

AWARD NUMBER: W81XWH-18-2-0043

TITLE: Development and Evaluation of a Solid State Head CT

PRINCIPAL INVESTIGATOR: Yueh Z. Lee, MD, PhD

CONTRACTING ORGANIZATION: The University of North Carolina, Chapel Hill, NC

REPORT DATE: October 2021

TYPE OF REPORT: Annual Report

PREPARED FOR: U.S. Army Medical Research and Development Command
Fort Detrick, Maryland 21702-5012

DISTRIBUTION STATEMENT: Approved for Public Release;
Distribution Unlimited

The views, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy or decision unless so designated by other documentation.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing this collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.

1. REPORT DATE October 2021		2. REPORT TYPE Annual Report		3. DATES COVERED 15Sep2020-14Sep2021	
4. TITLE AND SUBTITLE Development and Evaluation of a Solid State Head CT				5a. CONTRACT NUMBER W81XWH-18-2-0043	
				5b. GRANT NUMBER DM180025	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S) Yueh Z. Lee, MD/PhD E-Mail:leey@med.unc.edu				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) The University of North Carolina at Chapel Hill				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Army Medical Research and Development Command Fort Detrick, Maryland 21702-5012				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION / AVAILABILITY STATEMENT Approved for Public Release; Distribution Unlimited					
13. SUPPLEMENTARY NOTES					
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.					
15. SUBJECT TERMS None listed.					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT Unclassified	18. NUMBER OF PAGES 11	19a. NAME OF RESPONSIBLE PERSON USAMRMC
a. REPORT Unclassified	b. ABSTRACT Unclassified	c. THIS PAGE Unclassified			19b. TELEPHONE NUMBER (include area code)

TABLE OF CONTENTS

	<u>Page</u>
1. Introduction	1
2. Keywords	1
3. Accomplishments	1
4. Impact	5
5. Changes/Problems	5
6. Products	6
7. Participants & Other Collaborating Organizations	6
8. Special Reporting Requirements	7
9. Appendices	None

INTRODUCTION:

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.

KEYWORDS:

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

ACCOMPLISHMENTS:

What was accomplished under these goals?

In Phase II and III (Years 2 and 3), the primary goal of the project is to implement the stationary Head CT system and prepare for, and perform the clinical evaluation of the system.

The remaining relevant Aims and subtasks are summarized below:

Specific Aim 2c: GPU implementation (Major Task 3) & Prepare for Clinical trials (Major Task 4)

Major Task 3 tasks:

- Subtask 2c.1: Implement reconstruction code for GPU - Completed
- Subtask 2c.2: Optimize acquisition code for clinical use - Completed

Major Task 4 tasks

- Subtask 2c.1: Radiation Safety Testing - Completed
- Subtask 2c.2: Obtain electrical safety approval - Completed
- Subtask 2c.3: Prepare and submit IRB for HRPO preview and IRB submission - Completed

Major Tasks 3 & 4 Milestones:

Milestone 2.c-1: Complete implementation of GPU reconstruction algorithm for fast reconstruction

Milestone 2.c-2: Submission of manuscript for publication in a peer-reviewed journal.

Milestone 2.c-3: Presentation at a military-relevant or national meeting.

Milestone 2.c-4: Completed prototype s-HCT system for clinical evaluation.

Milestone 2.c-5: Submit IRB for HRPO pre-review

Specific Aim 3: Prepare sHCT system for clinical evaluation

Major Task 1 tasks:

- Subtask 3.1.1: Complete IRB Submission - Completed
- Subtask 3.1.2: Technologist Training – Partially Complete

Major Task 2: Recruit and Image Patients

- Subtask 3.2.1: Coordinate recruitment of patients – Pending clinical system completion

- Subtask 3.2.2: Image patients – Pending system completion

Major Task 3: Perform Reader study

- Perform Reader Study – Pending patient recruitment

Milestones: Completed patient recruitment and Reader study.

Year 3 Aims and Milestones:

The majority of the effort in year 3 has focused on refining the system development and preparation of the system for clinical evaluation. This has consisted of the engineering tasks of system integration, the physical move of the system to a new building/space adjacent active clinical radiology work and the work necessary for patient evaluation. This process has been somewhat delayed by COVID precautions and coordination of needed assistance from the building maintenance, electrical work, etc., but as of this report, all the hardware has been transferred from the laboratory space in Chapman Hall (an undergraduate education and laboratory space) to the former clinical CT room at the Ambulatory Care Center. A recent picture of that space is seen in Figure 1, with the patient translation table, detector holder in frame and electronics rack in position. The x-ray tube holder frame is to the left of the table and will be mounted surrounding the detector assembly. One tube (red-stripe) is already positioned underneath the detector assembly.

Stationary Head CT Hardware

The primary refinements to the hardware have focused on redesigning the detector assembly to allow a more rigid and compact structure to allow components to be positioned more closely to the anticipated design value. This, in turn, reduces the calibration requirements, and allow for a more robust assembly of the system. The use of the clinical procedure bed also reduced system design complexity by taking advantage of the existing engineering of a medical procedure table. Patient motion is controlled leaving the safety features in place while only actuating a single motor within the table, integrated with additional safety stop features. A clinical CT head holder will serve as the head holder for the subjects, also selected to minimize additional engineering effort. Each detector and source are individually collimated to minimize x-ray scatter, which substantially improves image quality.



Figure 1. Stationary head CT components in the former clinical CT space at the UNC Hospital's Ambulatory Care Center. The x-ray detector assembly, head holder and patient bed are all positioned as intended for the imaging study. The x-ray tube holder frame is to the left of the imaging bed. Sterilizable patient pads will be attached with the Velcro pads.

Image Acquisition Software:

One advantage of the multi-planar approach is that the three imaging planes may be acquired simultaneously, which increases the scan speed. We demonstrate this with the two electronic control system (ECS) control during our planned clinical acquisition. The intended bed-speed is 8.5 mm/sec, during which a full set of slice data is acquired approximately every 2.5 mm of bed travel. With a third ECS controller, we could further increase the scan speed by approximately 40%.

Software control was written to be "easy to use" from the technologists perspective, but the single activation activates both the x-ray detectors, but the two sets of microcontrollers that control the x-ray sources through the ECS and the bed controller. Safety provisions that activate full system stop are integrated in the software design.

Reconstruction Software:

The current version of the reconstruction software utilizes an iterative reconstruction approach that balances the smoothness of the image while maintaining details. This ASD-POCS approach has a number of parameters, which will be further optimized once actual patient data is acquired (Figure 2). The reconstruction is performed as a 3-D volume with continuous data. The 3-D volume acquisition approach has been directly compared against the 2-D acquisition to confirm that there is no loss of image quality associated with the approach.

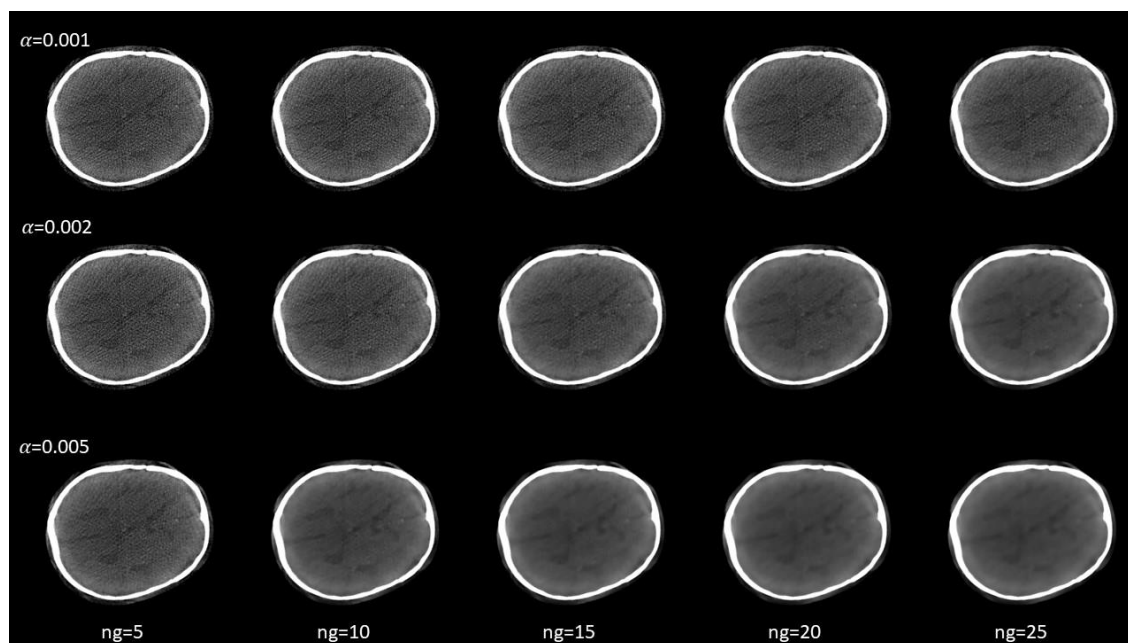


Figure 2. Reconstructed single slice image of the head phantom reconstructed with different alpha and ng parameters.

Clinical Study:

We have obtained IRB approval for the project and the research core team has also communicated with the FITBIR team about matching data libraries with our RedCap database. The Radiology research core has also met with the Physics team and manager of the clinical ACC space to discuss patient workflow, private space for consent and other trial details. The imaging technologist has also had a chance to evaluate the imaging space and will be further trained on the clinical software once the system is up and running.

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

Two graduate students within the Department of Physics and Astronomy (UNC Chapel Hill) and one additional graduate student from the Joint Department of Biomedical Engineering (UNC Chapel Hill/NCSU) have participated in the development of this hardware. Two additional post-doctoral fellows have assisted in the development of the programming necessary to run the system. 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 additional abstracts have been presented to SPIE Medical Imaging, 2021 (virtually due to the pandemic) related to the hardware and software reconstruction work associated with this project. A new paper has recently been accepted in the Journal of Medical Imaging (Special Issue for the 50th anniversary of CT) related to the reconstruction algorithms for the paper. Three additional abstracts

have been submitted to SPIE Medical Imaging, 2022, with one currently accepted. Other notifications for the 2022 meeting are still pending.

A poster was presented at the American Society of Neuroradiology (virtually) in 2021. An additional talk was presented to the American Society of Functional Neuroradiology (hybrid meeting) for the “new technologies” symposium. Additional abstracts will be submitted to the American Society of Neuroradiology in November 2021 for the 2022 meeting.

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

We will anticipate completion of the system installation and initiation the clinical trials within approximately 1 month, and to complete the reader study before the end of the project year.

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, with significant recent interest from a number of groups, both domestically and internationally. A few have proposed a very small number (tens) of x-ray sources as a potential model. 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.

Overall, our system demonstrates both the potential of stationary imaging systems, and addresses many of the technical difficulties other groups have yet to encounter, based on their published work.

What was the impact on other disciplines?

We have had the opportunity to introduce the proposed system to the Neuroradiology field through posters and presentations at the two most attended neuroradiology meetings.

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 requested a NCE for year 3 to complete the patient study due to delays related to system installation and COVID.

We are awaiting completion of the installation of the system at the clinical research site, which should be up and running before the end of October '21. The delay has been due to a combination of COVID barriers, and machine shop availability (also indirectly related to COVID). Barring any other unforeseen hardware failure, we will immediately begin subject recruitment for the study. COVID has significantly

altered the interest of subjects to participate in research studies, but our team has consistently recruited approximately 1 to 2 patients per week on studies with conditions of lower prevalence.

From an image quality perspective, we continue to explore machine learning reconstruction approaches for the system, to further reduce image artifacts. We narrowed our approaches to sinogram infilling to prevent “artifact creation” that may be associated with other machine learning approaches.

PRODUCTS:

A paper was published in Medical Physics this reporting period.

1. Spronk D, Luo Y, Inscoe CR, Lee YZ, Lu J, Zhou O. Evaluation of carbon nanotube x-ray source array for stationary head computed tomography. *Medical Physics*. 2021;48(3):1089–1099.

A second paper has recently (October 2021) been accepted by the *Journal of Medical Imaging* with Yueting Luo (graduate student) as the lead author focused on reconstruction algorithms used.

Two conference proceedings were presented at SPIE Medical Imaging 2021, one covering the hardware development, the second covering reconstruction.

1. Spronk D, Luo Y, Inscoe CR, Zhou O, Lu J, Lee YZ. Stationary head CT scanner using CNT x-ray source arrays. *Medical Imaging 2021: Physics of Medical Imaging* [Internet]. International Society for Optics and Photonics; 2021 [cited 2021 Feb 17]. p. 1159532.

2. Luo Y, Spronk D, Inscoe CR, Lee Y, Zhou O, Lu J. Stationary head CT with linear CNT x-ray source arrays: image quality assessment through simulation. *Medical Imaging 2021: Physics of Medical Imaging* [Internet]. International Society for Optics and Photonics; 2021 [cited 2021 Mar 26]. p. 1159536.

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: 0000-0003-1476-5517

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

Contribution to Project: Dr. Lu is assisting with the develop of reconstruction algorithms for the system.

Name: Deanna Sasaki-Adams

Project Role: Co-Investigator

Nearest person month worked: 1

Research Identifier: N/A

Contribution to Project: Dr. Deanna Sasaki Adams (neurosurgeon) is the PI of the clinical study. She has been managing IRB protocol development and approval.

Name: Sean Montgomery

Project Role: Co-Investigator

Nearest person month worked: 1

Research Identifier: N/A

Contribution to Project: Dr. Montgomery (Trauma Surgeon, Duke University) is assisting the team in maintain the military relevance of the project, and will assist in interpretation of images in the trial.

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 is assisting in system development and construction, and will coordinate radiation and electrical safety testing of the system.

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.

Name: Alex Billingsley

Research Identifier: 0000-0001-7630-2134

Project Role: Research Graduate Assistant

Nearest person month worked: 6

Contribution to Project: Mr. Billingsley has assisted with the hardware integration (microcontroller programming) and system calibration.

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