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Construction and Evaluation of Differential Phase-Contrast Cone Beam CT Imaging System

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Abstract

When X-rays travel through an object, both the intensity and phase status are varied. The amount of variation depends on the attenuation coefficients and phase coefficients of the materials that the object consists of. In recent years, cone beam breast computed tomography (CBBCT) has emerged as a cutting-edge X-ray imaging modality by excellently constructing the attenuation contrast. It is an effective method for screening breast cancer by providing isotropic three-dimensional images with high resolution and high contrast-to-noise ratio (CNR). However, due to the fact that the variation of attenuation coefficients among soft tissues is subtle, CBBCT is limited in further characterizing breast lesions. Phase contrast CT technology has been attracting research interests recently. It provides new insight into an object by imaging the phase coefficient that is more sensitive than attenuation coefficient. Therefore, it has the potential to overcome the drawback of CBBCT and deliver complementary information.

Several phase contrast imaging methods have been developed in the past years. However, the requirement of coherent X-ray source that is usually characterized with sufficiently small dimension impairs their application as a standard method in hospital-based medical imaging. In this thesis, a grating-based bench-top differential phase contrast cone beam CT (DPC-CBCT) system was designed and constructed. Based on the attenuation-based imaging system setup, it deploys three more major components: a source grating, a phase grating and an analyzer grating. The source grating enables the system to use hospital- grade X-ray tube and they together provide sufficient X-ray output power and spatial coherence. The phase grating and the analyzer grating transform phase shift into intensity contrast based on Talbot interferometry so that high-resolution detector is not necessary. One of the major challenges of system construction is grating fabrication because of their high aspect ratio and high precision requirements. This work designed robust recipes that produce gratings meeting our demanding criterion. Another challenge is that the system requires highly precise grating alignment to produce the best contrast effect. An effective method was presented in this work that aligns the phase grating the analyzer grating precisely.

The second part of this thesis is to evaluate our DPC-CBCT imaging system in terms of uniformity, CNR, noise property and contrast resolution. As the field of view of the imaging system is limited due to the current grating fabrication technique, it is necessary to investigate the performance of volume of interest (VOI) imaging. The VOI imaging experiment was carried out by scanning a large cylinder phantom. In order to evaluate the performance of DPC-CBCT on real soft tissues, we took the investigation to the next step. Human breast specimen and small animal experiments were carried out using our DPC- CBCT system.

Phantom experiment results indicate that, compared with attenuation image, phase image provides higher CNR and contrast resolution. However, in specimen and small animal experiments, phase image quality is greatly degraded. The coherence property of X-ray beam is critical in phase contrast imaging because the image formation mechanism is based on X-ray beam diffraction. Inhomogeneous objects, such as bones and soft tissues, have large amount of internal density fluctuations or small structures on micrometer scale. The small structures produce strong small-angle scattering and greatly reduce the coherence of X-ray beams reaching the detector. In order to quantitatively evaluate the coherence loss caused by object, the last part of this thesis introduces dark-field imaging, which forms image by computing small-angle scattering power. Dark-field imaging is also based on grating interferometry and the data can be obtained from the same scan with phase contrast imaging. It can be used to characterize the distribution of micro- structures and to investigate coherence loss in DPC-CBCT imaging. Besides coherence loss, there are several other factors that affect the performance of DPC-CBCT, such as polychromatic X-ray spectrum and imperfect gratings. We believe that phase contrast imaging has the potential to be a more powerful imaging tool and more work will be dedicated to the improvement of DPC-CBCT.