

CBCT Brain Perfusion: Digital Simulator and Physical Phantom

600.446 Computer Integrated Surgery II

Project Proposal

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Project Motivation and Relevance

In the United States, acute stroke is the third leading cause of death. Responsible for approximately 1 in 15 deaths, stroke affects approximately 700,000 individuals in the US annually. There are two types of stroke. Ischemic stroke is a lack of blood flow to certain regions of the brain due to a blockage of a vessel while hemorrhagic stroke is either a brain aneurysm burst or a weakened blood vessel leak. Approximately 80% of stroke cases are ischemic in nature and the remaining 20% are hemorrhagic. The rapid and reliable visualization of blood flow in the brain at the point of care is critical for differentiating between ischemic and hemorrhagic stroke.

These different types of stroke are identified using conventional, unenhanced CT scans to locate regions of hemorrhage in the brain. Current approaches towards treatment of ischemic stroke in particular, frequently involves thrombolytic drugs designed to dissolve blood clots. However, use of these drugs is limited to a time window as the chance of hemorrhage increases with increased waiting time post stroke occurrence. Rapid data acquisition, diagnosis, and treatment are paramount factors in improving outcomes in these stroke cases.

One technique used to diagnose ischemic stroke includes a combination of CT angiography (CTA) and CT perfusion imaging (CTP). CTA focuses on the anatomical aspect of the diagnosis by targeting specific regions associated with vessel blockage. This technique is based on contrast-enhanced imaging to better visualize the angiography or blood vessel architecture. CTA requires an approximate steady state level of contrast during the image acquisition. On the other hand, CTP focuses on the physiological aspect of the diagnosis and aids in determining recoverable and irrecoverable regions of

tissue. CTP tracks the motion of circulating iodinated contrast, known a contrast bolus as it moves through the vasculature.

A dedicated Cone-Beam Computed Tomography (CBCT) scanner is currently being developed at Johns Hopkins University, specifically for the detection and evaluation of intracranial hemorrhage. Our project is concerned with the evaluating the feasibility of applying this scanner towards diagnosis of ischemic stroke in addition to hemorrhagic stroke. We are especially interested in the potential for brain perfusion imaging in expediting the diagnosis of ischemic stroke by performing the perfusion imaging at the point of care.

The underlying goal of CT perfusion imaging aims to identify regions in the brain which can be categorized to an ischemic core of critically irreversible tissue and into a penumbra, a region which is severely damaged but recoverable. Once the scan is performed, imaging software is used to generate a time attenuation curve (TAC) for each voxel in the image. Using these resulting TACs, perfusion parameters such as cerebral blood flow (CBF), cerebral blood volume (CBV), and mean transit time (MTT) are then calculated. Based on these parameters, physicians can localize the penumbra and ischemic core.

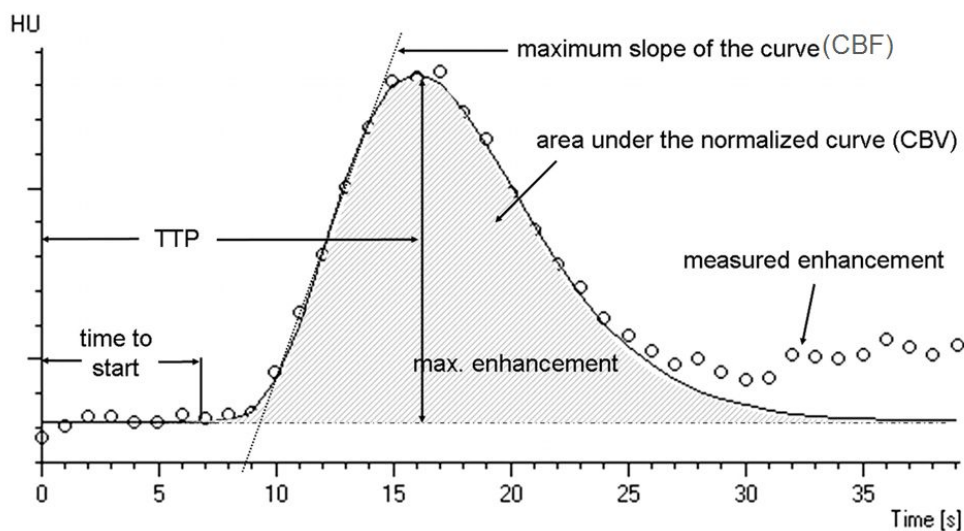


Fig. 1 (<http://neuroangio.org/neuroangio-topics/perfusion-primer/>)

Mission and Project Goal

Our aim is to evaluate the feasibility of CBCT scanner in conjunction with perfusion imaging by constructing a digital and physical phantom to reliably characterize perfusion parameters among a wide range of ischemic stroke cases.

Technical Approach for Digital Phantom

The first component of our project will be designing a digital phantom to simulate the entire diagnostic process. The two inputs to our digital phantom will be a specified TAC for a certain region of interest and a head phantom image. We will be able to robustly create TACs for a wide range of stroke cases. The TACs will be placed into specific regions in the head phantom and forward projected using various frame rates and acquisition times. This forward projection algorithm will be done in the typical case of changing the image over each frame and calculating many dynamic forward projections. Since this method is very computationally expensive due to the 4D representation of the brain, we will also explore an alternative option. This faster method involves cutting out a region of interest from the brain image and taking static forward projections of both the image and region of interest (ROI). The ROI projections are then scaled based on the TAC and added back to the head phantom. Our projection data will then be reconstructed using a filtered back projection model to create a brain perfusion map. We will validate this diagnostic simulation by assessing the computational overhead and robustness of our approach.

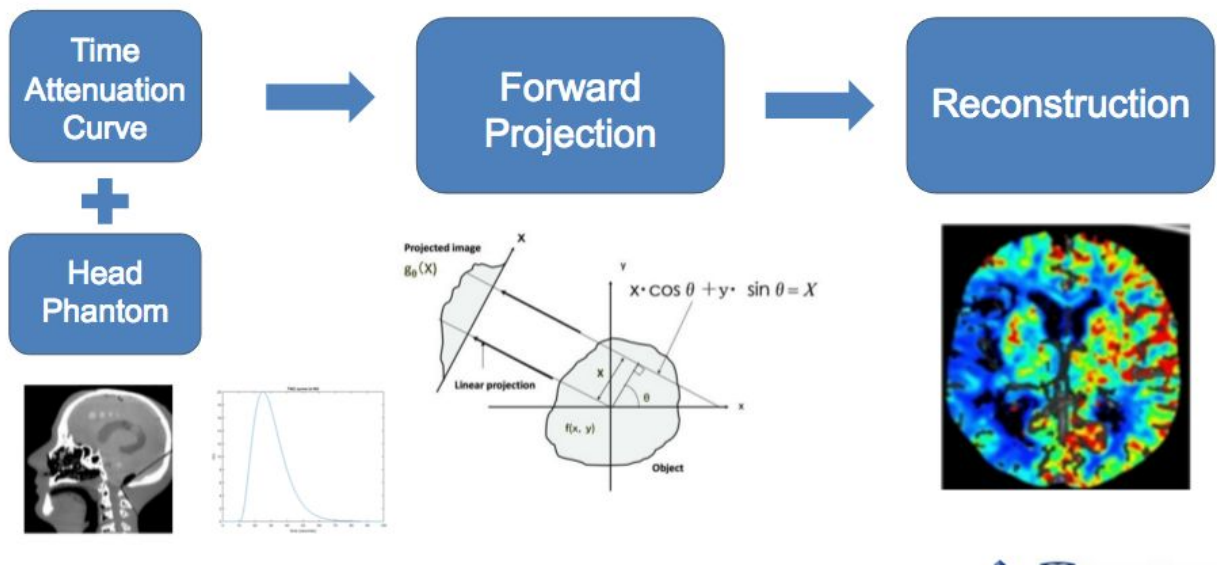


Fig. 2 Block Diagram of Digital Phantom Approach

Design Approach for Physical Phantom

We also plan to design and fabricate a physical phantom that models brain perfusion. Beginning with a literature review, we compare the advantages and disadvantages of previous perfusion designs. In addition, we will perform a fluid mechanics simulation using SolidWorks software to understand the possible range of flows. After a preliminary analysis, we will design and fabricate an initial prototype on SolidWorks. This prototype will be 3D printed using the Stratasys Connex3 printer located in the Carnegie Center for Surgical Innovation at Johns Hopkins Hospital. We will also begin composing a proposal for ordering a contrast injector, peristaltic pump, and additional materials suitable for our model.

A contrast injector is a required component for our model to deliver the contrast bolus into the phantom at a controlled rate. The peristaltic pump is also necessary to accurately control an input flow rate to our system. Based on our model considerations, we may need to implement a system to further control the flow rate. Once assembled, we will begin initial testing on the CT scanner bench located in the I-STAR Laboratory. We plan to transition our testing towards the new CBCT scanner which is anticipated to be completed in April.

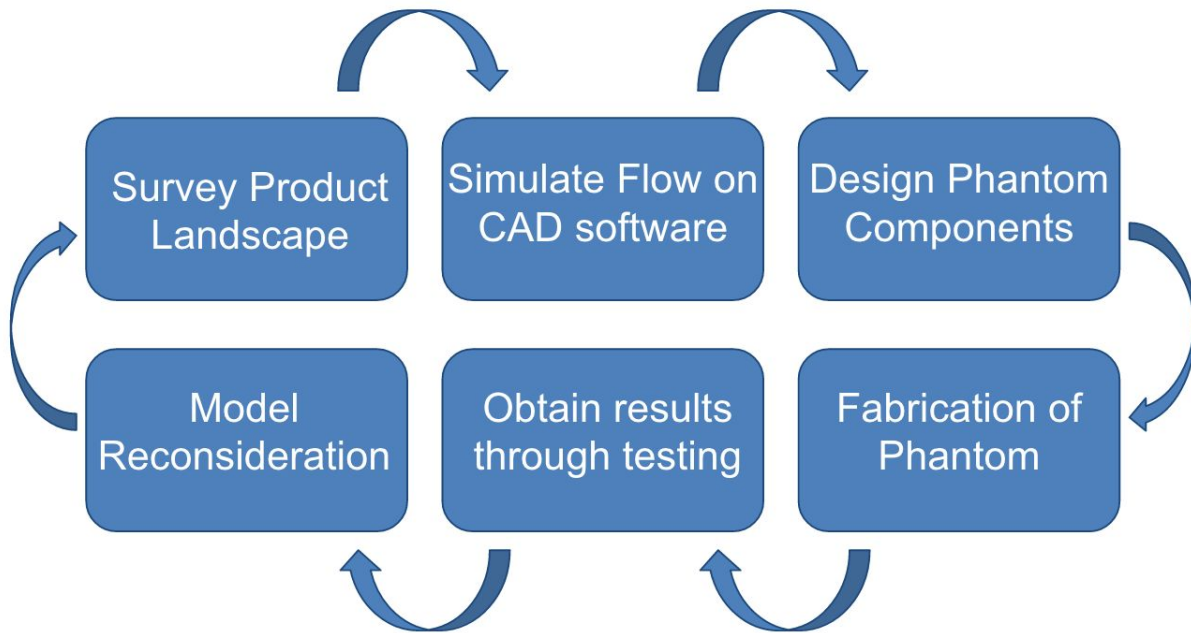


Fig.3 Block Diagram of Physical Phantom Approach

Deliverables

Minimum

For our minimum deliverable, we plan to generate time attenuation curves, to model a wide range of stroke cases. In order to comprehensively characterize the perfusion, we will ensure control over the following parameters: TAC delay, maximum enhancement, initial slope, width of TAC. We also plan to complete both forward projection algorithms specified in the technical design approach paragraph describe in addition to the filtered backprojection reconstruction. We will also validate this approach by extensively testing the entire range of scan speeds and corresponding impact on accuracy.

Expected

For our expected deliverable, we plan to thoroughly survey the existing brain perfusion phantoms through literature. A detailed comparison of advantages and disadvantages will be made. We will also simulate flow models using CAD software to develop the initial prototype.

This work will go into forming a budget proposal for additional components including the contrast injector and peristaltic pump. We will then fabricate the physical phantom using our initial designs and ordered parts.

Maximum

Taking our constructed physical phantom, we strive to perform rigorous testing and measurements of time attenuation profiles, perfusion parameters, and related metrics. This will be done on the CT scanner bench in the I-STAR and translated onto the new CBCT scanner when it arrives. If these results can be compiled, we plan to go ahead and prepare a manuscript for submission to a conference.

Dependencies

Dependencies for Digital Phantom

- Access to a GPU Workstation (Met)
 - If Workstation fails, access to various other GPU workstations in I-STAR lab through remote desktop (Met)
- Access to CUDA Tools (Met)
- Digital Brain Phantom (Met)

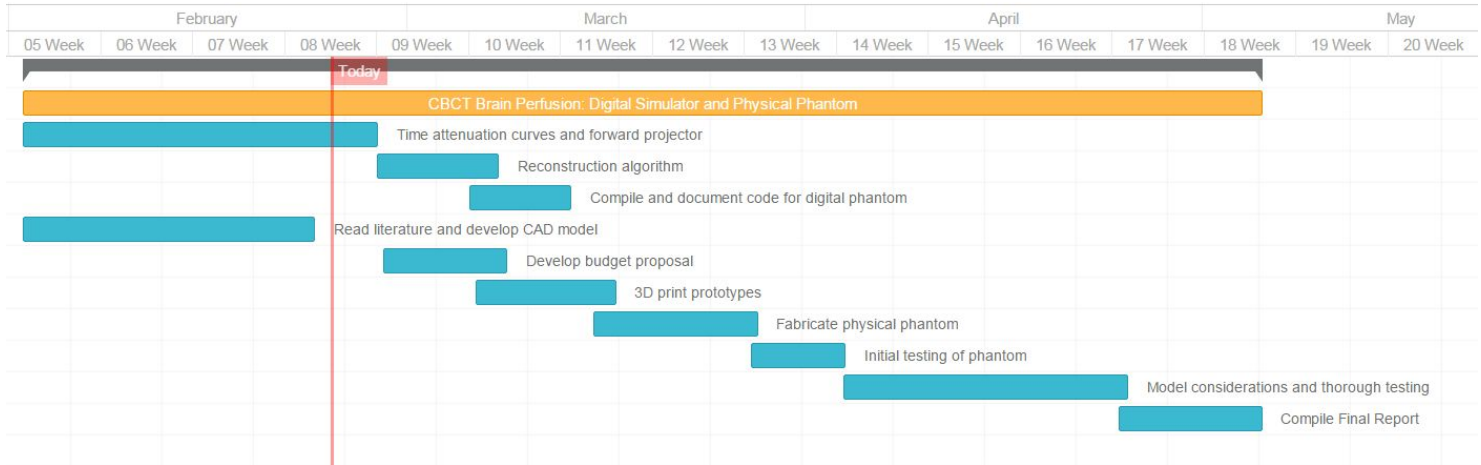
Dependencies for Physical Phantom

- Access and training for 3D Printer in Carnegie at JHMI (Met)
 - If 3D printer breaks or becomes unavailable, other options include fabrication at the JHU BME Design Studio, the JHU Digital Media Center, or outsource to other makerspace
- Access and training for machine shop at JHMI (Unmet, training will take place in March)
 - Other options for machine shop access may include Wyman Park Building machine shop or outsourced components
- Access to a CT scanner for testing (Met)
 - If CT bench in I-STAR lab breaks or becomes unavailable, we will consult our advisors about finding a substitute facility such as a clinical CT scanner

Advising Dependencies

- Funding for physical phantom component (Met)
 - We have obtained verbal agreement for funding from our advisors
- Availability of collaborators (Met)
 - We have arranged weekly meetings on Monday mornings with our advisors to obtain feedback and advice towards completing our project.

Timeline



Milestones

- February 25:** Finalize Literature Review
- February 25:** Submit proposal documents
- February 29:** Complete forward projection for digital phantom
- March 7:** Complete reconstruction algorithm for digital phantom
- March 7:** Propose Budget and Begin ordering Parts
- March 14:** Finalize digital phantom (**Minimum Deliverable**)
- March 14-21:** Spring Break
- March 28:** Finalize design of physical phantom (**Expected Deliverable**)
- April 25:** Complete testing and standardization of the physical phantom (**Maximum Deliverable**)
- May 06:** Final report Presentation

Management Plan

Karthik	Michael
Lead proposal of physical phantom	Lead design of digital simulator
Extensive survey of existing product landscape	MATLAB implementation using CudaTools
Phantom testing protocol	MATLAB code documentation
Administrative Operations (i.e. Budget Proposal, BitBucket management, etc.)	Fabrication of phantom
Develop CAD/flow simulation Design physical phantom component layout	

Reading List

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