THE DEPARTMENT OF BIOMEDICAL ENGINEERING

Cooperative Agreement U01EB018758

Task-driven dynamic beam modulation for high-performance, low-dose CT

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NIH National Institute of Biomedical Imaging and Bioengineering | PHILIPS | Johns Hopkins University Schools of Medicine and Engineering

Disclosures

NIH Support:

U01EB018758 (Stayman)
R21CA219608 (Stayman)
R01EB018896 (Zbijewski)
R01EB017226 (Siewerdsen)
R21EB026849 (Stayman)
R01EB025470 (Stayman/Zbijewski)
R01EB025829 (Abbey)
R01EB027127 (Stayman)

Current and Former Academic-Industry Partnerships and Research Relationships:

Elekta AB
Carestream Health
Siemens Medical
Philips Healthcare
Varex
Varian Medical Systems
Canon Medical Systems
Fischer Imaging
Medtronic

Funding Overview

U01 Research Project Cooperative Agreement

- Supports discrete, specified, circumscribed projects to be performed by investigator(s) in an area representing their specific interests and competencies
- Used when substantial programmatic involvement is anticipated b/w awarding Institute and Center

PAR-12-206: Decreasing Patient Radiation Dose from CT Imaging: Achieving Sub-mSv Studies

Study Section: NIH-NIBIB ZEB1 OSR-D (M1) S Low-Dose CT Imaging (U01)

Grant: U01EB018758 Task-driven dynamic beam modulation for high-performance, low-dose CT

Team:

Johns Hopkins University Schools of Medicine and Engineering
PI: Web Stayman
Engineering: Jeff Siewerdsen, Wojtek Zbijewski
Radiology: Satomi Kawamoto

PHILIPS
Site PI: Reuven Levinson
Engineering: Kevin Brown

Submission History:

July 2013: Request for Budget >$500k/year
Aug 2013: Letter of Intent to Submit
Sept 2013: Grant Submitted
Feb 2014: Review, Impact Score: 19
July 2014: Milestones Established
Sept 2014: Grant Award/Start

Clinical Motivation/Significance

NIH Initiative for dose reduction in CT

- February 2011 NIBIB/NIH to identify possible steps that could be taken to reduce the average patient exposure from each CT exam to less than 1 mSv.
- Suggested improvements in data acquisition, image reconstruction, and optimization processes as important research areas.
- Engagement of users, investigators, and manufacturer communities would be important to achieving the implementation of reducing patient radiation exposure.
- General agreement that achieving the lowest possible patient radiation exposures from CT scans would require a multi-faceted approach.

Relevant Prior Experience/Preliminary Data

Johns Hopkins University
Schools of Medicine and Engineering

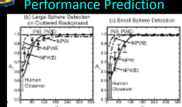
Web Stayman
Iterative Reconstruction/Analysis
System Design (CBCT)
System Modeling

Jeff Siewerdsen
Imaging Physics
System Design (CBCT)
Image Quality Analysis

Wojtek Zbijewski
Imaging Physics
Iterative Reconstruction

Satomi Kawamoto
Diagnostic Radiologist
Abdominal Imaging

Performance Prediction



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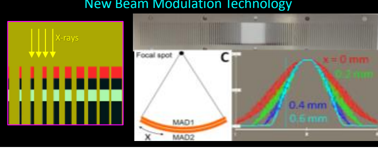
Reuven Levinson
CT System Hardware/Design
Novel Modulation Scheme

Kevin Brown
CT System Hardware/Design
Reconstruction

New Beam Modulation Technology



Specific Aims

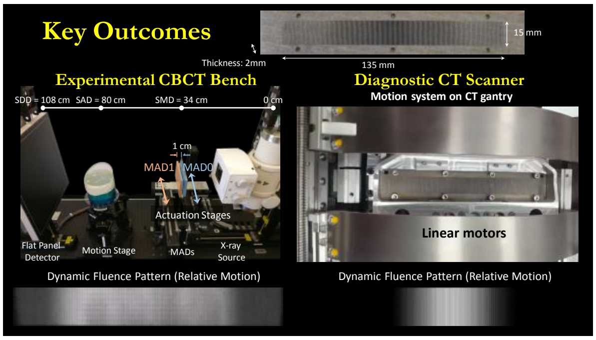
Aim 1: Develop dynamic beam modulation hardware for integration into diagnostic CT scanners.

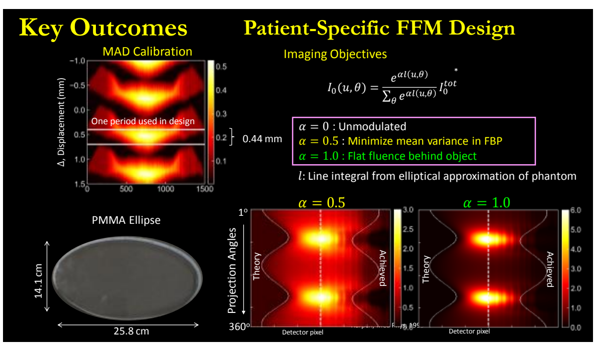
Aim 2: Create a reconstruction framework for dynamically modulated CT acquisition.

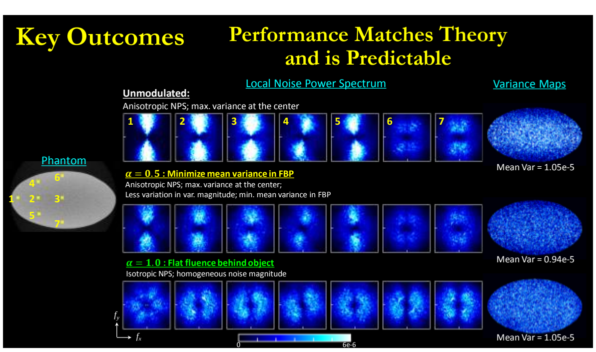
Aim 3: Develop a performance prediction framework for dynamically modulated CT.

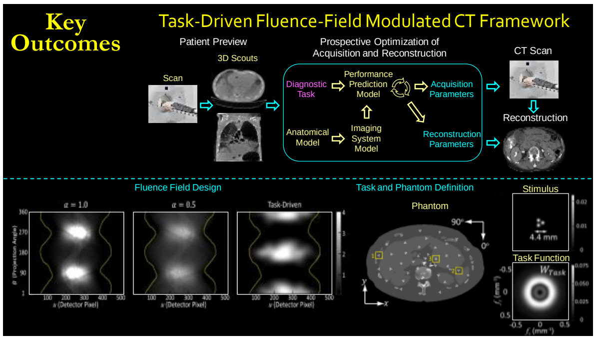
Aim 4: Develop strategies for driving patient- and task-based beam modulations.

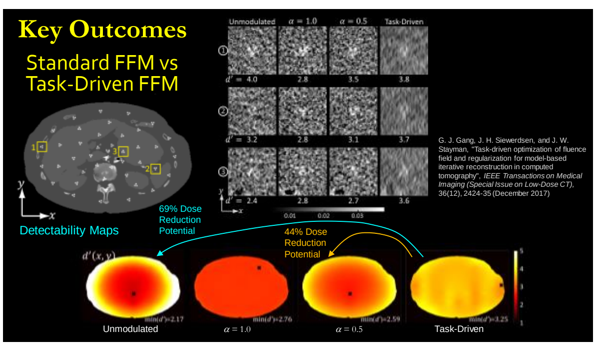
Aim 5: Assess patient- and task-specific beam-modulated CT.

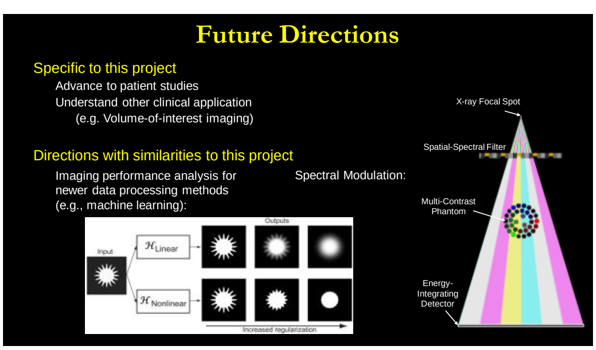

Key Outcomes
15 mm
Thickness: 2mm
135 mm
Experimental CBCT Bench
Diagnostic CT Scanner
Motion system on CT gantry
SDD = 108 cm SAD = 80 cm SMD = 34 cm 0 cm
1 cm
MAD1 MAD0
Actuation Stages
Flat Panel Detector
Motion Stage
MADs
X-ray Source
Linear motors
Dynamic Fluence Pattern (Relative Motion)
Dynamic Fluence Pattern (Relative Motion)


Key Outcomes
Patient-Specific FFM Design
MAD Calibration
Imaging Objectives
$I_0(u,\theta) = \frac{e^{\alpha l(u,\theta)}}{\sum_\theta e^{\alpha l(u,\theta)}} I_0^{tot}$
One period used in design
0.44 mm
α = 0 : Unmodulated
α = 0.5 : Minimize mean variance in FBP
α = 1.0 : Flat fluence behind object
l: Line integral from elliptical approximation of phantom
PMMA Ellipse
14.1 cm
25.8 cm
α = 0.5
α = 1.0
Projection Angles
Theory
Achieved
Detector pixel


Key Outcomes
Performance Matches Theory and is Predictable
Local Noise Power Spectrum
Variance Maps
Unmodulated:
Anisotropic NPS; max. variance at the center
Mean Var = 1.05e-5
Phantom
α = 0.5 : Minimize mean variance in FBP
Anisotropic NPS; max. variance at the center;
Less variation in var. magnitude; min. mean variance in FBP
Mean Var = 0.94e-5
α = 1.0 : Flat fluence behind object
Isotropic NPS; homogeneous noise magnitude
Mean Var = 1.05e-5


Key Outcomes
Task-Driven Fluence-Field Modulated CT Framework
Patient Preview
3D Scouts
Scan
Prospective Optimization of Acquisition and Reconstruction
Diagnostic Task
Performance Prediction Model
Acquisition Parameters
Anatomical Model
Imaging System Model
Reconstruction Parameters
CT Scan
Reconstruction
Fluence Field Design
α = 1.0
α = 0.5
Task-Driven
Task and Phantom Definition
Phantom
Stimulus
4.4 mm
Task Function


Key Outcomes
Standard FFM vs Task-Driven FFM
Unmodulated
α = 1.0
α = 0.5
Task-Driven
d' = 4.0
2.8
3.5
3.8
d' = 3.2
2.8
3.1
3.7
d' = 2.4
2.8
2.7
3.6
G. J. Gang, J. H. Siewerdsen, and J. W. Stayman, "Task-driven optimization of fluence field and regularization for model-based iterative reconstruction in computed tomography", IEEE Transactions on Medical Imaging (Special Issue on Low-Dose CT), 36(12), 2424-35 (December 2017)
Detectability Maps
69% Dose Reduction Potential
44% Dose Reduction Potential
Unmodulated
α = 1.0
α = 0.5
Task-Driven


Future Directions
Specific to this project
Advance to patient studies
Understand other clinical application
(e.g. Volume-of-interest imaging)
Directions with similarities to this project
Imaging performance analysis for newer data processing methods (e.g., machine learning):
Spectral Modulation:
Input
Outputs
Increased regularization
X-ray Focal Spot
Spatial-Spectral Filter
Multi-Contrast Phantom
Energy-Integrating Detector

Grant Advice for AAPM Members

- General Advice
  - Tell the story
  - Why is this research necessary?
  - Why is this the best possible team to do it?
- Responding to Program Annoucements
  - NIH is telling you what they want to fund.
- Talk with your Program Officer
  - Is your idea a good match to the announcement?
  - Is the NIH “excited” about the idea?
- Regarding U01 Mechanism (for this grant)
  - Increased reporting requirements (e.g., semiannual reports, annual NIH meetings)
  - Careful milestone planning