Preliminary Study on the impact of sample orientation to CT reconstruction result

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Abstract: In this paper, we report the results of our preliminary study on the effects of the different sample orientation to the final CT reconstruction quality. We fabricated a aluminum phantom with various known dimensional features on two surfaces perpendicular to each other, then scanned it with one surface parallel to the axis-of-rotation, and another perpendicular to the axis-of-rotation. The CT reconstruction results show that although the two sets of patterns are approximately identical, their reconstruction quality, such as feature profile, feature edge sharpness and barreling artifact, are quite different just due to their different mounting orientation with respect to the axis-of-rotation.

Keywords: X-ray computed tomography, CT, X-ray scattering, CT image quality

Introduction
Nowadays industrial X-ray CT is so popular that its application can be found in almost all sectors of manufacturing industry, such as Aerospace, Advanced Material, Electronics, Welding, Casting and Precision Engineering, and so on. This CT system generally is equipped with a digital area detector and uses the cone-beam reconstruction technologies. In many situations when CT operators arrange their scan, they normally consider issues such as penetration, mounting convenience, visualization convenience, and the required resolution, etc.. There are some reports discussing the drawback of Filtered Backprojection (FBP) cone-beam reconstruction, such as its incomplete sampling due to missing frequencies, mishandled data and axial truncation [1], or the artifacts-related metrology problems such as barreling or cupping [2], however it is quite rare to see reports that systematically talk about how a mounting orientation of the sample in a scan would affect the final reconstruction result.

The objective of this paper is to investigate the possible impact of the sample mounting orientation to the quality of the CT reconstruction result. We will mainly present our observations with the experiment and discuss possible cause for them. However, we would like to address any fundamental deductions to future works.

Methods
To evaluate the effects of the sample mounting orientation to the CT reconstruction output, we designed a low-cost special phantom (Figure 1). Basically it is a aluminum square-shaped pipe with a outer geometry of 15x15x15mm³. The wall thickness is CMM, and a pattern that consists of a rectangle area, a circle area and a triangle area are carved on two side walls.
Although all these features are designed to be 100µm in depth, their fabricated forms are actually far from that value due to a low-cost fabrication process. Figure 2 shows the measured profiles of the features using Stylus Profilometer, with the depth of triangle, circle and rectangle on the side wall surface being about 45µm, 55µm, and 75µm respectively, and those on the top surface being 40µm, 40µm, and 70µm respectively.

The rectangle and triangle on both walls were also measured with Alicona microcopy. Here we just show in Figure 3 the 3D profile of the rectangle and triangle on the top surface. This measurement is consistent with the measurement with the Stylus Profilometer.
After having verified its actual dimensions of the surface features, CT scan was conducted to investigate the effect of the mounting orientation of the features to the CT inspection results. In this study, the rotation axis is perpendicular to the side wall and roughly passed through the centre of the sample, as indicating in Figure 1b. A scan setup of 120kV, 9µA for X-ray source, and 720 projections were used with a magnification of 7.05X.

The reconstruction software used is developed by SIMTech based on our unique differential CT reconstruction algorithm [3] (Figure 4). The most remarkable advantage of this reconstruction technology is that it can automatically determine the sample mounting orientation and reconstruct the sample along its main orientation with desired resolutions on different dimensions (only limited by the hardware resolution). In this scan, the reconstruction volume is (XxYxZ= 1024x702x1024) with voxel size (dXxdYxdZ = 24.41x24.41x24.41). A ROI reconstruction strategy was adopted so that the resolution in all three dimensions are similar for the benefit of easy comparison.
CT Results, Observation and Discussion
Figures 5 and 6 respectively show one 2D image and the 3D display of the phantom’s CT reconstruction result. From the later, it is obvious that the three surface features on the side wall (perpendicular to the rotation axis) are less sharp and more blur than those on the top surface (parallel to the rotation axis). This difference is more clear with the orthogonal views in Figure 7. Figure 7a is the CT image of the top wall and Figure 7b is that of the side wall. By visual comparison, one can easily see that the features on the top wall have very clear and clean edges and the edges of the features on the side wall are very blur. Actually in the visualization process, the top-wall features are much easier to obtain than the side-wall features by adjusting the contrast and intensity window level of the CT image.
Another very interesting observation is the barreling (or cupping) effect. It is surprising to find it is also linked to the orientation of the features. As shown in the cross-section images obtained by clipping the CT model of the object along the lines in Figure 7, there is no detectable barreling for the walls parallel to the axis-of-rotation, however, for the walls perpendicular to the axis-of-rotation, significant barreling is observed. This makes dimensional measurement inaccurate and misleading. In this case study, the measured top wall thickness is 2.02mm, and the side wall thickness is 2.70mm. Compared to their real value of 2.00mm. The cupping effect for the walls perpendicular to the axis-of-rotation couldn’t be neglected and would cause serious problem if subsequent feature registration or classification are needed, for example, in Reverse-Engineering application.

As the sample is made of aluminum and its maximum dimension is only 15mm, there should be no obvious insufficient penetration problem with a 120kV X-ray tube voltage. Therefore, we suspect this orientation-related cupping effect may mainly come from material scattering. While the scattering from the side walls that are perpendicular to the axis-of-rotation, forms a relatively stable distribution on the detector during the scanning process, the scattering distribution from the walls parallel to the axis-of-rotation varies dramatically throughout the scanning and may average out in the reconstruction process. This cupping should also be a key contribution to the blurring of the surface features.
Sampling may be another contribution to the relative poor quality of the reconstructed features on the side walls. Because the actual depths of the three features are about 40-50µm for the triangle and circle areas, and about 80µm for the rectangle. It only occupies about 2-4 pixels on the detector. On the contrary, for features on the wall aligned with the axis-of-rotation, the pixel number involved in the projection throughout the scan is much larger. For example, the maximum projection of the rectangle on the top surface is about 165x276 pixels. With this fact, it is logical to deduce that features on the side wall is more sensitive to any uncertainty or instability of the X-ray source spot and the mechanical rotary system.

**Conclusion**

In this paper, we report some preliminary study about the impact of sample mounting orientation on the CT reconstruction output. By scanning a aluminum square pipe phantom with approximately identical features on two surfaces perpendicular to each other, we find that the features on the wall parallel to the axis-of-rotation are reconstructed with much better quality that those on the side wall surface. It is also observed that the barreling effect mainly affect the side walls that are perpendicular to the axis-of-rotation, but cause little influence to the walls parallel to the axis-of-rotation.

**Reference**

2. J.P. Kruth (1)a,* M. Bartscher b, S. Carmignato c, R. Schmitt (2)d, L. De Chiffre (1)e, A. Weckenmann (1)f, Computed tomography for dimensional metrology, CIRP-760, (2011).