Project Proposal

Needle Localization In CT-Guided Tumor Ablation

EN 601.456 Computer Integrated Surgery II

Giang Hoang
giang@jhu.edu
B.S., M.S.E. Biomedical Engineering

Table of Contents

1. Project Statement

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

2. Clinical Motivation

Radiofrequency Ablation or Microwave Ablation are minimally invasive surgical procedures that utilize the heat generated from electrical energy to destroy cancer cells [1]. The procedure is commonly used to treat small tumors, especially in areas that are close to important anatomical structure (**Figure 1**) [2]. Tumor ablation involves inserting a needle that allows the passage of high-frequency energy, which heats up a targeted area in the tumor and induces coagulative necrosis. The efficacy of the treatment is affected by the impedance and heat regulation of the tissue and most importantly, the location of the ablation needles with respect to the tumor [3]. Thus, it is highly dependent on image guidance to help physicians accurately insert the needles to the ablation site. However, over-treated and under-treated tumors are very common. A 2009 report on liver tumor ablation with RFA showed 9% of cases have major complications from overtreatment and around 40% of cases had undertreated tumors that may result in recurrence [3]. This urges for current image guidance practice to be enhanced in order to improve clinical outcomes in tumor ablation.

This project aims to automate the needle identification process in Computed Tomography (CT) images to help physicians better identify the ablation zone intraoperatively. Moreover, in most occasions, many ablation needles need to be inserted either concurrently or sequentially to cover the span of the entire tumor. Thus, the algorithm should be able to compute the location and orientation of each needle in the image and approximate their combined ablation effect.

Fig 1. Image-guided Tumor Ablation Procedure *(images provided by Dr. Sheng Xu, NIH Clinical Center)*

3. Prior Work

A. Prior work in ablation needle localization

There have been multiple attempts to automatically localize needles in tumor ablation procedures. Most notably, the incorporation of electromagnetic (EM) trackers onto the ablation needle has resulted in promising outcomes [4, 5]. Specifically, an EM tracker is incorporated into the ablation needle and the location of the needle is tracked with respect to the CT scan of the patient **(Figure 2)**. While EM tracker can help decrease the dependence on frequent imaging input, the procedure requires an elaborated calibration protocol to relate the EM tracker coordinate system with the CT coordinate system. Moreover, the incorporation of EM tracker onto the ablation needle often requires the modification of surgical tools, which pose a barrier to its clinical adoption. Despite its barriers, this work provides an important clinical interface for the adoption of new needle localization methods into the workflow.

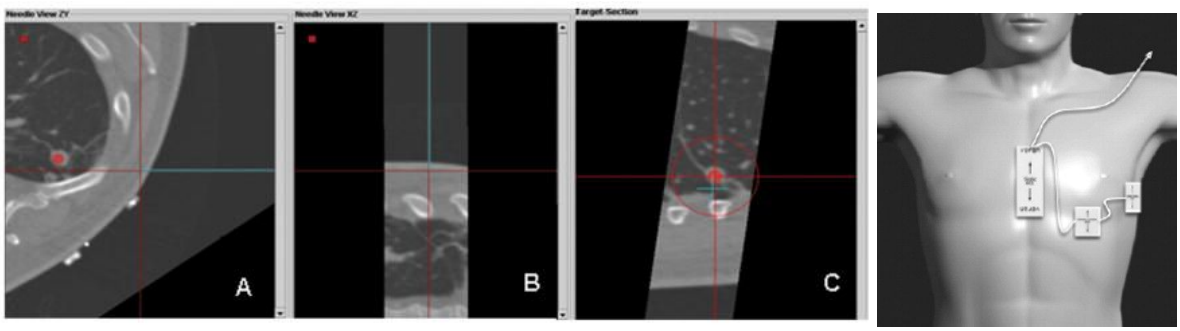

Fig 2. (A-C) Ablation needles tracked by EM with custom tracking software [5]; **(D)** EM tracker pads are placed on the patient's chest and an EM generator is mobile which can be placed on the patient's skin [4].

B. Prior work in needle detection in 3D ultrasound images

Several needle localization algorithms have been developed for 3D Ultrasound images and have been proven to be effective [6, 7]. A popular algorithm is the 3D Hough transform, which can be used to determine the location and orientation of a line segment by working with a polar coordinate representation of a line in 3D (**Figure 3**). A 3D modified Hough transform algorithm was previously developed and showed a less than 2° and 2 mm deviation in angle and location, with a run time of 2 seconds per computation. This is a promising algorithm for application to the current project.

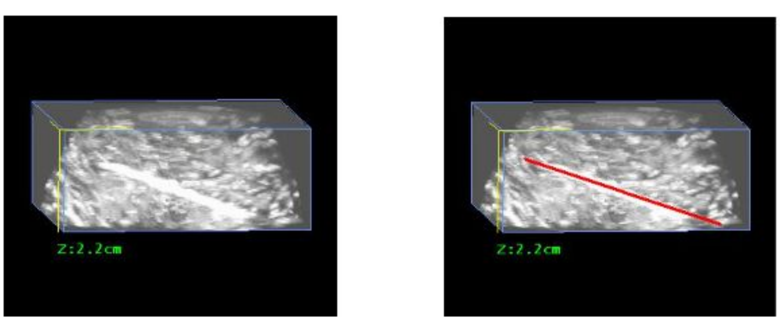

Fig 3. Segmentation of a needle in 3D Ultrasound Image using 3D Improved Hough Transform [6].

4. Goals

Building upon previous work and taking into account the clinical motivation, this project aims to fully implement a CT image segmentation algorithm to localize the ablation needles intraoperatively. With the information extracted from the location of the needle in the image, an approximate ablation zone can be generated and displayed to serve as guidance for the physician.

The algorithm developed will be tested on a medical imaging dataset and evaluated for accuracy and efficiency. If successful, further evaluation can be performed on-site using phantom, with existing clinical instruments and interfaces.

5. Technical Approach

A. Overall Integration Into The Workflow

This section will give a big picture of how the proposed technology fits into the current tumor ablation workflow. After patient assessment for the procedure (medical history, pre-op imaging, general health assessment,...), on the day of the procedure, the patient is first positioned on the procedure/CT table in the operating room and receives anesthetics (locally or intravenously). The physician would then insert the ablation needle with the help of CT imaging. Each time the physician acquires a CT image, for safety precautions against radiation exposure, they have to leave the operating room and then return to continue the procedure. Once the needle is in place, the physician inserts the electrodes that would transmit electrical impulses to ablate the tumor. This process is done until the tumor is completely removed. The incorporation of the needle localization algorithm and ablation zone approximation would be utilized every time a CT image is acquired. This would automatically provide the physician with information such as the current distance and angle between the needle tip with respect to the tumor and other anatomical structures, as well as the approximate coverage of the ablation zone. This not only can support the efficacy of the ablation but may also enable physicians to better evaluate ablations that are close to crucial anatomical structure such as nerves or blood vessels. A diagram of this intervention is shown in **Figure 4**.

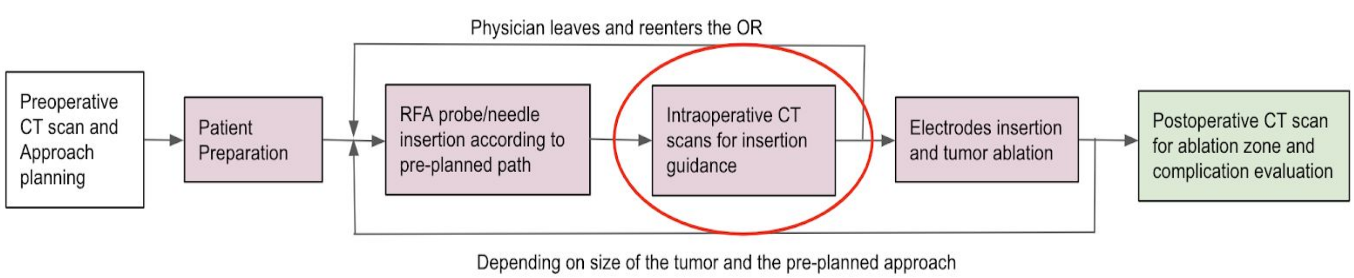

Fig 4. The integration of the project into the RFA procedure workflow

B. **Needle Segmentation and Identify Orientation With MATLAB**

This project will implement medical imaging analysis algorithms to segment the ablation needles and determine their orientation. A block diagram of the technical approach is presented in **Figure 5** .

- First, since the needles are very bright and distinct in the images, the images are simply standardized and thresholded to obtain a binary mask of all the needles in the images. Note this may include unwanted structure and artifacts.
- The masked structures will then go through connected components analysis and filtered based on volume and shape to obtain only the objects that may represent the ablation needles.
- Next, based on previous needle segmentation work in 3D ultrasound images, a Spherical (3D) Hough Transform Algorithm would be developed and applied onto the image to segment for the needle lines of interest.
- Next, evaluation can be done to check for the validity of the segmented needle such as elongated intersection with the skin. Depending on the performance of the algorithm, the number of needles inserted or/and a region of interest (ROI) maybe prompted as user inputs to help narrow down the problem.
- Once the line segments representing the needles are obtained, the location of the needle tip and the orientation of the needle is determined with respect to the CT coordinate system. This needle location can be transformed to the coordinate system of interest such as the tumor coordinate system or the insertion site coordinate system, depending on the clinical need.

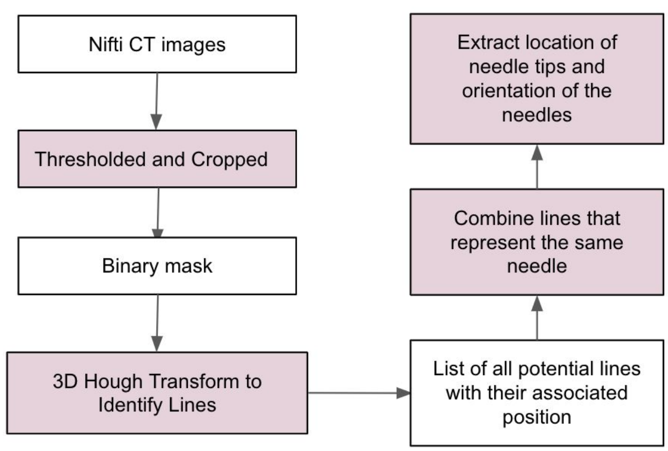

Fig 5. Proposed technical steps to implement the needle extraction algorithm

C. **Ablation Zone Approximation Using Ellipsoidal Approximation Model**

Currently, the volume of the ablation region can be approximated with an ellipsoid using the technical information noted for needle type, pulse type, and amount of energy. Using the location of the needle, colorized isotherms can be superimposed on the image based on the technical information and existing algorithms such as Finite Element Algorithm

(FEA) and Pennes bioheat equation to form a contour map (**Figure 6**) [8, 9]. This can be implemented using MATLAB 3D FEA simulation in the PDE toolbox.

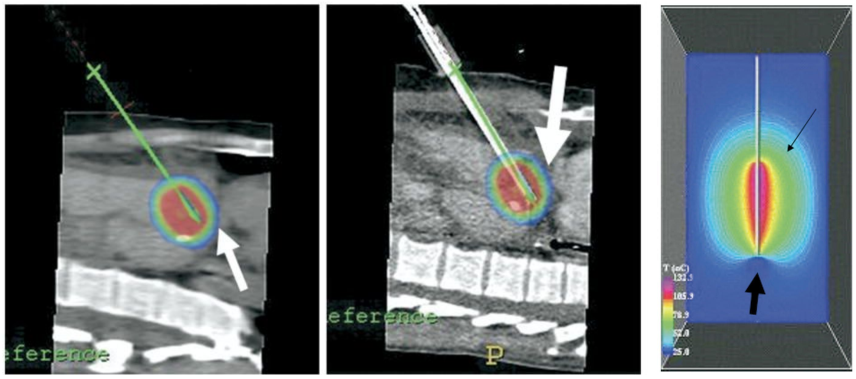

Fig 6. Colorized isotherms superimposed on CT images of ablation needles [8]

6. Testing Plan

A. Needle segmentation algorithm evaluation using medical images

Medical images for testing will be provided by the NIH Center of Interventional Oncology. The acquired images will be manually segmented by marking the endpoints of the ablation needles manually. The corresponding angles and locations will be computed from the two endpoints and will serve as the ground truth reference for testing.

Next, the automatic segmentation algorithm will be applied to the unmodified image and the results (locations and angles) will be compared to the manually annotated image. The resulting deviations will be computed and statistically analyzed to evaluate the performance of the algorithm.

Algorithm modification can be applied to improve its performance when needed.

B. Ablation zone prediction evaluation with phantom or *ex vivo* experiments

RFA experiments will be done on medical imaging phantom or *ex vivo* samples at the NIH facility, and intraoperative and postoperative CT images will be acquired. Intraoperative images will be processed using the current algorithm, which would predict an ablation zone based on the needle's location and orientation. The postoperative CT images will be segmented to find the ground truth ablation zone for reference using verified segmentation algorithms. The two ablation zones generated will be compared and statistically analyzed.

7. Key Activities and Deliverables

The key activities and deliverables for this project are listed in Table 1 and are categorized into the minimum, expected, and maximum activities and corresponding deliverables. Essentially, the minimum deliverable for this project is to implement the MATLAB code to identify the needle location and orientation using the existing Hough transform algorithm. The expected deliverables are to test and evaluate the needle segmentation algorithm accuracy and efficiency and refine the algorithm as needed. The maximum deliverables are to incorporate ablation zone prediction algorithms on top of the current needle detection implementation and to evaluate the accuracy of the prediction with phantom experiments.

Table 1. The key activities and corresponding deliverables

	Activity	Deliverable
Minimum	• MATLAB implementation to process and standardize Nifti CT images • Segment ablation needles from background	• MATLAB program and documentation on how to implement the code
Expected	• Extract needle tip location and needle orientation using 3D Hough Transform • Evaluate algorithm accuracy using manually labeled medical images	• MATLAB code and documentation • Manually labeled CT images • Reports on algorithm performance with graphs and statistical analysis
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

8. Dependencies

There are several dependencies crucial for the continuation of the project and they are listed in **Table 2**. The explanation of these dependencies, the actions taken, their deadlines, and the respective contingency plan are also detailed in the table.

Table 2. Details associated with project 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	N/A
NIH badge and server access	Access to patient medical images Access to NIH clinical center for onsite testing and clinical observation	NIH admin	Paperwork and security training completed Waiting for authorization	Obtain clinical data transfer agreement. Can work with phantom/swine images first to develop algorithm before testing	02/26	03/03
Medical Images	Crucial for algorithm development and testing	Dr. Xu and Dr. Wood	Have access to some phantom images. Will obtain clinical data once have NIH access		02/20	03/05
Image Conversion to Nifti File	Simplify the image preprocessing process	Dr. Xu	Dr. Xu agreed to send converted data	Work with smaller dataset or research on way to convert image (potentially using MIPAV)	03/10	03/15

Manually Labeled Medical Images	Reference for testing, crucial to evaluate algorithm performance	Dr. Xu and Dr. Wood	Requesting	Self label images	03/10	03/15
Phantom and ex vivo samples, experiment space and instrument	Evaluate ablation zone prediction algorithm	Dr. Xu and Dr. Wood	Waiting for NIH badge access authorization	Evaluate using previously acquired phantom images	04/15	04/25

9. Timeline

A. Key Activities and Deliverables

The provisional timeline for the key activities and deliverables of the project is detailed in **Figure 7 Section 1**. The duration are color coded based on the assignment of the tasks to minimum, expected or maximum deliverables.

B. Resolving Dependencies

The timeline for resolving dependencies are outlined in **Figure 7 Section 2** based on the details listed in **Table 2**. All dependencies are expected to be resolved by the end of March.

C. Documentation and Reports

The timeline for required documentation and reports for the course are detailed in **Figure 7 Section 3**. This includes both the written documentation for the implementation of the project as well as the course requirements.

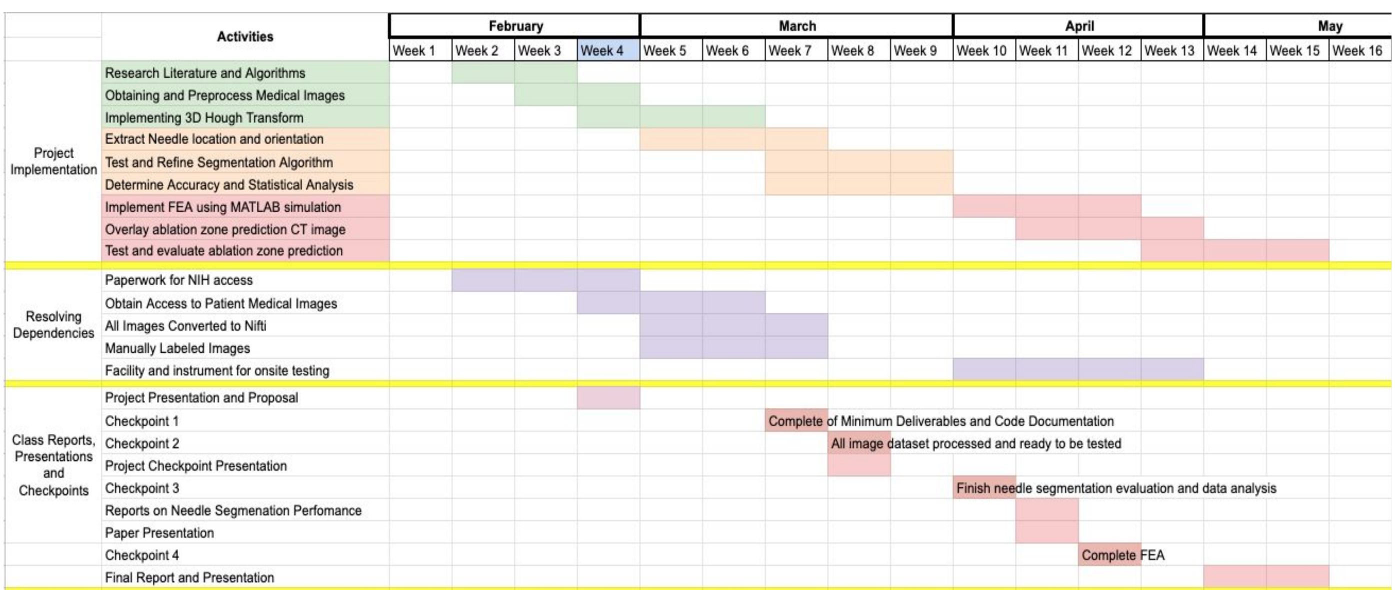

Fig 7. Expected timeline for the project implementation, resolving dependencies and fulfilling class requirements

10. Team Members and Mentors

A. Team member:

Giang Hoang (giang@jhu.edu): Responsible for all tasks

BS, MSE Biomedical Engineering, Johns Hopkins Whiting School of Engineering

B. Mentors:

Dr. Sheng Xu (xus2@cc.nih.gov): Lead Advisor

Dr. Michael Kassin (michael.kassin@nih.gov): Clinical Advisor

Dr. Bradford J. Wood (bwood@cc.nih.gov): Clinical Advisor

NIH Center for Interventional Oncology

Interventional Radiology Section

11. Management Plan

A. 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 (to be scheduled throughout the semester)

B. Communication

- All communication is via email and phone/text
- All imaging data sets and codes will be uploaded through the NIH Box account
- All documentation including proposals, presentations, reports, and other resources will be stored and maintained on the CIS II project Wiki page

12. Reading List

Below are the resources crucial for the project and will be updated accordingly.

- Amalou, H., Wood, B.J. Electromagnetic tracking navigation to guide radiofrequency ablation of a lung tumor. *J Bronchology Interv Pulmonol*. 2012;19(4):323-327. doi:10.1097/LBR.0b013e31827157c9
- Egger, Jan et al. "Interactive Volumetry Of Liver Ablation Zones." *Scientific reports* vol. 5 15373. 20 Oct. 2015, doi:10.1038/srep15373
- Wood B.J., Locklin J.K., Viswanathan A, et al. Technologies for guidance of radiofrequency ablation in the multimodality interventional suite of the future. *J Vasc Interv Radiol*. 2007;18(1 Pt 1):9-24. doi:10.1016/j.jvir.2006.10.013
- 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
- Dong J, Li W, Zeng Q, et al. CT-Guided Percutaneous Step-by-Step Radiofrequency Ablation for the Treatment of Carcinoma in the Caudate Lobe. *Medicine (Baltimore)*. 2015;94(39):e1594. doi:10.1097/MD.0000000000001594
- Xu, S. et al. "Smartphone-Guided Needle Angle Selection During CT-Guided Procedures American Journal of Roentgenology". 2018;210: 207-213. 10.2214/AJR.17.18498
- Zhou, H., Qiu, W., Ding, M., and Zhang, S., "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.
- Rieder, C. et al. "Interactive Approximation of the Ablation Zone incorporating Heatsink Effects for Radiofrequency Ablation." *CURAC*, 2010.
- 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.

References

[1] (ACR), Radiological. "Radiofrequency Ablation (RFA) | Microwave Ablation (MWA) - Liver Tumors". *Radiologyinfo.Org*, 2019, https://www.radiologyinfo.org/en/info.cfm?pg=rfaliver.

[2] "Radiofrequency Ablation For Cancer - Mayo Clinic". *Mayoclinic.Org*, 2018, https://www.mayoclinic.org/tests-procedures/radiofrequency-ablation/about/pac-20385270.

[3] Egger, Jan et al. "Interactive Volumetry Of Liver Ablation Zones." *Scientific reports* vol. 5 15373. 20 Oct. 2015, doi:10.1038/srep15373

[4] Santos, Ricardo S. et al. "Electromagnetic Navigation To Aid Radiofrequency Ablation And Biopsy Of Lung Tumors". *The Annals Of Thoracic Surgery*, vol 89, no. 1, 2010, pp. 265-268. *Elsevier BV*, doi:10.1016/j.athoracsur.2009.06.006. Accessed 25 Feb 2021.

[5] Amalou, H., Wood, B.J. Electromagnetic tracking navigation to guide radiofrequency ablation of a lung tumor. *J Bronchology Interv Pulmonol*. 2012;19(4):323-327. doi:10.1097/LBR.0b013e31827157c9

[6] Zhou, H., Qiu, W., Ding, M., and Zhang, S., "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.

[7] 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

[8] Wood B.J., Locklin J.K., Viswanathan A, et al. Technologies for guidance of radiofrequency ablation in the multimodality interventional suite of the future. *J Vasc Interv Radiol*. 2007;18(1 Pt 1):9-24. doi:10.1016/j.jvir.2006.10.013

[9] 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