Spectral Mammography with X-Ray Optics and a Photon-Counting Detector

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Abstract

Early detection is vital to successfully treating breast cancer, and mammography screening is the most efficient and wide-spread method to reach this goal. Imaging low-contrast targets, while minimizing the radiation exposure to a large population is, however, a major challenge. Optimizing the image quality per unit radiation dose is therefore essential. In this thesis, two optimization schemes with respect to x-ray photon energy have been investigated: filtering the incident spectrum with refractive x-ray optics (spectral shaping), and utilizing the transmitted spectrum with energy-resolved photon-counting detectors (spectral imaging).

Two types of x-ray lenses were experimentally characterized, and modeled using ray tracing, field propagation, and geometrical optics. Spectral shaping reduced dose approximately 20% compared to an absorption-filtered reference system with the same signal-to-noise ratio, scan time, and spatial resolution. In addition, a focusing pre-object collimator based on the same type of optics reduced divergence of the radiation and improved photon economy by about 50%.

A photon-counting silicon detector was investigated in terms of energy resolution and its feasibility for spectral imaging. Contrast-enhanced tumor imaging with a system based on the detector was characterized and optimized with a model that took anatomical noise into account. Improvement in an ideal-observer detectability index by a factor of 2 to 8 over that obtained by conventional absorption imaging was found for different levels of anatomical noise and breast density. Increased conspicuity was confirmed by experiment. Further, the model was extended to include imaging of unenhanced lesions. Detectability of microcalcifications increased no more than a few percent, whereas the ability to detect large tumors might improve on the order of 50% despite the low attenuation difference between glandular and cancerous tissue. It is clear that inclusion of anatomical noise and imaging task in spectral optimization may yield completely different results than an analysis based solely on quantum noise.

Key words: mammography; x-ray optics; photon counting; spectral shaping; spectral imaging; collimation; radiation dose; signal-to-noise ratio; quantum noise; anatomical noise; spatial resolution; x-ray flux;