A 3D X-Ray Microscopy

Jing Zou² and Ying Xu¹

¹Sanying Precision Engineering Research Center, Dongying, 257000, China
²State Key Lab of Precision Measurement Technology and Instruments, Tianjin University, Tianjin, 300072, China

INSTRUCTIONS
In the past decades, the development of microscopy technology has had a tremendous progress. The new technologies has been continuously developed, such as various advanced optical microscopes, SEM/TEM, AFM/STM, etc., which pushes the imaging resolution from micrometer, down to nanometer, or even atomic level. However, all those microscopy technologies can only image the surface (or shallow subsurface) of the samples. A destructive method has to be used to observe the internal micro features of an object. In the paper, a new 3D X-ray microscopy is introduced, which can provide a 3D imaging capability with sub-micron spatial resolution for observing the internal micro structures of the samples non-destructively. It provides a powerful tool for scientific research and industrial non-destructive inspection and quality control.

PRINCIPLE OF OPERATION
The imaging principle of the 3D X-Ray Microscopy is based on advanced X-ray computed tomography (CT) scanning technology. The imaging system is composed of a micro-focus X-ray source, a precision sample stage and a lens-coupled CCD detector as shown in Figure 1 and a 3D image is shown in Figure 2. The 3D image is reconstructed with a series of projection images (2D images). The sample is loaded in a rotary sample stage. As the sample stage rotates step by step, a series 2D image is collected by the detector. The CT reconstruction algorithm, filtered-back projection (FBP), requires the projection data acquired within the angular range from 0 to 2pi. Then, those projection images are used to reconstruct a 3D image which is combined by a series of slices. Next, 3D image could be viewed with our 3D Visualization Software Package. Data analysis could be operated to the 3D images for various applications.


FIGURE 2. 3D image of an electronics component.

KEY ISSUES
1. To achieve ultra-high spatial resolution
The imaging principle of conventional micro-CT is similar to industry CT, which uses a flat panel detector to collect images. In this case, the spatial resolution of the imaging system is limited by the spot size of the X-ray source, the pixel size on the X-ray detector, and the geometric amplification of the cone-beam projection. To achieve high spatial resolution a lens-coupled detector is used in our system, which is composed of a phosphor, a lens optical system and a CCD. The spatial resolution of the 3D X-Ray Microscopy depends on combination effects of the geometric amplification of X-ray cone beam projection and the amplification of the lens optical system. As a result, a 500nm resolution with a multi-scale imaging magnification is achieved.
2. To improve the image quality
The image quality of 3D X-Ray Microscopy is
generally defined by a few parameters and is influenced by many factors, including spatial resolution, contrast resolution, linearity, noise and artifacts [1]. There are many different types of image artifacts, including noise, beam hardening, scatter, pseudo enhancement, motion, ring and metal artifacts. A few techniques for improving the image qualities are discussed in the paper.

Beam hardening causes the edges of an object in image appearing brighter than the center, as shown in FIGURE3(left). Beam filtration and software correction techniques are adapted to improve the image quality. The result is shown in FIGURE3(right).

Ring artifact is caused by the miscalibration or the defects of detector element, which results in ring artifacts at the center of the images, see FIGURE4(left). The image is corrected with mechanical dithering and image darning, as shown in FIGURE4(right).

Reconstruction of 3D image is very intensive in computation. So it is very time consuming. An efficient GPU based algorithm is developed to accelerate the whole process of reconstruction, which could reconstruct a volume image of $1024^3$ with 720 projection data of $1024^2$ within 5 minutes.

APPLICATIONS
3D X-Ray Microscopy provides a powerful tool for scientific research and industrial non-destructive inspection and quality control. It has been widely used in many application fields, such as geology/oil gas, advanced materials, life science and advanced manufacturing/failure analysis. Some typical images are shown in FIGURE5. Application analysis software is being developed to extract useful information from the 3D images. For example, in oil geology field, the digital rock analysis becomes a hot technique for oil exploring and development. The rock samples are scanned by high resolution 3D X-Ray Microscopy. The data is analyzed to provide the information of pore size and pore throat distribution in 3D dimension.

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