SOCIETY FOR SCIENCE AND EDUCATION
UNITED KINGDOM

JBEMi JOURNAL OF BIOMEDICAL ENGINEERING AND MEDICAL IMAGING VOLUME 1, ISSUE 1

Recovery and processing of 3D images in X-ray tomography

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ABSTRACT

The article is to study operating procedures of an X-ray micro tomographic scanner, and the module of reconstrusction and analysis 3D-image of the test sample in particular. An algorithm for 3D-image reconstruction based on the image shadow projections and mathematical methods of the processing are described. Chapter 1 describes the basic principles of X-ray tomography, general procedures of the device developed. Chapter 2 and 3 are devoted to the problem of resources saving by the system during the X-ray tomography procedure, what is achieved by preprocessing of the initial shadow projections. Preprocessing includes background noise removing from the images, which reduces the amount of shadow projections in general and increases the efficiency of the group shadow projections compression. Chapter 4 covers general procedures of defect search, which is based on the vector analysis principles. In conclusion, the main applications of X-ray tomography are presented.

Keywords: X-ray tomography, 3D-image analysis, 3D-reconstruction, data compression, background noise removing, defect search.

1. INTRODUCTION

Modern manufacturing, including production and application of medical equipment and devices, require adequate methods of diagnostic quality control of structure of organic and inorganic topologically and compositionally heterogeneous objects. Detection and precise localization of defects are the main advantages of X-ray micro tomographic control [1].

X-Ray micro tomography is a layer-by-layer method of study of the internal structure of an object with the aid of multiple radiographic X-rays in different directions, followed by 3D-reconstruction recovery and processing of images. Scanning visualizes the entire internal 3D structure of the object, keeping it safe for other types of research. High-resolution of the model received is another advantage of the X-ray micro tomographic scanning method.

X-Ray micro tomographic scanner developed by the research group of Tomsk State University is designed to study the spatial structure of materials and crystals with a resolution of 1-13 microns.

DOI: 10.14738/jbemi.11.102
Publication Date:15th February 2014
URL: http://dx.doi.org/10.14738/jbemi.11.102

2. BASIC PRINCIPLES OF X-RAY MICRO TOMOGRAPHIC SCANNING

After installation of the test sample on the desktop (working area) of the scanner and giving a command for 3D recovery by an operator the system starts processing.

The desktop, with the sample on it, begins to rotate. At the same time the capture device of shadow projections with fixed frequency, connected with the rotation angle of the desktop, takes pictures of shadow projections and transmits the data to the working (memory) storage.

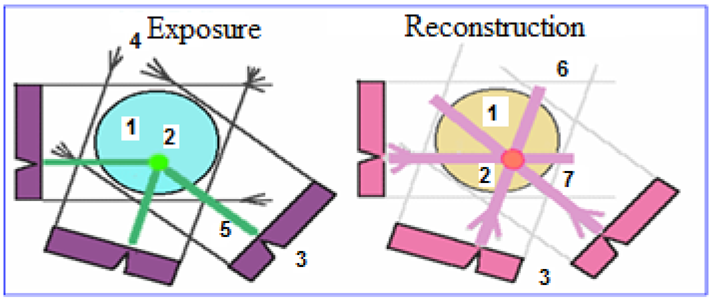

Figure 1. Diagrammatic view of the three different positions of the absorbing area and the reconstruction of the shadow projections received

In Figure1,

1 - Sample

2 – Heterogeneity area

3 - Capture device of shadow projections

4 - X-ray direction

5 – Projection lines of the heterogeneity area

6 - Lines of the sample recovery boundaries

7 – Lines of heterogeneity area recovery .

Central processing unit copies the information into the selected area of memory storage for images of shadow projections received and starts the process of multithreading computing via nVidiaTesla graphic module for removing noise on shadow projections images and projections and for the compression in the archive file.

In each new position of the object the lines of possible positions of the object are added to the reconstructed field in accordance with the position of the shadow projections (back projecting). After a few turns, the position of the absorbing area can be localized. With an increasing number of shadow projections in different directions, this localization becomes clear (Figure 2) [3].

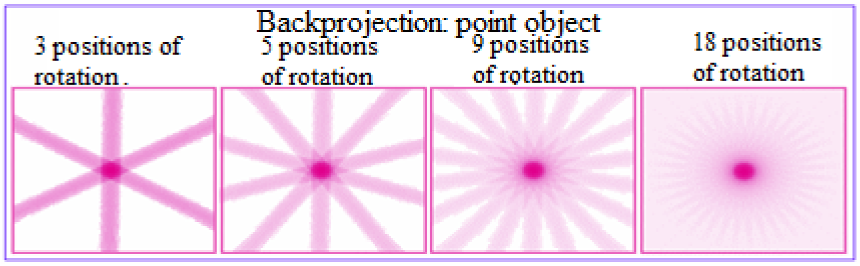

Figure 2. Reconstruction of a point object by means of a different number of displacements

3. BACKGROUND NOISE REMOVING FROM THE IMAGES

Removing background noise is an important function of the image processing, which allows to replace homogeneous background areas with single color in order to improve final image compressibility. Finding areas of the image corresponding to the background, allows to get rid of the data containing no useful information.

In practice, the images of the shadow projections are very noisy. The main noise sources - inhomogeneous X-ray tube radiation and the residual luminescence of the detector screen. As a consequence, the image of shadow projections, both in the background and in the shadow areas of the object have a wide range in the brightness level. The basic idea of a method determination the area of the image corresponding to the background noise, is to break the image into sections and then analyze its sites.

Operating mode of the tomographic scanner includes such specifications as:

1) The density of pixels and the resolution of the detector;

2) Radiation power X-ray tube;

3) Filters (generally aluminum or copper ones) and the materials applied.

The specifications calculated are:

1) The minimum brightness of the pixel;

2) The maximum brightness of the pixel;

3) The average brightness of the pixel;

4) The mean square deviation of the pixel brightness.

To improve the speed and quality of background noise removal it is convenient to define a boundary value of pixel brightness the way it will be possible to interpret any point of greater brightness as background and replace it with the highest possible brightness value (65535 for 16-bit color) . If you select the minimum brightness as the boundary brightness for the points of the background area, a small part of the background noise belonging to border areas of the object will remain on the image, as the area close to the boundary is noisier than in the background.If you select maximum brightness as boundary brightness of the object, then some part of the image pixels belonging to the object on the border with the background will be interpreted as background and replaced with the maximum brightness.

Due to the statistical averaging, both ways for removing pixels may lead to the same results (in terms of accuracy required for reconstruction) and improve the quality of reconstruction.

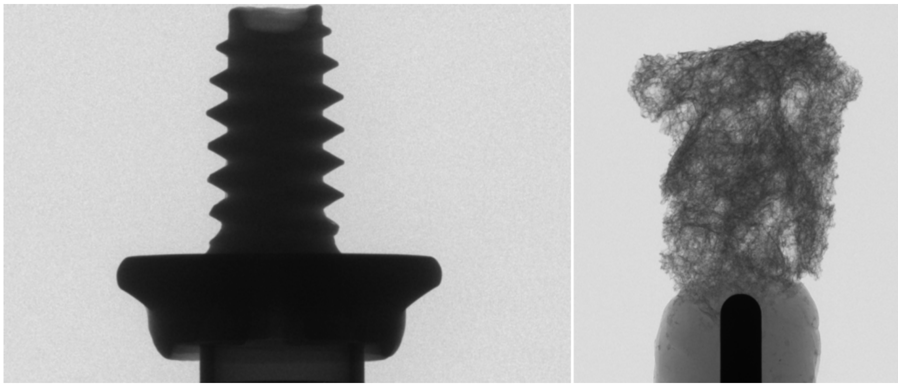

Figure 3 – Illustration of shadow projections.

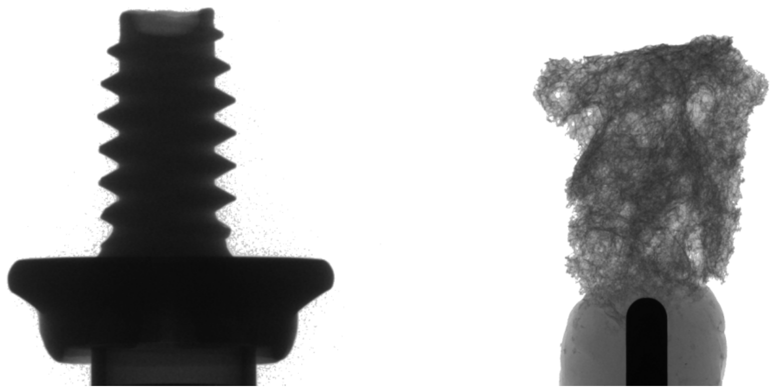

Figure 4 – Shadow projection images after the removal of background noise.

Figure 2 shows the typical images of shadow projections received using an X-ray micro tomographic scanner, Figure 3 - modified images with background noise removed. [2,3].

4. DATA COMPRESSION

There are various methods of data compression without sacrificing. The fastest and easiest to implement is RLE- compression: coding of the series of repeated values, which can be done in one pass. [4,5]

If the original image is represented by a sequence of double-byte characters (16 bits), the values of which range from 0 to 65535, then after the construction of the difference each point must be encoded by 17 bits, as the values must range from - 65535 to 65535.

Original image occupies $P_0 = 2 * W * H$ bytes of information, where W and H - number of dots (pixels) horizontally and vertically. Transformed image, in which each pixel is encoded with i number of bits, will occupy the following number of bytes:

$$P_i = W * H * \frac{i}{8}.$$

Points, the storage of which require more than i bits, are entered into delete set, which takes E = 2 (N-N_i) bytes. The total volume of the transformed data:

$$S_i = W * H * \frac{i}{8} + 2(N - N_i).$$

Thus, the required number of bits j, which is required to encode the image is $S_j = \min(S_0,\ S_1, \dots, S_{17})$.

Image preprocessing module connects with other modules through the integrated management environment and provides the undistorted compression and decompression of the images received on the X-ray micro tomographic scanner .

5. 3D-RECONSTRUCTION ANALYSIS

After completion of the 3D- reconstruction the central processing unit determines the user-visible areas of 3D- reconstruction, reads data from the hard disk (RAM) and sends to the graphic module for visualization and display on the screen. 3D- reconstruction requires a large number of high resolution images of the sample, which needs a computer system with advanced performance and capacity of memory resources for storing and processing the data. There are various methods for the automatic search of defects that give acceptable results for certain objects under study. Gradient analysis method allows to search defects in the density of quite homogeneous non-biological objects [5, 6]. Initial data for gradient analysis method is the density values array at each point of the sample, which determine the material density distribution function ρ (x, y, z), thus the gradient field of the sample can be constructed. Defects will be determined by inhomogeneity of the field, that is, the presence of density gradients:

$$\nabla\rho(\mathrm{x,y,z}) = \left(\frac{\partial\rho}{\partial \mathrm{x}}, \frac{\partial\rho}{\partial \mathrm{y}}, \frac{\partial\rho}{\partial \mathrm{z}}\right).$$

The image gradient $f(x,y)$ is defined at the point (x,y) as two-dimensional vector

$$G[f(x,y)] = \begin{bmatrix} \mathrm{G_x} \\ \mathrm{G_y} \end{bmatrix} = \begin{bmatrix} \frac{\mathrm{df}}{\mathrm{dx}} \\ \frac{\mathrm{df}}{\mathrm{dy}} \end{bmatrix}.$$

As it can be seen from vector analysis the vector G indicates the direction of maximum change of function f at point (x,y):

$$G[f(x,y)] = [G_x{}^2 + G_y{}^2]^{1/2} = [\left(\frac{\partial f}{\partial x}\right)^2 + \left(\frac{\partial f}{\partial y}\right)^2]^{1/2}.$$

Location based on the volume of these gradients can determine the size and nature of the defects.

The size and structure of the defects can be detected by the means of 3D location of the gradients.

Advantages of this method:

- Possibility to identify the type of defect;
- Possibility to determine the localization of the defect
- Possibility to identify the geometric and physical characteristics of the defect [7].

The proposed algorithms are used to achieve high degree detailing and accuracy of reconstruction and analysis of 3D-models (Figure 5):

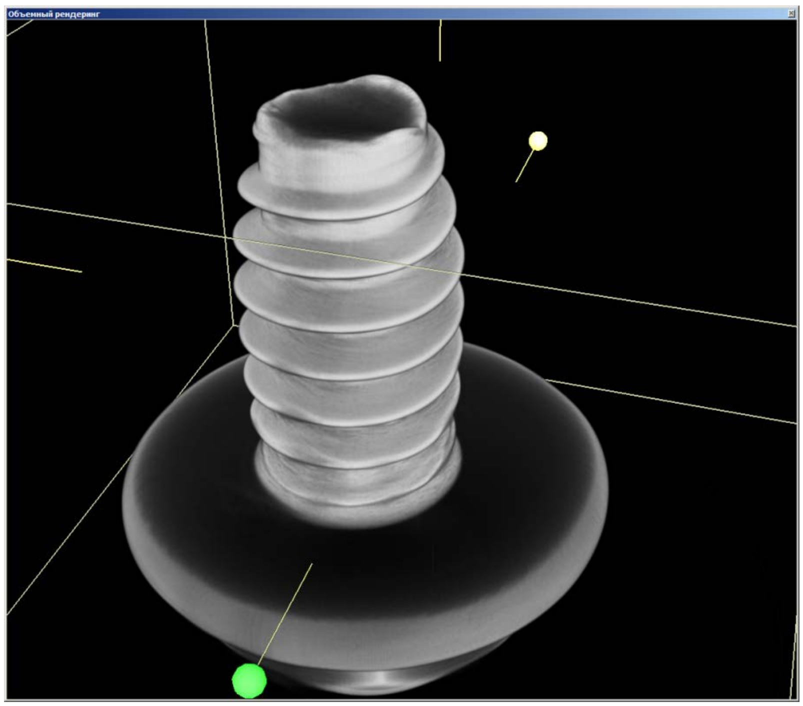

Figure 5 – 3D reconstruction

6. CONCLUSION

X-ray micro tomographic imaging for non-destructive testing for the technological and scientific purposes to study the internal structure of organic and inorganic objects in the following industries:

- in metallurgy for assessing the quality and structure of manufactured products;
- in machinery manufacturing and instrument engineering for quality control of the parts assembled;
- in the electronics industry for semiconductor assembly control and soldering electronic components with printed circuit boards;
- in physics for experiments carried out to visualize the internal structure of objects and physical processes of the samples [8];
- in biology and medicine for the optimization of X-Ray testing and diagnosis methods [9];

- in chemistry to visualize the internal structure of test samples, to observe the mechanism of the appearance of defects, to design and investigate new materials [2,10].

ACKNOWLEDGEMENT

Described methods form the image preprocessing module of the X-Ray micro tomographic scanner software, developed with the support of the Ministry of Education and Science in the framework of the Federal special purpose program of the Russian Federation (State contract № 16.523.11.3009).

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