PhD Thesis Title: "Task-Based Optimization of Computed Tomography Imaging Systems"

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ABSTRACT:

From its inception in 1972, x-ray computed tomography (CT) quickly developed a role as an indispensable tool in the diagnosis of disease. By illuminating a patient with X-rays at varying angles, three-dimensional information could be obtained. Along with the invention of Magnetic Resonance Imaging (MRI), CT enabled doctors to non-invasively visualize volumetric anatomical information for the first time in history. In the decades that followed, diagnostic CT has become a staple of clinical radiology, while other more specialized applications of CT have rapidly developed as well. While standard diagnostic CT consists of a circular gantry through which a patient couch is translated, CT in modern clinical practice takes on many forms, from interventional cone-beam CT which guides surgical procedures to dedicated-purpose CT systems for dentistry or orthopedics.

A number of technological advancements have enabled this blossoming of new CT applications. One vital aspect has been the development and refinement of CT image reconstruction algorithms, or the mathematical processes that transform the many x-ray projections into a single volumetric image. Work on CT reconstruction has been as diverse as CT itself. In the research community, reconstruction is nearly always listed as a potential source of improvement for existing CT systems or as an enabling force for novel, previously infeasible CT system designs.

Unfortunately, many of the advancements that reconstruction methods could enable are difficult to realize in practice, since even the simplest reconstruction algorithms involve a wide array of implementation decisions. For well established CT applications, contributing marginal image quality improvements through better reconstruction is therefore challenging, since a delicate balance of optimal implementation options must be achieved in order to observe any benefits from the improved reconstruction method. For more novel CT applications, the situation is even worse, since we lack the benefit of several decades of experience to guide our search for the "best" reconstruction methods, and we often find ourselves paralyzed by the incredible variety of methods and algorithms that now exist. Even after considering only a single class of algorithms narrows the field, there is still a wide array of parameters for any algorithm, and the selection of appropriate values for these parameters is often difficult. This causes many problems in CT research and development. Specifically, one of the major issues that arises is that it is surprisingly

difficult to objectively compare two reconstruction methods to determine which is better.

In general terms, this thesis aims to address this issue by defining image quality metrics, which facilitate the objective assessment and design of CT reconstruction algorithms. Further, the metrics which we will apply here can be used not only to guide reconstruction development, but also in the assessment of a completed CT system, including the impact of system design, hardware, and even the patient being imaged. We support the view that task-based metrics of image quality can be useful in guiding the algorithm design and implementation process in order to yield images of objectively superior quality and higher utility for a given task. Furthermore, we believe that metrics, such as the Hotelling observer (HO) Signal-to-Noise Ratio (SNR), can be used as summary scalar metrics of image quality for the evaluation of images produced by novel reconstruction algorithms. The bulk of the thesis focuses on linear analytical algorithms, specifically the ubiquitous filtered back-projection (FBP) algorithm. However, due to the demonstrated importance of optimization-based algorithms in a wide variety of CT applications, we devote one chapter to the characterization of noise properties in TV-based iterative reconstruction, as the understanding of image statistics in optimization-based reconstruction is the limiting factor in applying HO metrics.

References to author publications that relate specifically to the dissertation:

A. A. Sanchez, “Estimation of Noise Properties for TV-regularized Image Reconstruction in Computed Tomography,” Phys. Med. Biol. 2015; 60(18): 7007 – 7033.

A. A. Sanchez, E. Y. Sidky, and X. Pan, “Task-based optimization of dedicated breast CT via Hotelling observer metrics,” Med. Phys. 2014; 41(10): 101917 (16pp).

A. A. Sanchez, E. Y. Sidky, and X. Pan, “Region of interest based Hotelling observer for computed tomography with comparison to alternative methods,” Journal of Med. Imaging 2014; 1(3): 031010 (9pp).

A. A. Sanchez, E. Y. Sidky, I. Reiser, and X. Pan, "Comparison of human and Hotelling observer performance for a fan-beam CT signal detection task," Med. Phys. 2013; 40(3): 031104 (9pp).