleaner from different angle of view. This helps inspectors to have a more detailed understanding of object structure.

3.3 3-d analysis module

The function is designed to get information of inner structures or find out possible interior defects of objects nondestructively. Reconstructed images can be clipped according to angles or coordinate values. For objects composed of several layers, the reconstructed images can be peeled off just like taking the clothes off one by one. Figure 3 demonstrates the contrast between digital radiography image and some 3-d image, 3-d half cut off image, 3-d peeled off image of the air cleaner. It shows the inner structure without cut the object open.

The function also develops dimensional measurement. But as the three coordinate scale factor always can’t be the same because of the limitation of linear array detector, the measurement precision is not good enough for application. It’s also the bottleneck for reconstruction research.
Figure 3. images from left to right in order are: digital radiography; 3-d reconstructed image; 3-d half cut off image; 3-d peeled off image of the same air cleaner

4 conclusion

Through 3-d reconstruction and visualization of serials of ICT images, it helps inspectors to better understand or get more information of inner structures of objects. It makes the qualitative analysis and even quantitative analysis of the inner dimensional structure or existent defects nondestructively possible. Meanwhile if the dimensional arrays are be saved as stl format, reconstructed 3-d images can be exported to soft like SOLIDWORKS and prepare for reverse engineering. But some more work about measurement precision and functional development should be done for further application.