Automatic Industrial CT Image Processing and Analysis of Batch Workpiece NDT Based on the VGStudio SDK

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Abstract. The Industrial Computed Tomography (ICT) is an advanced NDT technology to get exact internal and external structure information of the tested specimen. The nondestructive testing personnel can control the outgoing quality of workpieces by ICT image processing and data measurement. In this paper, we introduce high energy industrial CT system with accelerator X-ray source which is developed for batch NDT of production process. In this ICT system, multiple workpieces CT scanning can be carried out at the same time, and the CT images of different positions can be acquired to the image inspection workstation. Obviously, the testing personnel are very difficult to meet the requirements of batch NDT manually. In this study, the template matching algorithm was adopted to split this kind of CT image into single specimen and store in different images. This paper introduces the development of image auto-analysis based on the SDK of the VGStudio Max. The results show that individual specimen is more accurate and the effect of automatic analysis is satisfactory. In Summary, we propose the auto-processing method for the batch NDT and for high efficiency in application.

Introduction

Since 1972, the British EMI engineer Hounsfield invented the world's first CT scanners, CT imaging technology with excellent performance has been widely used in medical diagnosis and non-destructive testing (NDT). This article focuses on the NDT. In addition to obtaining the internal structure information of the tested sample, we can also use CT technology for defect detection, dimension measurement, reverse engineering, the finite element analysis, etc. After the development in the recent decades, the performance of ICT is increased gradually, the scope of the tested sample is becoming more and more widely, for example: Automobiles, Materials, Geology, Petroleum, Ships, Railways, Electronics, Aerospace, Nuclear power, Food, etc. [1-3]

When modern industry moves into the era of batch production process, it is required faster and more efficient detection and analysis than any time before. With the significant improvement in penetration and resolution, the high energy industrial CT system can provide a good solution for batch detection and analysis in the modern industrial production. We developed an automatic turnover device for this ICT system, as shown in Figure 1. It can
detect multiple workpieces simultaneously and receive the CT images of different direction and different position. When the production processes in a batch, it is obviously not feasible to control and analyze the quality of products by testing personnel manually. We introduce automatic image processing and analysis methods into the batch production with the most advanced digital image processing technology. ICT generates a CT image with a few workpieces at the same time, and then the CT image of individual workpiece is extracted with our image matching method. VGProject SDK has a powerful function to execute the macro recorded in the individual artifact CT data and to automatically analyze the defect detection and to measure the wall thickness and the dimension of the workpieces.

Fig. 1. Turnover device for the high energy ICT system

The outline of the rest of this paper is organized as follows: Section 2 is mainly about the composition of high energy industrial CT system. Section 3 introduces the automatic image processing and analysis method for batch, including image matching method that separates the original CT images into several workpieces, and how to implement automatic analysis by using VGProject SDK. Experimental results are presented to demonstrate the capabilities of this approach. Section 4 has the discussion and conclusion.

1. The Composition of High Energy Industrial CT System

The high energy industrial CT system consists of X-ray source, detector, scanning device, scanning control and reconstruction system. The system structure is shown in Figure 2. The X-ray source of this high energy CT system is a small volume, high power standing wave linear accelerator, which generates X-ray of 6MeV. The X-ray is featured of strong penetration and high resolution, which is appropriate for batch NDT. The X-ray projection image is collected through the tested sample by low noise, high efficiency linear array detector and transferred to the reconstruction inspection system. Scanning device system carries the equipment such as X-ray source and imaging device, and is responsible for the mechanical movement of the testing process accurately. The Scanning control system is responsible for the motion control of the scanning device system, and receives the instruction of the reconstruction inspection system to trigger accelerator for X-ray. Reconstruction inspection system is the brain of the entire industrial CT system, including System Control Station(SCS), ReConstruction Station(RCS), Inspection Station(IPS), database and others related network hardware equipment.
Testing personnel can configure the scanning parameters and issue the scanning command through the SCS, which controls the coordination of the various modules in CT system. RCS reads the X-ray projection data acquired by the detector and reconstructs the CT image. Through IPS, Image inspection personnel can complete the quality evaluation of tested sample by reviewing image, gray scale transformation, dimensional measurement, etc. \cite{4,5}

![Diagram](image.png)

Fig. 2. The composition of high energy industrial CT system

2. Automatic image processing and analysis method

The automatic image processing and analysis technique for batch workpieces in this thesis is divided into two steps. From the forgoing, batch detection can detect multiple artifacts of the same type synchronously, and then all of these workpieces appear in reconstructed CT image. Therefore, the template matching methods is aimed at extracting the single workpiece at first. The same module of the workpiece adopted consistent operation and parameters to execute analysis in VGStudio MAX. In the second step, we recorded the procedure as a macro, and applied the function provided by VGProject SDK in IPS to call the macro to complete the analysis of the same model of workpieces.

2.1 CT image segmentation

In this paper, we take water pump as an example in our experiment. The placement of the tested samples and reconstruction results are shown in Figure 3. Though we needn’t take the turnover device in Figure 1, the various positions of the parts are displayed clear.
The image template matching is the process to search a matching sub-image in the result with a known template image. Generally, it is classified into two categories: one is based on the gray value and the other is based on image feature. The image processing function that we developed can locate the multiple workpieces to implement segmentation by Normalized cross correlation matching algorithm (NCC) based on gray value \[6\][7]. If the image template matching based on image feature is used on this kind of CT image, a single workpiece cannot be obtained perfectly because that there will be a number of workpieces that those features match the templates, and the image feature is not stable as well.

Let’s assume that \(T\) is the template image, the size of which is \(M_x \times M_y\) and \(S\) is the matching image, the size of which is \(N_x \times N_y\). The template image translates on the matching image according to Figure 4, where \(S^{i,j}\) is the possible sub-image, \(i\) and \(j\) is the position of the upper left corner of the sub-image in the matching image, \(1 \leq i \leq N_x - M_x + 1, 1 \leq j \leq N_y - M_y + 1\). The position of the maximum normalized cross correlation coefficient between sub-image and the template is defined as the matching result. The calculation formula of the normalized cross correlation coefficient can be written as:

\[
R(i, j) = \frac{\sum_{m} \sum_{n} S^{i,j}(m,n) \cdot T(m,n)}{\left(\sum_{m} \sum_{n} (S^{i,j}(m,n))^2\right)^{1/2} \left(\sum_{m} \sum_{n} [T(m,n)]^2\right)^{1/2}}
\]

**Fig. 3.** The placement of the tested samples (a, b) and reconstruction results (c, d)
Fig. 4. Left is matching image, right is template image

Image template matching segmentation algorithm steps:

1. Creating template and workpiece region

Figure 5 reveals the operation of creating template and workpiece region in IPS: the small rectangle area is viewed as template image because of its unique and distinctive features, and the large rectangle defines the region occupied by a workpiece. Before creating the two regions, we rotated the picture so that the sample is well placed. The relative position between the two rectangles is utilized to achieve single workpiece location directly in (3) step. We also have to set the number of same module artifacts in matching image as decision condition to terminate the template matching method and assume that the number was $m$.

2. Matching the image

Sometimes, rotation angle exists between template image (such as small rectangle in Figure 5) and matching image (such as Figure 3(c)), therefore, using the warpAffine() and matchTemplate() of OpenCV to obtain the normalized cross correlation coefficient of template image.

3. Getting segmentation results
By comparing the normalized cross correlation coefficient, we adopt the angle span and distance span among workpieces as judgement to get matching position results. According to the relative position between the template and the workpiece that is given in step (1), all the workpieces can be divided individually. We see from Figure 6 that each workpiece can be segmented correctly.

![Fig. 6. The separation results](image)

2.2 CT image analysis based on VGProject SDK

VGStudio MAX is the high-end software from the Volume Graphics range of products for the visualization and analysis of industrial CT data, which includes the optional analysis modules Coordinate Measurement, Nominal/Actual Comparison, Porosity/Inclusion Analysis, Wall Thickness Analysis, Fiber Composite Material Analysis, and CAD Import(with PMI)[8][9]. Volume Graphics provides free VGProject SDK which is supported with VGStudio MAX to CT manufactures[10]. Applying VGProject SDK in IPS, we are able to start up VGStudio MAX instance with scanned CT data remotely or locally, start up macro instruction without operating the VG software manually and actualize automatic analysis. Several major classes in SDK: Project, VolumeDescriptor, ReconstructionDescriptor, RemoteControlClient, Job.

The steps of automatically analyzing CT data based on SDK are as follows:

1. Saving CT image containing single workpiece
   Saving CT image containing single workpiece involves VolumeDescriptor and Project classes. The function of VolumeDescriptor is to describe the CT data, such as filename, file format, data type, image size, image resolution and other parameters. Project, which calls save() to save the CT data described by VolumeDescriptor as .vgl file, is to define all the related information with the VG project.

2. Recording macro file
   Using macro instruction can batch CT data. Each step process was recorded as .vge macro file, and the workpiece of same type applied the macro to achieve the results of the same processing steps.

3. Starting up the macro
   RemoteControlClient class, as its name suggests, is remote control VGStudio MAX. In this class, createApplication() is to start a new VGStudio MAX instance on host, loadProject() is
to load .vgl file into existing VGStudio MAX instance, runJob() is to use an instance of the Job class to run a macro on a VG project, terminateApplication() is to terminate a running VGStudio MAX instance. Using those functions in IPS can deal with CT data automatically according to the macro. Figure 7(a) is the result of visualization of wall thickness analysis, the color bar is mapped by wall thickness. Figure 7(b) shows the saved .csv file, which records the location and wall thickness information.

![Figure 7(a)](image1)

![Figure 7(b)](image2)

Fig. 7. (a) result of visualization of wall thickness analysis, (b) records of the location and wall thickness information.

3. Discussion and Conclusion

In this paper, we propose automatic image processing and analysis technique for batch detection based on high energy industrial CT system. With template matching method, an
individual workpiece can be segmented accurately. CT image inspection station IPS start up macro by the function of VGProject SDK to accomplish the automatic analysis, and the result is satisfactory. We not only take wall thickness as an example, but also perform others analysis, such as defect detection, coordinate measurement. The normalized cross correlation matching algorithm based on gray value is chosen to segment CT image in this paper, but it is time-consuming, so we will explore how to finish the image segmentation more quickly in the future.

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References