CBCT Brain Perfusion: Phantom and Digital Simulator

Computer Integrated Surgery II Checkpoint Presentation

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I-STAR LAB





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- 2. Project Summary
- 3. Deliverables
- 4. Progress
 - **Digital Phantom**
 - Physical Phantom

Project

- 5. Dependencies
- 6. Timeline
- 7. Milestones

CBCT Brain Perfusion



Project Background

 A dedicated Cone-Beam Computed Tomography (CBCT) scanner for the detection and evaluation of intracranial hemorrhage (ICH) is being developed at JHMI

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• 87% of stroke cases are diagnosed as ischemic rather than hemorrhagic

Project

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 One established method for the evaluation of ischemic stroke is brain perfusion imaging which describes the passage of blood flow through the brain's vasculature

Project

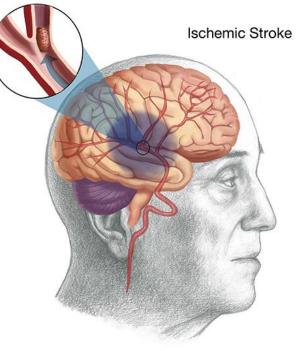
Summarv

Deliverables

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Timeline







Develop a digital and physical brain perfusion imaging phantom to evaluate the feasibility and performance of a new CBCT scanner for characterization of perfusion parameters relevant to the detection of ischemic stroke

Project

Background

CBCT Brain Perfusion

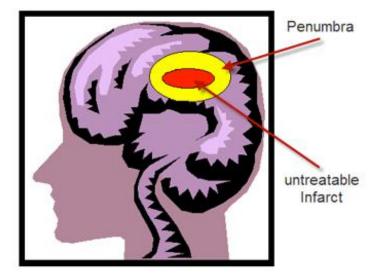
Project

Summary

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Dependencies



(StrokeCareNow, 2009)

Timeline





Minimum

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- Generate time attenuation curves for a wide range of stroke cases
- Complete a forward projection and reconstruction of a region of interest in the digital head phantom
- Perform validation by testing entire range of scan speeds and corresponding impact on accuracy

Expected

- Survey existing product landscape and literature
- Design CAD of phantom

ery, Therapy, and Radiology

- Order parts/equipment for phantom
- Fabricate phantom and begin initial testing

Maximum

- Thorough testing and measurements of time attenuation profiles and perfusion parameters in the phantom
- Submission to conference

Project

Background



Minimum

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- Survey existing product landscape and literature for physical phantom \checkmark
- Generate time attenuation curves for a wide range of stroke cases in digital phantom \checkmark
- Complete a forward projection of a region of interest in the digital head phantom $\sqrt{}$

ry, Therapy, and Radiology

Expected

- Account for various scan speeds, rotation methods, enhancement curves, regions of interest, and computational cost of digital phantom
- Obtain parts/equipment for phantom
- Fabricate phantom and begin initial testing
- Complete a reconstruction method of the projection data
 Maximum
- Thorough testing and measurements of time attenuation profiles and perfusion parameters in the phantom
- Submission to conference

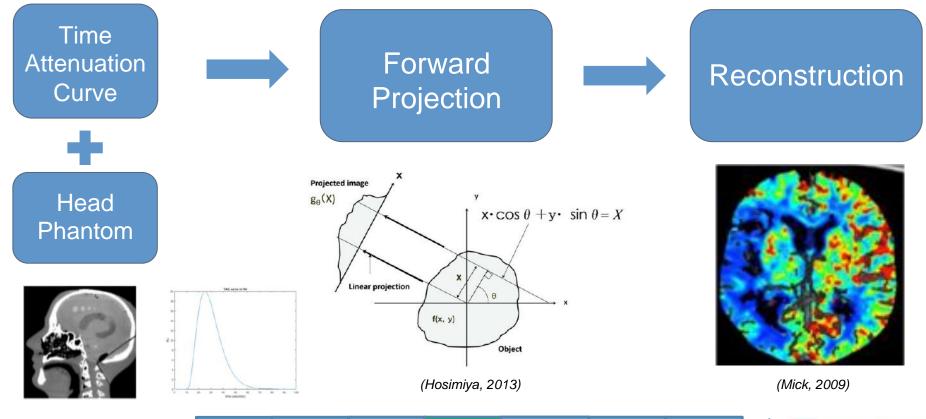
CBCT Brain Perfusion

Deliverables Progress Dependencies

Timeline Miles



Technical Approach for Digital Phantom



CBCT Brain Perfusion

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Summary Delive

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Progress: Digital Phantom – Flow Chart

Head Phantom Voxel Image Input

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Geometry Inputs

- Voxel size
- Detector size
- SAD & SDD
- Rotation method

Region of Interest Inputs

- Radii and centers or
- Specific voxels
- Optional smoothing

Time Attenuation Inputs

- Max enhancement
- Time delay
- Time at which max occurs
- Alpha parameter

Time Inputs

- Angle step (degrees)
- Frame rate (frames/sec)
- Acquisition time (sec)

Head Phantom

Projection Data

CBCT Brain Perfusion

Project Project Background Summar

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Brute Force Forward Projection

- Enhancement addition in voxel image data
 - For each time point, a 3D matrix is moved to GPU space and a separable footprint forward projection is completed using CudaTools

Faster Forward Projection

- Head phantom and ROI go through a static forward projection using CudaTools
- Enhancement addition in projection data based on scaling of the ROI

Projection Data with Enhancement



Progress: Digital Phantom – Flow Chart

Head Phantom Voxel Image Input

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Imaging for Surgery, Therapy, and Radiology

Geometry Inputs

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Head Phantom

Projection Data

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Projection Data with Enhancement





Progress: Digital Phantom – Head Image

0.07

0.06

0.05

0.04

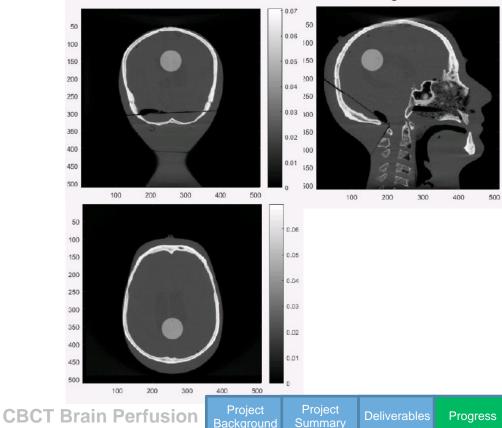
0.03

0.02

0.01

Dependencies

Voxel Based Head Phantom Image with ROI



Head Phantom Projection Data with ROI





Progress: Digital Phantom – Flow Chart

Head Phantom Voxel Image Input

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Geometry Inputs

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Time Attenuation Inputs

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Time Inputs

- Angle step (degrees)
- Frame rate (frames/sec)
- Acquisition time (sec)

Head Phantom

Projection Data

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Projection Data with Enhancement



TAC: Gamma Variate Function

• Describes the dispersion of a bolus as it passes through a series of compartments

$$y(t') = y_{max} t'^{\alpha} \exp(\alpha(1 - t'))$$

$$t' = \frac{t - t_0}{t_{max} - t_0}$$

$$t_0 \text{ is the delay time}$$

$$y_{max} = y(t_{max})$$

$$\alpha \text{ determines onset, decay}$$

Project

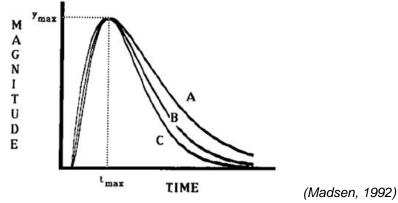


Figure 2. Three plots of equation (7) with $\alpha = 1.0$ (curve A), $\alpha = 1.5$ (curve B) and $\alpha = 2.0$ (curve C). Note that both the location and the magnitude of the curves remain stable as α is increased.

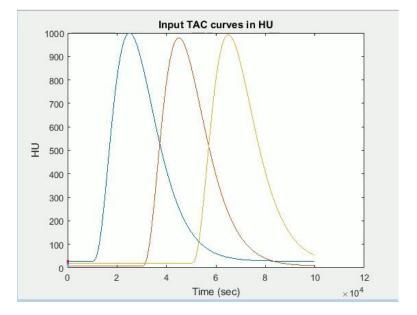
CBCT Brain Perfusion Background

Project Summary

Progress **Dependencies**



Progress: Digital Phantom – Multiple ROI



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Progress: Digital Phantom – Rotation Method

Full Sweep Rotation (Clinical CT)

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Partial Sweep Rotation (C-arm)





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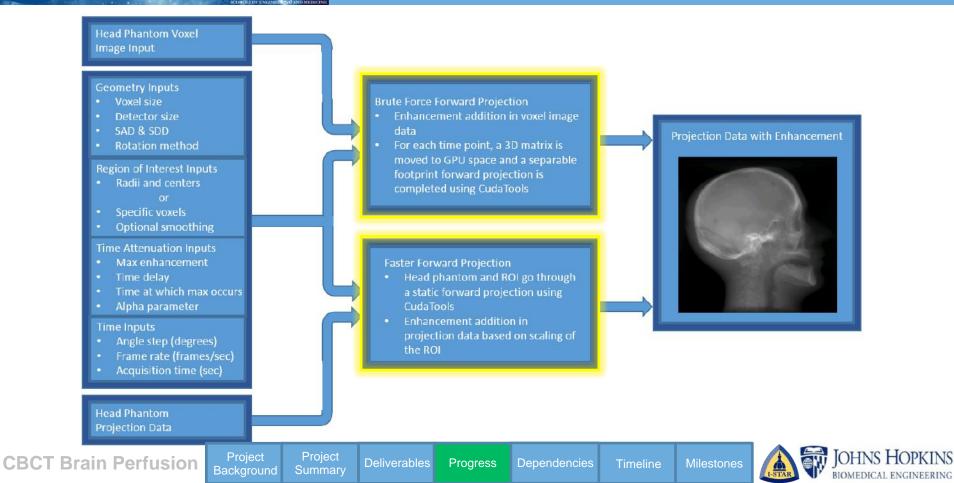
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Progress: Digital Phantom – Flow Chart



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Progress: Digital Phantom – Forward Projection

Brute Force Forward Projection

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- Load head phantom voxel based image
- For each frame, add enhancement value from TAC time point to head phantom image over the ROI
- Complete separable footprint forward projection for each frame

$$\int_{SDD} (\mu_{head \ phantom} + \mu_{enhancement}) \ dL$$

Faster Scaling Forward Projection

Load head phantom projection image data

Project

- Create projections of ROI mask
- For each frame, scale ROI projection mask by enhancement value from TAC time point and add to head phantom projection

$$\int_{SDD} \mu_{head \ phantom} \, dL + \mu_{enhancement} \int_{ROI} dL$$

Project

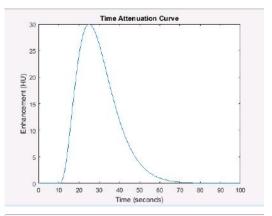
Summarv

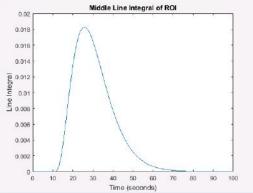


Deliverables

Progress Dependencies Timeline







Progress: Physical Phantom – Wood

• "Initial testing of a 3D printed perfusion phantom using digital subtraction angiography" (Wood, 2015)

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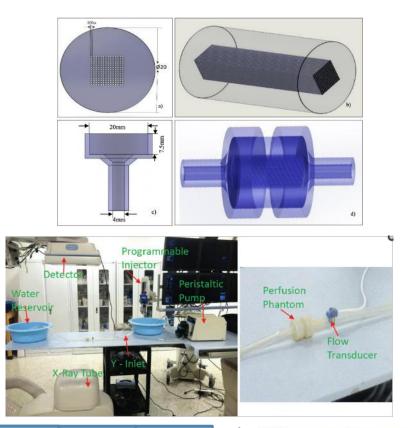
- Phantom was designed on SolidWorks and build with Objet Eden 260V Stratasys printer (200 micron resolution in XY-plane, 17 micron in Z-plane)
- Printed using Duraswhite material polypropylene like
- Dimensions:

Diameter: 20mm Length: 20mm or 30mm Capillaries: 196 300umx300um channels

• Flow rates: 250,300,350 mL/min

Project

Background



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Project Summarv De

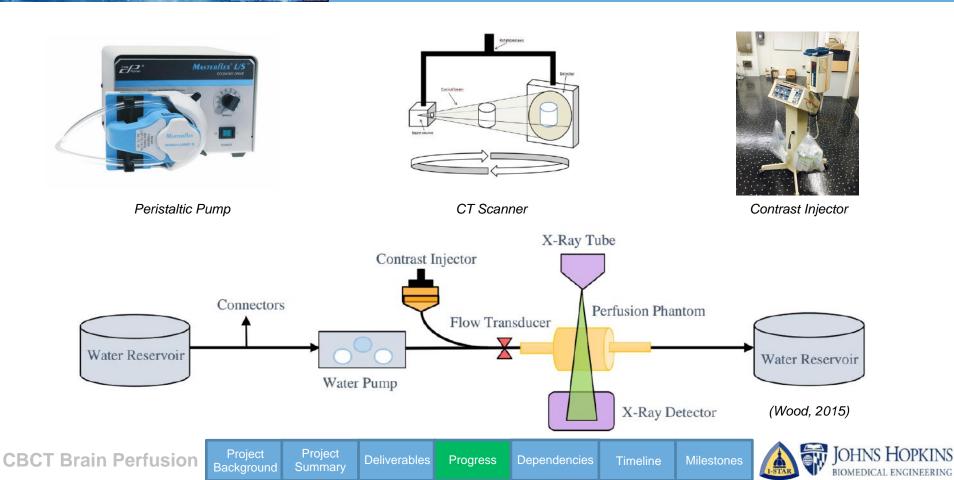
Deliverables

Progress Dependencies

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Progress: Physical Phantom - Diagram



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Progress: Physical Phantom - Budget

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CBCT Brain Perfusion

The I-STAR Lab

Imaging for Surgery, Therapy, and Radiology

Summary

Project

JOHNS HOPKINS UNIVERSITY

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Progress Depender



L/S Economy Pump System with Easy-Load 3 Pump Head

Cole-Palmer Masterflex

- Min Flow Rate: 16 mL/min
- Max Flow Rate: 480 mL/min

for Surgery, Therapy, and Radiology

- Speed control: 20 to 600 rpm
- Cost: \$916.20

CBCT Brain Perfusion

The I-STAR Lab

• ±5% speed regulation

Status: Obtained quote and ready to be purchased

Project

Summary

Deliverables

Progress

Dependencies

Project

Background





Progress: Physical Phantom - Injector

Medrad Mark V Plus Contrast Injector

• Min Flow Rate: 0.005 mL/min

Surgery, Therapy, and Radiology

The I-STAR Lab

• Max Flow Rate: 3000 mL/min

Proiect

Background

• Syringe Volume sizes: 60mL, 150mL, 200mL

Status: Obtained from Dr. Nafi Aygun (JHMI) for use on our project along with compatible syringes and Omnipaque contrast agent





CBCT Brain Perfusion

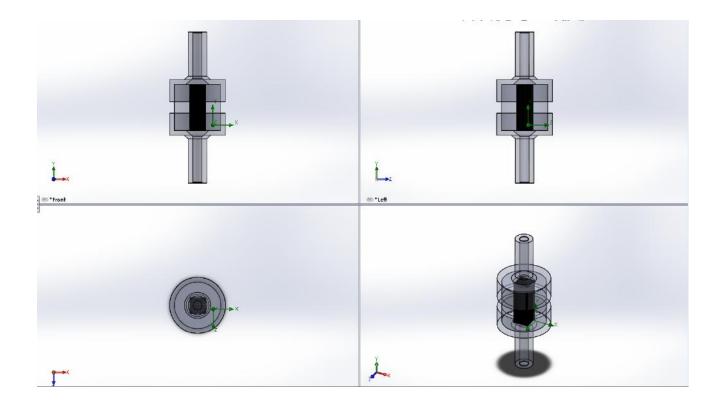
Project Deliverables

Progress Dependencies

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Progress: Physical Phantom - CAD





CBCT Brain Perfusion

Project Summary Delivera

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Dependencies

Dependencies for Digital Phantom

The I-STAR Lab

• Access to a GPU Workstation (Met)

irgery, Therapy, and Radiology

- 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
- Obtain a contrast injector and peristaltic pump (Unmet, currently in budget proposal stage)
- Access to a CT scanner for testing (Met)
 - If new head scanner 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)

Project

Background

- 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.

CBCT Brain Perfusior

Project Summary Deliverab

Progress Dependencies

Timeline Mil





	Fe	bruary			March					Apri	May				
05 Week	06 Week	07 Week	08 Week	09 Week	10 Week	11 Week	12 Week	13 Week	14 Week	15 Week	16 Week	17 Week	18 Week	19 Week	20 Week
			Today												
				CBCT	Brain Perfus	ion: Digital Si	imulator and F	Physical Phan	tom						
				Time atten	uation curves	and forward p	projector								
					Recor	struction algo	orithm								
						Compile	and documen	t code for digi	tal phantom						
			Read li	iterature and (develop CAD	model									
					Deve	elop budget pr	roposal								
						30	O print prototy	pes							
								Fabricat	e physical pha	intom					
									Initial tes	ting of phanto	m				
												Model c	onsiderations a	and thorough	testing
													Co	ompile Final R	eport

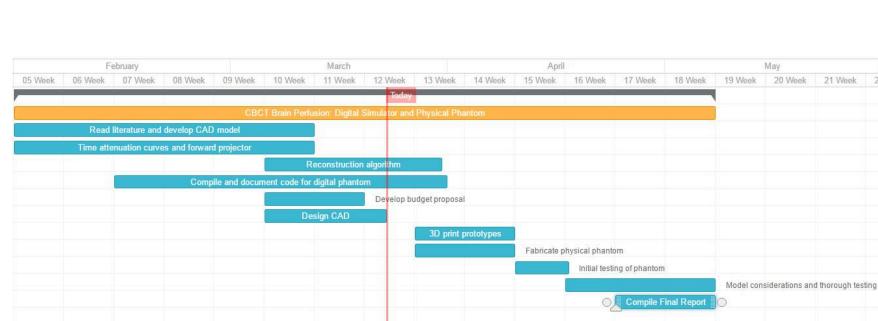
CBCT Brain Perfusion

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CBCT Brain Perfusion

The I-STAR Lab

Imaging for Surgery, Therapy, and Radiology

Summary Delive

Project

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22 Week

February 25: Submit proposal documents ✓

Therapy, and Radiology

The I-STAR Lab

March 7: Complete forward projection for digital phantom \checkmark

Project

Summarv

Deliverables

Project

Background

CBCT Brain Perfusion

March 12: Propose budget and begin ordering parts \checkmark

March 20: Finish CAD design 🖌 (Minimum Deliverable Completed)

April 1: Complete reconstruction algorithm for digital phantom and finalize digital phantom

April 7: Complete initial prototype of physical phantom and begin testing (Expected Deliverable)April 4: Finalize design of physical phantom

April 25: Complete testing and standardization of the physical phantom (Maximum Deliverable) May 06: Final report Presentation

Progress

Dependencies



Milestones