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TITLE: Development and Evaluation of a Solid State Head CT

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14. ABSTRACT

The goal of this work is to develop a stationary head CT system that would enable head imaging at Forward Operating Bases or similar areas. Without the need for moving parts, such a system could address the clinical need of cross-sectional imaging of the brain, but in a more robust imaging system. Our design relies on linear x-ray source arrays enabled by the novel carbon nanotube x-ray source. The goals in this project extends from prototype design and development, development of reconstruction approaches and an eventual clinical trial in medically stable head trauma patients.

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INTRODUCTION:

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KEYWORDS:

Traumatic Brain Imaging, Computed Tomography, Trauma, Brain, Imaging, Forward Deployment.

ACCOMPLISHMENTS:

What was accomplished under these goals?

In Phase I (Year 1), the primary goal of the project is to perform the simulation studies for designing the system, then designing and mocking up a physical system.

The relevant Aims and subtasks are summarized below:

Major Task 1 - Specific Aim 1a: Head Phantom Simulations

- Subtask 1: Conventional CT Geometry Simulation to evaluate dose reduction with conventional CT geometry.
- Subtask 2: System geometry evaluation for effects of polygonal shape, projection planes, x-ray source array spacing, detector pixel size on imaging resolution, UQI, and artifact formation.

Major Task 2 – Specific Aim 1b: System Mockup Using Single Source/Detector Pair

- Subtask 1: System CAD design for super-structure
- Subtask 2: Linear Array Tube Acquisition and setup
- Subtask 3: Detector Acquisition and setup
- Subtask 4: System Structure design and construction

Our Year 1 milestones addressed individually:

Milestone 1: Determine the minimum number of projection views and the lowest radiation dose needed to obtain diagnostic quality CT images of a head phantom using a custom CT scanner.

We currently estimate that we will need between 120 and 160 x-ray projections to achieve the minimum number of projections necessary to obtain a clinically useful image. For example, the figure below represents a simulated reconstruction of our digital test phantom, modified from a conventional digital test phantom (Shepp Logan) with three foci of hemorrhage in the bottom of the digital phantom. This reconstruction is based on our proposed three plane setup, seen in Milestone 2, reconstructed utilizing our iterative reconstruction technique developed for this geometry. The reconstruction is based on a total variation corrected Randomized Kazcmarz approach, currently implemented in Matlab. We

are in the process of converting this code to GPU enabled code, which will significantly speed up reconstruction.

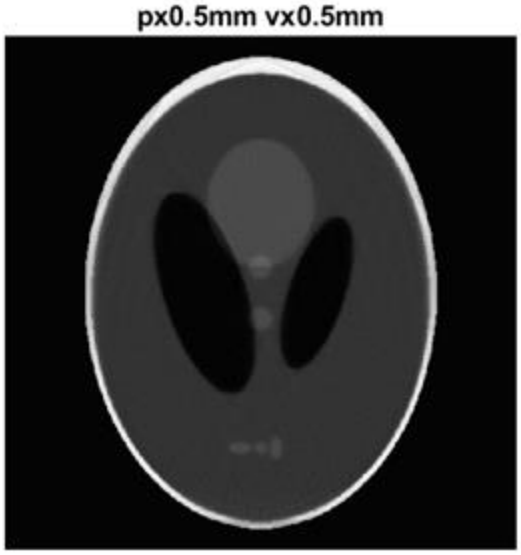

Figure 1. Sample reconstruction from our simulated system, discussed further in later milestones, reflecting the use of 135 x-ray sources.

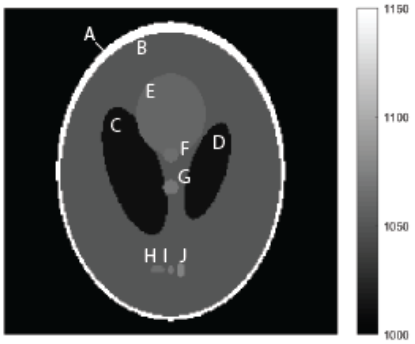

Figure 2. Low-contrast Modified Shepp-Logan Phantom. The Hounsfield unit (HU) scale values [10] used for parts in head are – bone (A): 750 HU, white matter (B): 50 HU, grey matter (C, D): 10 HU, blood (E-J): 60~75 HU and air (background): -1000 HU

Milestone 2: Determine the optimal distribution of reduced number of x-ray projection views identified in Subtask 1.

The single plane configuration (right side of figure), corresponds to the setup in Milestone 4. We have modeled the source distribution based on a customized x-ray tube, and is shown in the left side of Figure 3. A conceptual model of how the head would move through the system is seen in Figure 4. The three plane model allows the necessary coverage, and solves the need for x-ray sources to be in the same position as detectors by move the sets into multiple planes. We anticipate that the minimum entrance/exit plane to be less than 10 cm.

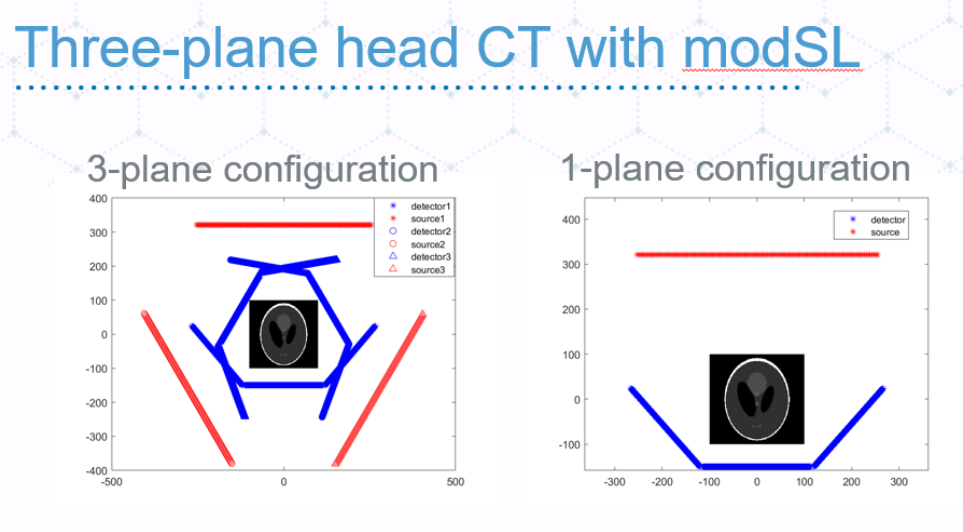

Figure 3. The three plane (left) and single plane (right) configuration of the proposed system. Objects may be rotated to three different positions in the single plane system to achieve the configuration shown in the three plane system, allowing us to simulate the "final" geometry using the generation 0 x-ray tube with 200 sources.

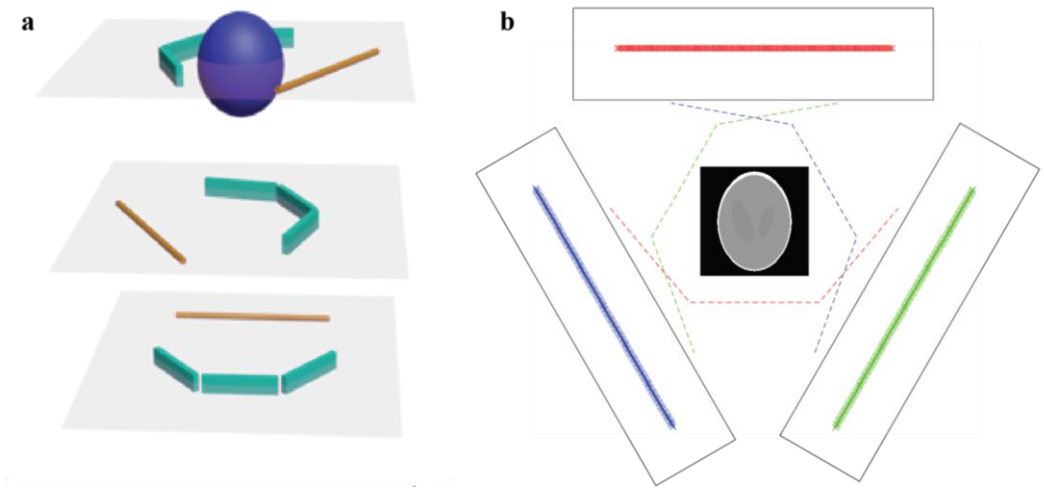

Figure 4. Additional renderings of how an object (the purple ball) may be scanned by translating it the three plane system (left), and a rendering of the x-ray source / detector sets (right), demonstrating the relative size of a head phantom relative to the sources (solid lines, with the x-ray housing) and matching detectors (dotted lines).

Milestone 3: Achieve reduction of dose without compromising MTF and SdNR in comparing with rotating gantry CT using FBP algorithm with a goal of 50% dose reduction.

We have focused our energies on the reduction of courses as a measure of dose; ie, our simulations do not currently take into x-ray dose. However, using the number of projections as a surrogate, we estimate a 36% reduction in dose with our current setup. In an optimized angular setup, a greater dose

reduction could be achieved, however, due to the physical limitations of x-ray tube design, we are taking a more conservative dose reduction approach, to insure that there is sufficient angular coverage for a high quality reconstruction.

Milestone 4: Completed single source based system mockup and finalized system design. Identification of optimal geometry and configuration for the sHCT system.

We have constructed the first mockup of the initial head CT single plane shown in Figure 5. This setup enabled rapid testing and acquisition of test projection images.

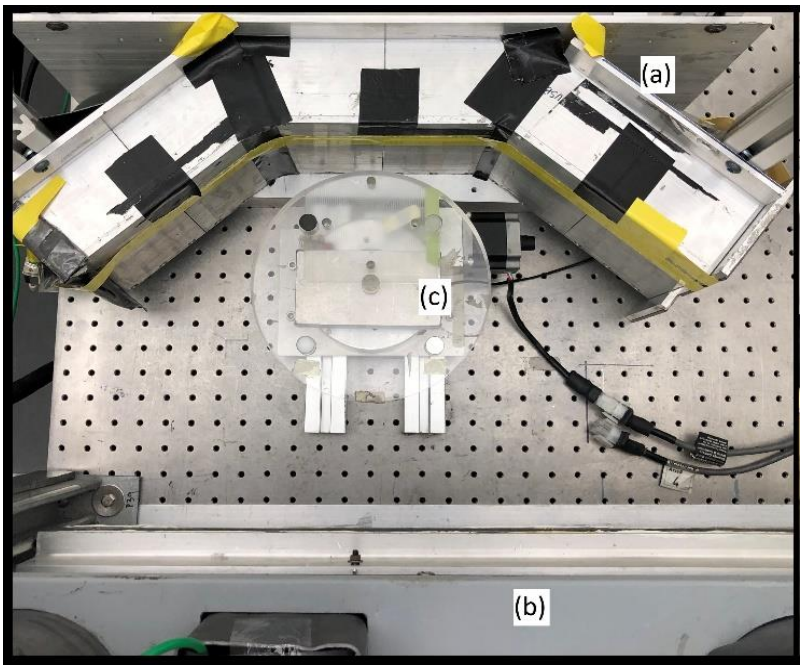

Figure 5: Bench-top stationary head CT system with (a) Linear segmented detector array, (b) CNT multi-beam FEX source array, and (c) Acrylic geometric phantom containing cylinders of aluminum, Delrin, graphite, and water. The test phantom is rotated on a rotary stage to generate the full data necessary for reconstruction.

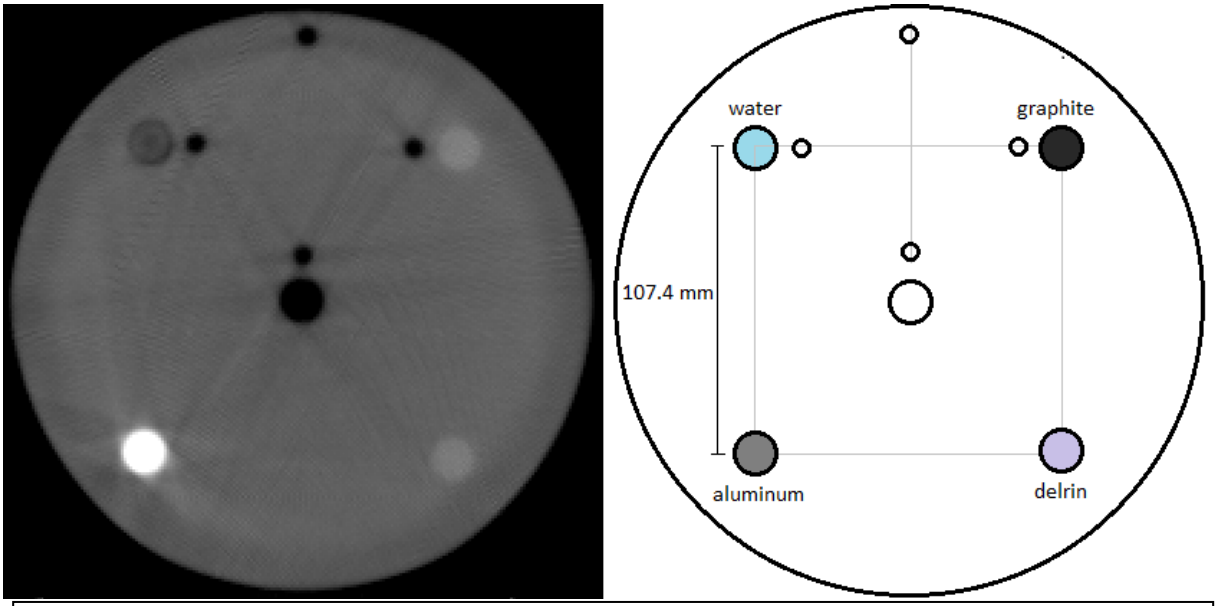

FIGURE 6. RECONSTRUCTED AXIAL SLICE OF THE 20 CM DIAMETER ACRYLIC GEOMETRY PHANTOM FROM THE STATIONARY HEAD CT SIMULATION (1.6 MM SLICE THICKNESS). THIS INITIAL IMAGE TAKEN BY THE S-HCT SYSTEM HAS NOT BEEN CORRECTED FOR BEAM HARDENING ARTIFACTS.

Milestone 5: Conference abstract submission and paper submission on proposed imaging geometry

We have submitted two conference paper abstracts to SPIE medical Imaging regarding the system design titled:

"Simulation and Optimization of a sHCT using CNT X-ray Source "

"Feasibility of a Stationary Head CT Scanner using a CNT Multi-beam Field Emission X-ray source Array"

An additional abstract will be submitted to the American Society of Neuroradiology in May 2020.

What opportunities for training and professional development has the project provided?

Two graduate students were recruited within the Department of Physics and Astronomy at UNC Chapel hill to participate in the development of this hardware. We are in the process of hiring a post-doctoral fellow to assist in system integration programming. Mentorship by the three faculty, Zhou, Lu and Lee continues from both direct and group interactions.

How were the results disseminated to communities of interest?

Two abstracts have been submitted to SPIE Medical Imaging, 2020 related to the hardware and software reconstruction work associated with this project.

What do you plan to do during the next reporting period to accomplish the goals?

We are transitioning to finalizing the system design, acquiring the additional x-ray tubes (already ordered) and x-ray detectors (already ordered) for building the final system. Reconstruction code is being adapted to GPU acceleration to speed reconstruction.

IMPACT:

What was the impact on the development of the principal discipline(s) of the project?

The potential for a stationary CT system has been proposed or suggested by a number of groups in the field. However, implementation of such a system is difficult, given the requirements of a clinical need, capable x-ray source and reconstruction expertise. We feel that our work in this area will bring the field forward beyond "simulated" systems, to an actual complete system capable of imaging. This will likely convince others in the field that these systems are truly feasible, and will result in innovation for other medical imaging applications. Furthermore, this will enhance interest in improved reconstruction approaches.

What was the impact on other disciplines?

Northing to Report.

What was the impact on technology transfer?

Nothing to Report

What was the impact on society beyond science and technology?

Nothing to Report

CHANGES/PROBLEMS:

We have not encountered any scientific difficulties that are not unsurmountable at this time. We are currently proposing a 3 plane system to provide sufficient x-ray beam coverage. Some of our example mockups in the initial proposal focused on a 2 plane system. However, with the 3-plane system implemented, we will attempt to reduce projections from the 3rd plane and maintain CT quality. Currently, all tube and detector deliveries are on schedule. We remain hopeful that we can complete the prototype system before the end of Phase 2. We will begin regulatory paperwork for the FITBIR documentation and IRB protocols before the end of this calendar year (2019).

We had a delay in hiring a postdoctoral fellow for the project, due to lack of qualified personnel, but we have identified a candidate for the position and am in the process of onboarding. This has reduced personnel costs, but we may hiring a second post-doctoral fellow to compensate for some of the additional reconstruction needs of the system.

PRODUCTS:

Two abstracts are submitted to SPIE Medical Imaging.

No other products at this time.

PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS

What individuals have worked on the project?

Name: Yueh Lee

Project Role: Principal Investigator

Research Identifier: ORCID 0000-0003-1846-7680

Nearest person month worked: 3

Contribution to Project: Dr. Lee is leading the project as PI.

Name: Otto Zhou

Project Role: Co-Investigator

Nearest person month worked: 1

Research Identifier: N/A

Contribution to Project: Dr. Zhou is assisting Dr. Lee in supervising graduate students in both system construction and design.

Name: Jianping Lu

Project Role: Co-Investigator

Nearest person month worked: 1

Research Identifier: ORCID 0000-0001-9963-9741

Name: Christina Inscoe

Research Identifier: 0000-0001-8681-9030

Project Role: Co-Investigator / Laboratory Manager

Nearest person month worked: 3

Contribution to Project: Dr. Inscoe has assisted Dr. Lee in x-ray source requirement selection and coordination of the design efforts.

Name: Derrek Spronk

Research Identifier: Not available

Project Role: Research Assistant

Nearest person month worked: 12

Contribution to Project: Mr. Spronk is developing the CAD models and selecting hardware for construction of the prototype system.

Name: Yueting Luo

Research Identifier: 0000-0002-9217-4002

Project Role: Research Assistant

Nearest person month worked: 12

Contribution to Project: Ms. Luo is developing the simulation and reconstruction software for the novel geometries.

Has there been a change in the active other support of the PD/PI(s) or senior/key personnel since the last reporting period?

Nothing to Report.

What other organizations were involved as partners?

Provide the following information for each partnership:

Organization Name: Duke University, Durham NC USA

Partner's contribution: Dr. Sean Montgomery is a trauma surgeon with military experience, and is assisting on system design and capability in the military context.

SPECIAL REPORTING REQUIREMENTS

Quad chart will be enclosed as an attachment