Needle Localization In CT-Guided Tumor Ablation

Group 14:
Giang Hoang (giang@jhu.edu)

Mentors:
Dr. Sheng Xu (xus2@cc.nih.gov)
Dr. Michael Kassin (michael.kassin@nih.gov)
Dr. Bradford J. Wood (bwood@cc.nih.gov)

Project Overview

This project aims to develop an algorithm to **localize and identify the orientation of the ablation needles** to predict the **ablation zone** during minimally-invasive **tumor ablation** procedures

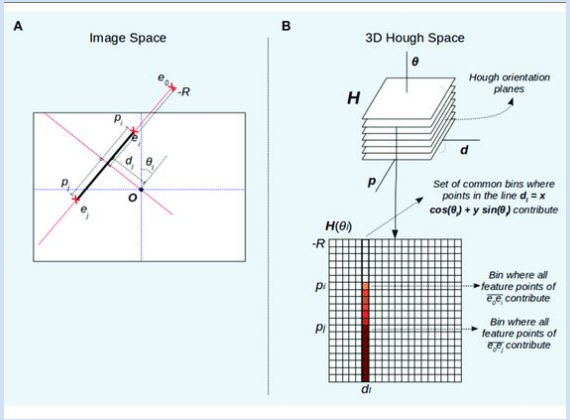
Provided by Xu, Sheng and Wood, Bradford

Project Goals

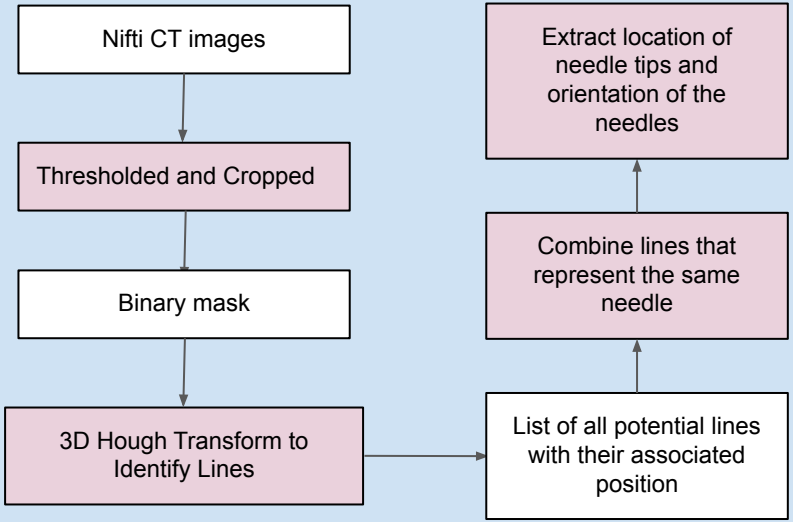
- Localize and identify the orientation of the ablation needles in CT images to support the insertion accuracy
- Generate and superimpose colorized isotherms to predict the ablation zone based on the orientation of the needles and location of the tip
- Evaluate the accuracy and efficiency of the implemented algorithms

Previous Approach: Needle Segmentation

Key Algorithm: 3D Hough Transform[*Zhou et al.*]



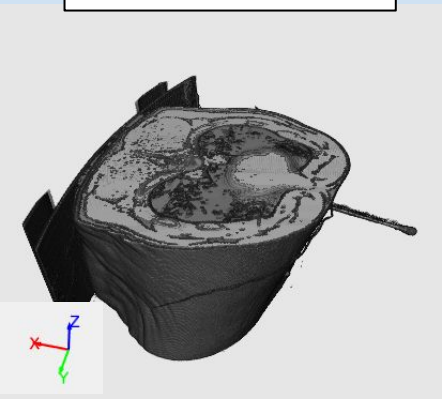
Bachiller et al.



Main Concern: Trade off between Runtime and Resolution
Next Step: Use 3D Hough Transform to find the number of needles in the image

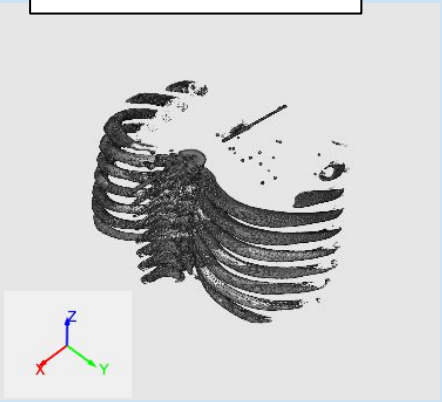
Current Approach: Needle Segmentation

3D CT Image



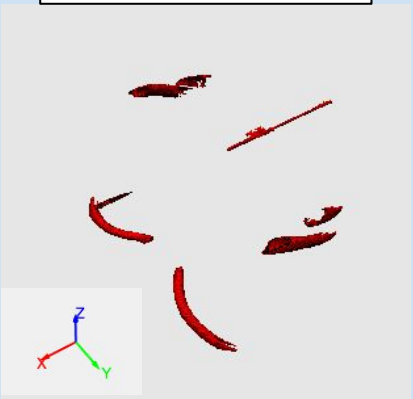
Standardize with
Histogram equalization

Thresholded Image



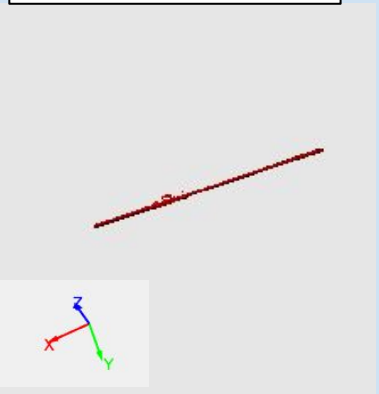
Remove soft tissue safely

Volume Filtered Image



Remove noise and large bone fragments

Shape Filtered Image



Evaluate the elongated shape of bounding box using shape ratio [*Alpers et al.*]

Image Preprocessing

Segmentation with Connected Component Analysis

- 3D (18-connected)
- Flood-fill algorithm

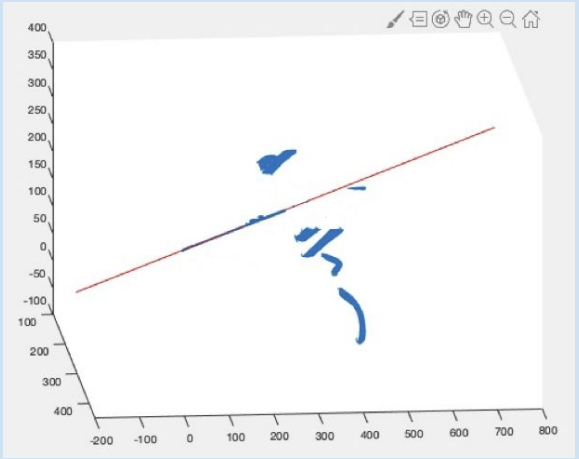
Orientation and Needle Tip Location Extraction

Principal Component Analysis to Identify Needle Orientation

First principal axis is the orientation of the line representing the needle in x-, y-, and z-direction.

Needle tip is the end-point of the segmented region that is closer to the center of the image

Line Generated using PCA direction Superimposed on Thresholded Image

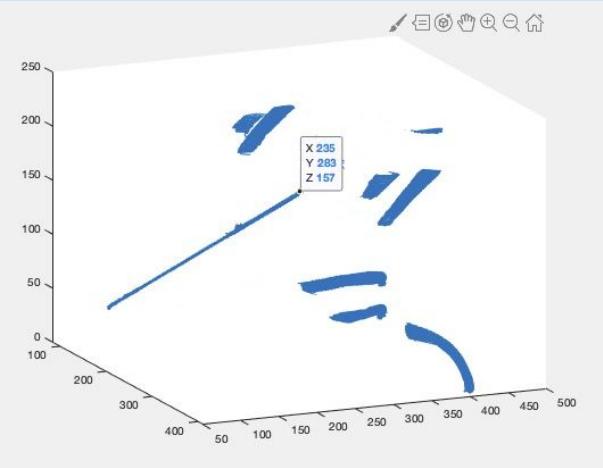


Validation Testing

Algorithm evaluation with medical images

Ground truth determined by marking the endpoints of the ablation needles

→ Compute needle orientation and needle tip location



	start	tip	direction	unit direction
x	172	235	63	0.263799297
y	79	283	204	0.854207247
z	50	157	107	0.448040076

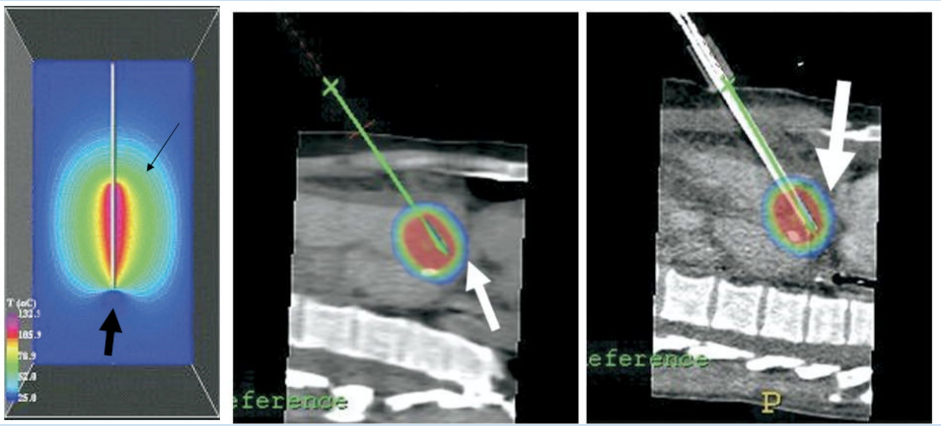
Orientation error

[*Zhou et al.*]

$$\cos(\beta) = \frac{|b_{dx}b_{sx} + b_{dy}b_{sy} + b_{dz}b_{sz}|}{\sqrt{b_{dx}^2 + b_{dy}^2 + b_{dz}^2} \cdot \sqrt{b_{sx}^2 + b_{sy}^2 + b_{sz}^2}}$$

Needle Tip location error: Mean square error

Next Step: Ablation Zone Prediction



Wood et al.

- Use MATLAB 3D Finite Element Analysis in PDE toolbox to simulate heat transfer model[*Paul et al.*]
- Model with Epilliptic Heat Transfer model and Pennes Bioheat Transfer equation[*Zhang et al.*]

Predicted Ablation zone evaluation with phantom or *ex vivo* experiments

- Conduct at the NIH facility → acquire intraoperative and immediate postoperative CT images
- Segment ground truth ablation zone using verified algorithms
- Compute volume and dimension deviations and analyze results

Key Activities and Deliverables

	Activity	Deliverable	Status
Minimum	• MATLAB implementation to process and standardize Nifti CT images • Segment ablation needles from background	• MATLAB program • Documentation on how to implement the code	• Completed • Finalizing
Expected	• Extract needle tip location and needle orientation • Evaluate algorithm accuracy using manually labeled medical images	• MATLAB code • Documentation • Ground truth from CT images • Reports on algorithm performance with graphs and statistical analysis	• Completed • Finalizing • Completed for available images • In Progress
Maximum	• Superimpose colorized isotherms using FEA to predict the ablation zone • Evaluate prediction accuracy with phantom/ex vivo experiments	• MATLAB code and documentation • Reports on algorithm performance with graphs and statistical analysis	• Not Started • Not Started

Dependencies

Dependency	Reasoning	Personnel	Current Status	Contingency Plan	Expected	Deadline
Access to internet and MATLAB, and other softwares	Crucial for research, code implementation and communications	N/A	Continuous access through JHU secured		N/A	N/A
Image Conversion to Nifti File	Simplify the image preprocessing process	Dr. Xu	Completed		03/10	03/15
Ground Truth for Medical Images	Reference for testing, crucial to evaluate algorithm performance	Dr. Xu and Dr. Wood	Completed for obtained images		03/15	03/20
Medical Images	Crucial for algorithm development and testing	Dr. Xu and Dr. Wood	Obtained phantom images, more data will be obtained after data transfer agreement		03/15	03/20
Clinical Data Transfer Agreement	Access to patient medical images	NIH admin, Dr.Xu	Processing	Work with phantom/swine images and modified medical images	03/25	03/31
Phantom and ex vivo samples, experiment space and instrument	Evaluate ablation zone prediction algorithm	Dr. Xu and Dr. Wood	Processing	Evaluate using previously acquired phantom images	04/15	04/25

Timeline

	Activities	February				March					April				May			
		Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13	Week 14	Week 15	Week 16	Week 17
Project Implementation	Research Literature and Algorithms																	
	Obtaining and Preprocess Medical Images																	
	Needle Segmentation																	
	Extract Needle location and orientation																	
	Test and Refine Segmentation Algorithm																	
	Determine Accuracy and Statistical Analysis																	
	Implement FEA using MATLAB simulation																	
	Overlay ablation zone prediction CT image																	
	Test and evaluate ablation zone prediction																	
	Obtain Medical Images																	
	Ground Truth for Images																	
	Clinical Data Transfer Agreement																	
	Facility and instrument for onsite testing																	
Class Reports, Presentations and Checkpoints	Project Presentation and Proposal																	
	Checkpoint 1							Complete of Minimum Deliverables and Code Documentation										
	Checkpoint 2								All image dataset processed and ready to be tested									
	Project Checkpoint Presentation																	
	Checkpoint 3										Finish needle segmentation evaluation and data analysis							
	Reports on Needle Segmenation Perfomance																	
	Paper Presentation																	
	Checkpoint 4												Complete FEA					
	Final Report and Presentation																	

Management

Meeting

- Weekly call with Dr. Xu at 2:30 pm - 3:30 pm on Friday
- On-site meeting with Dr. Xu, Dr. Kassin, and Dr. Wood during scheduled clinical procedures (scheduled throughout the semester)

Communication

- Communication via email and phone/text
- Imaging data sets (nonclinical) and codes shared through Box
- Documentation stored and maintained on the CIS II project Wiki page

References

Alpers, J., Hansen, C., Ringe, K., & Rieder, C. “CT-Based Navigation Guidance for Liver Tumor Ablation”. In *Eurographics Workshop on Visual Computing for Biology and Medicine*. The Eurographics Association. 2017.

Bachiller-Burgos, Pilar et al. “A Spiking Neural Model of HT3D for Corner Detection.” *Frontiers in computational neuroscience* vol. 12 37. 1 Jun. 2018, doi:10.3389/fncom.2018.00037

Paul (2021). 3D Finite Element Analysis with MATLAB (https://www.mathworks.com/matlabcentral/fileexchange/50482-3d-finite-element-analysis-with-matlab), MATLAB Central File Exchange. Retrieved February 23, 2021.

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Zhang, J., Chauhan, S. Real-time computation of bio-heat transfer in the fast explicit dynamics finite element algorithm (FED-FEM) framework, Numerical Heat Transfer, Part B: Fundamentals. 2019; 75:4, 217-238, DOI: 10.1080/10407790.2019.1627812

Zhou, H. *et al.* “Automatic needle segmentation in 3D ultrasound images using 3D improved Hough transform”, in Medical Imaging 2008: Visualization, Image-Guided Procedures, and Modeling, 2008, vol. 6918. doi:10.1117/12.770077.

Thank you

Question?