Biomedical Imaging Division
VIRGINIA TECH WAKE FOREST UNIVERSITY
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How to Define the Next Generation Cardiac CT Architecture?
— A Contemporary Challenge for Interdisciplinary Collaboration

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Abstract

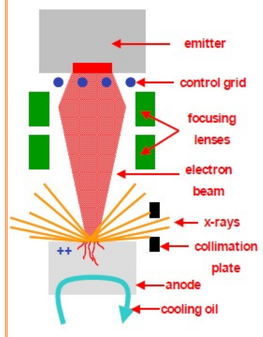
Cardiovascular diseases are pervasive with high mortality and morbidity at tremendous social and healthcare costs. There are urgent needs for significantly higher fidelity cardiac CT with substantially lower radiation dose, which is currently not possible because of technical limitations. Although cardiac CT technology has improved significantly from 16 to 320 detector rows and from single to dual source, there remain technical challenges in terms of temporal resolution, spatial resolution, radiation dose, and so on. Based on an ideal academic-industrial partnership between Virginia Tech and the GE Global Research Center (GEGR), we are motivated to advance the state-of-the-art in cardiac CT.

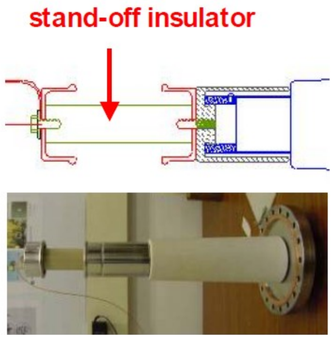
The overall goal of this project is to develop novel cardiac CT architectures and the associated reconstruction algorithms, and define the next-generation cardiac CT system. The specific aims are to (1) design, analyze and compare novel cardiac CT architectures with novel sources and scanning trajectories; (2) develop analytic and iterative cardiac CT reconstruction algorithms for ROI-oriented scanning and dynamic imaging for the proposed cardiac CT architectures; and (3) evaluate and validate the proposed architectures and algorithms in theoretical studies, numerical simulations, phantom experiments and observer studies.

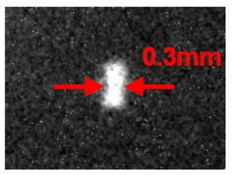
On completion of this project, we will have singled out the most promising cardiac CT architectures and algorithms to achieve **16cm coverage**, **50ms temporal resolution**, **20lp/cm spatial resolution**, **10HU noise level**, and **1mSv effective dose** simultaneously for the entire examination, with detailed specifications and performance evaluation, setting the stage for prototyping a next-generation cardiac CT system in a Phase-II project. This project will enable significantly better diagnostic performance and bring major therapeutic benefits that affect over 60 million Americans.

The purpose of this poster is for you to advise us with novel ideas and constructive suggestions. We are particularly interested in hearing about architectural candidates, algorithmic schemes, clinical tasks, generic criteria, and task-specific studies. Will we need an enhanced general CT scanner or a dedicated cardiac CT scanner in the future? Please feel free to discuss with our team members in person, by phone, and via email.

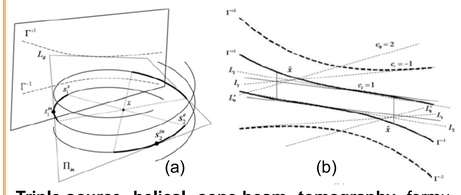
Key Components





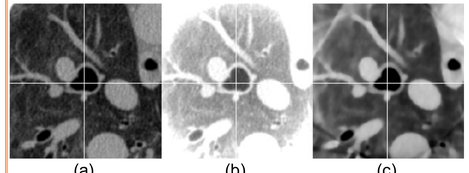


Distributed x-ray source technology developed by GE Global Research Center. (a) Diagram of a multi-source electron gun topology, (b) drawing and picture of a high-voltage standoff insulator, and (c) a fast-switching x-ray cathode with 4 focal spots, with measurement of a focal spot.



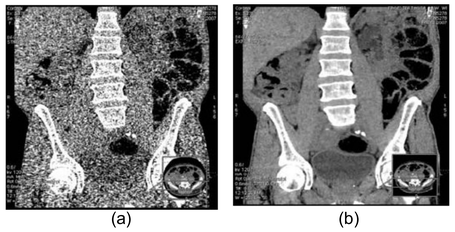
(a) (b)

Triple-source helical cone-beam tomography formulated by Lv Y, Katsevich A, Zhao J, Yu H and Wang G (2010). (a) An intersection line of an osculation plane and the detector plane and (b) representative filtering lines.



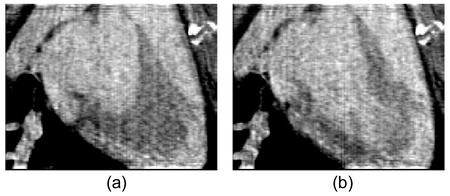
(a) (b) (c)

Interior tomography of the sheep chest performed by Virginia Tech and Univ. of Iowa (2007). (a) The image reconstructed by the global FBP, (b) that reconstructed by a local FBP after smooth data extrapolation, and (c) that by compressive-sensing-inspired interior tomography without precise knowledge of a subregion in the ROI.



(a) (b)

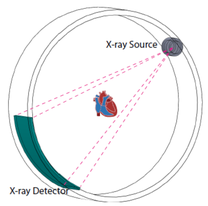
Statistical reconstruction performed by GE Healthcare. (a) A slice reconstructed with FBP and (b) the counterpart by statistical reconstruction (Courtesy of Jean-Baptiste Thibault, GE Healthcare).

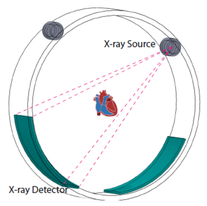


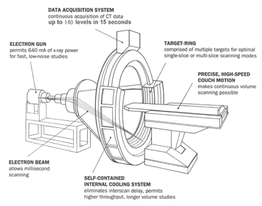
(a) (b)

Dynamic reconstruction at end-systole performed by GE Global Research Center. (a) and end-diastole (b) based on PW-MLTR using 50 views per phase.

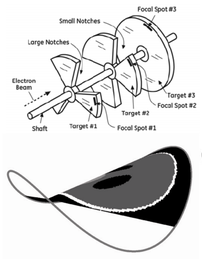
Candidate Architectures

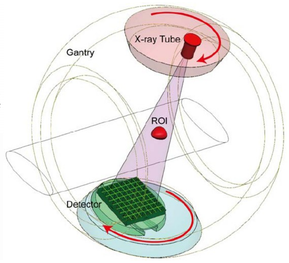




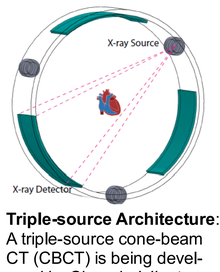


Baseline Architectures: This includes all commercially available CT architectures. Most commercial CT scanners use the third-generation geometry. The Siemens dual-source system has been well received for its improved temporal resolution and dual-energy imaging potential. The best temporal resolution today is achieved with the EBCT scanner.

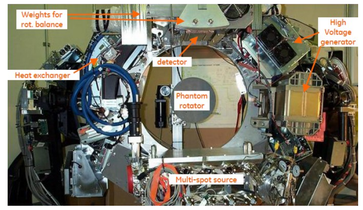


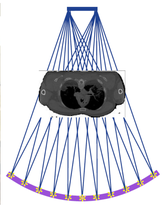


Saddle-curve Architectures: Line sources with longitudinally offset focal spots were proposed by GE Global Research Center and can be used to implement a saddle trajectory. A composite-circling scanning mode was proposed by Virginia Tech as an alternative to solve the short object problem. The saddle-curve scanning mode is feasible for multi-source systems too.

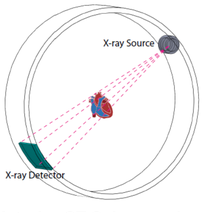


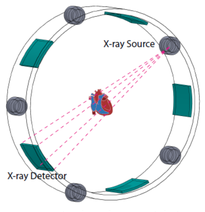
Triple-source Architecture: A triple-source cone-beam CT (CBCT) is being developed by Shanghai Jiaotong Univ., Central Florida Univ. and Virginia Tech. The apparent merit is a good improvement in temporal resolution at an incremental cost.

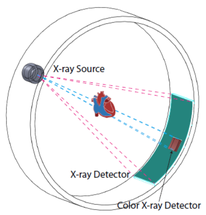




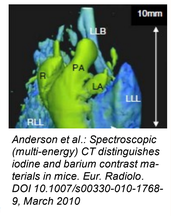
Inverse Geometry Architecture: Inverse-geometry CT (IGCT) developed by Stanford Univ. and GE Global Research Center consists of multiple focal spots each emitting a relatively narrow x-ray beam through a small portion of the field-of-view. By scanning the source and detector configuration, a complete dataset can be collected.





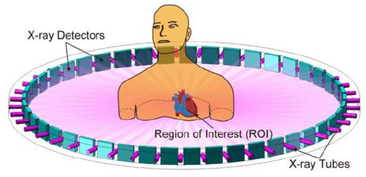


Interior CT Schemes: An easy way to implement interior CT is to collimate x-rays to an ROI. This requires centering the ROI. More ideas were proposed by us and others including aggressive and dynamic bowties.



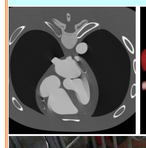
Anderson et al.: Spectroscopic (multi-energy) CT distinguishes iodine and barium contrast materials in mice. Eur. Radiolo. DOI 10.1007/s00330-010-1768-9, March 2010

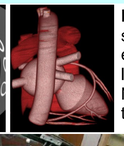
Hybrid CT Schemes: A spectral detector can be embedded in a conventional detector array to implement color interior CT for characterization of plaques and other features.



Instant CT Scheme: Similar to EBCT, an instant CT scanner is optimized for temporal resolution. We recently introduced a stationary interior cardiac CT concept according to interior tomography and compressive sensing. This scheme is conceivable with a cardiac ROI of 10cm, a magnification of 2, and a detector width of 20cm, and an architecture with tens of source-detector pairs. Scattering can be addressed by collimation, multiplexing and spectral imaging.

Evaluation Strategy





Numerical Simulation: GE Global Research Center developed a simulation environment *CatSim* for x-ray CT and licensed to Virginia Tech. The well-known NCAT and UCAIR phantoms will be used to generate realistic datasets.

Phantom Experiments: GE Global Research Center has an experimental platform capable of emulating a very wide range of CT geometries. A cardiac CT phantom with beating heart inserts will be used, along with a CT performance phantom and a dosimeter.

Approach for Initial Evaluation: Modified Completeness Maps based on the Tuy's condition and interior tomography theory respectively.

Approach for General Evaluation: Traditional image quality matrix and radiation dose indexes.

Approach for Specific Evaluation: Mathematical and human observer studies will compare both imaging performance and system superiority.

Project Timeline (08/2010-08/2013)

	Aim/Task	Year 1	Year 2	Year 3	Milestone
1	**Architecture Innovations**				Designed and analyzed multiple cardiac CT architectures, selected two architectures for more detailed evaluation
1.1	Architecture Definition	■ ■	■ ■	■ ■	
1.2	Detailed Design	■	■ ■	■ ■	
1.3	Comparative Studies		■ ■	■ ■	
2	**Algorithm Development**				Developed and optimized global, interior and dynamic reconstruction algorithms for selected cardiac CT architectures
2.1	Global Reconstruction	■ ■ ■	■ ■ ■	■ ■ ■	
2.2	Interior Reconstruction	■ ■ ■	■ ■ ■ ■ ■ ■	■ ■ ■	
2.3	Dynamic Reconstruction	■ ■ ■	■ ■ ■ ■ ■ ■	■ ■ ■	
3	**Performance Evaluation**				Characterized the two selected cardiac CT systems, and identified the best system
3.1	Theoretical Studies		■ ■	■ ■	
3.2	Numerical Simulation	■ ■	■ ■ ■ ■	■	
3.3	Phantom Experiments		■ ■ ■ ■	■ ■	
3.4	Observer Studies		■ ■	■ ■ ■ ■	

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SBES Division/ICTAS Center for Biomedical Imaging: http://www.imaging.sbes.vt.edu; GE Global Research Center: http://ge.geglobalresearch.com

May 21, 2010