Abstract

Photon counting detectors (PCDs) use semiconductors such as silicon (Si) or cadmium telluride (CdTe) to directly convert the energy of X-rays to electric (i.e. voltage) pulse signals. The semiconductor sensor and readout electronics of PCDs are fast enough such that the pulses induced by individual X-ray photons can be discriminated and recorded as separate digital counts. Compared with conventional scintillator-based indirect-conversion detectors, the direct conversion mechanism of PCDs can effectively improve spatial resolution. PCDs are equipped with voltage comparators to effectively reject electronic noise and improve images' contrast-to-noise ratio, particularly at low radiation dose levels. By introducing multiple comparators to each detector pixel, the energy of each X-ray photon can be estimated based on the height of the voltage pulse. These attractive features of PCDs offer the potential of further reducing radiation dose and achieving routine spectral imaging in x-ray computed tomography (CT). However, there is a technical challenge in the way of using PCD in clinical CT: the energy response functions of PCDs are inconsistency across different semiconductor panels due to slight variations in the semiconductor impurity level, threshold voltage, and other physical reasons. This spectral inconsistency problem leads to concentric artifacts in reconstructed PCD-CT images that severely degrade low-contrast detectability and material quantification accuracy. This thesis presents two methods to address the spectral inconsistency-induced concentric artifacts in PCD-CT: The first method method leverages the energy-resolving capability of PCDs to perform project-domain material decomposition to decouple the image object's information from the detector response function. The second method does not require a PCD to be operated under the spectral imaging mode; instead, it uses an image-domain segmentation process to help estimating the non-water contents in an image object, based on which detector pixel-specific correction functions were applied to address the nonuniformity in the raw projection data. Both methods were experimentally evaluated on a benchtop PCD-CT system and a prototype C-arm PCD-CT system with human-sized phantoms, human cadavers, and in vivo large animals. The experimental results demonstrated that the spectral inconsistency-induced artifacts in PCD-CT can be effectively addressed with the proposed methods. Finally, this thesis demonstrates examples of how the correction methods can be employed to accomplish high-quality and quantitative virtual non-contrast imaging, virtual monoenergetic imaging, and dual K-edge contrast material PCD-CT imaging.