Performance studies of x-ray differential phase contrast tomographic imaging systems in medical diagnosis using modern signal detection theories

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While the absorption properties of x-rays by the human body have been utilized to generate medical images for over a century, the quest for alternative wave-based uses of x-rays in medical diagnosis never stops. X-ray differential phase contrast tomographic imaging (DPC-TI) is one such method based on the phase shift of x-rays (a wave phenomenon) by the image object to produce image contrast. In the past decade or so, tremendous progress has been made in DPC-TI, including its successful implementation using a medical grade x-ray tube, a commercial digital flat panel detector, and a compact system setup. However, in order to determine the pros and cons of DPC-TI in medical diagnosis, several fundamental questions must still be addressed. First, for a given task in medical diagnosis, how should the DPC-TI system be designed to maximize its diagnostic performance with the least patient radiation exposure? Second, given a radiation dose constraint to minimize the potential risks of the exposure to ionizing radiation, what would be the clinical benefits of DPC-TI relative to the well studied absorption imaging methods for the same medical imaging task? To fully address these questions, the imaging performance of DPC-TI and its dependence on the system parameters and radiation dose must be thoroughly investigated. In this thesis work, modern spatial frequency-dependent statistical signal detection theories have been utilized to investigate the potential performance of DPC-TI systems. One fundamental contribution of this work is the discovery of an intrinsic relationship between the noise properties in phase contrast and conventional absorption imaging. This fundamental discovery enables one to predict the noise performance of DPC-TI system from its associated absorption tomographic image system and vice-versa. Using this fundamental discovery, the medical diagnosis performance of DPC-TI systems including both cone-beam CT system and cone-beam tomosynthesis imaging system have been studied for a variety of medical diagnosis tasks. The results have demonstrated that a combined use of both contrast mechanisms has great potential to improve diagnostic performance of current x-ray tomographic imaging systems.