Title: An apodized-aperture x-ray detector design to improve image quality in mammography

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Structured Abstract:

Dose-efficient x-ray detectors are paramount for applications such as screening mammography which requires low doses of radiation and high image signal-to-noise ratio (SNR). Detective quantum efficiency (DQE) describes the ability of an x-ray detector to acquire an image with high SNR for a given number of x-ray quanta incident on the detector. An ideal detector has unity DQE across all spatial frequencies, where low frequencies (approaching zero) pertain more to large structures such as breast parenchymal tissue, and high frequencies (approaching the image cut-off) are crucial for detecting small structures such as breast calcifications. High-frequency DQE is fundamentally design-limited by noise aliasing, which refers to the misrepresentation of frequencies above the image cut-off frequency, and could reduce DQE values by 60%. Although previous methods have attempted to eliminate noise aliasing, they also suppress signal and therefore do not improve DQE.

We describe a new x-ray detector design, called apodized-aperture pixel (AAP), that consists of an array of sensor elements (e.g. 5-25μm) that are smaller than the desired image pixel size (e.g. 50-100μm). The "over-sampled" sensor signal is used to synthesize image pixels without aliasing to improve the modulation transfer function (MTF) and DQE. This approach takes advantage of new sensor technology having small sensor elements and could be beneficial in cases when large file sizes are not manageable clinically. Our overarching objective is to determine MTF and DQE performance of the AAP x-ray detector design.

We use the AAP approach to show: (1) proof-of-concept demonstration, (2) investigation of x-ray physics impact on detector performance, and (3) implementation on a small-area prototype detector. With a high-resolution converter layer, the AAP approach has the double benefit of improving MTF by 53% (while reducing both signal and noise aliasing) and DQE by 2.5x at high frequencies. X-ray physics factors that cause noise correlations, such as x-ray reabsorption and converter blur, reduce noise aliasing and the AAP design may only provide modest DQE improvement. Implementation on a selenium (Se/CMOS) micro-sensor prototype with 7.8μm element size with image 50μm pixel size show a flat DQE curve (ideal) across 10cyc/mm. AAP images of resolution test patterns, mammography phantoms, and specimen imaging of micro-calcifications from biopsies shows improved SNR and visibility of fine-detail.

In conclusion, we have developed a new x-ray detector design with improved high-frequency MTF and DQE by removing aliasing artifacts that may cause inconsistent detection due to partial volume effects. Future work is focused on determining the minimum among of DQE improvement that will result in human observer difference in task detection and use of this new x-ray detector design to acquire imaging biomarkers (such as microcalcification morphology) that could help with detection of aggressive cancer.