# CIS II Project Proposal
# In Situ Needle Path Adjustment and Trajectory Optimization

Member: Yanzhou Wang
Mentors: Prof. Iulian Iordachita, Prof. Russell Taylor

February 28, 2022

## 1 Background and Relevance

Low back pain is an extremely common condition that has a huge economic impact; yet despite its prevalence, the actual source of pain is often times difficult to diagnose, and many different treatment methods have been proven effective to various degrees. Lumbar injection is among the most common tools to diagnose and treat low back pain, and typical targets of injection include the facet joint, sacroiliac joint, and the epidural space. These procedures are commonly performed under X-ray and fluoroscopy guidance, which inevitably exposes both the clinician and the patient to ionization radiation.

Image guided needle insertion with robot assistance is a research area that has amassed huge interest in the past two decades, since robots have higher motion accuracy and repeatability, and are not affected by radiation. However, although many teams have demonstrated great targeting accuracy with flexible needles in a lab environment, few have implemented these methods in actual products; and as far as we know, all commercialized needle insertion robots have a manual operation mode, where the actual insertion step is still performed by the clinician themselves. It is a diverse field that involves a number of different subject areas, such as robot system design, soft tissue and needle modeling, control, and path planning.

During an actual procedure, when the clinician detects an error in needle placement, they can quickly gather their prior experience and utilize the reaction force from the needle to make small, yet effective, adjustment at the needle base. These fine finger and hand motions, coupled with intermediate imaging, help the clinician to guide the needle closer and closer to the actual target. One of the main goals of my current research is to examine this adjustment process in greater detail, and enable future robotic systems to make such adjustments while the needle is still inserted into the tissue, correcting the needle from its deviated path.

## 2 Objectives and Technical Approach

The main objectives of this project are to, **1.** design and fabricate experiment setup to mimic, as well as capture, this needle base motion; **2.** to evaluate a mechanics based model for the interaction between tissue and needle when the needle base undergoes such manipulation; and **3.** to combine the needle base motion with path planning and optimal control algorithms, and simulate *in situ* needle path correction.

To achieve the first goal, a setup will be built to with an active linear stage and a passive rotary stage to allow natural needle rotation when the base is displaced. Steel markers will be added to establish a coordinate relation between the needle and tissue phantom. Segmentation and registration method will also be written to automatically detect the needle base motion based on image registration alone.

To achieve the second goal, samples of tissue-mimicking phantoms will be tested under unconstrained uniaxial compression, and different hyper elastic material models will be fitted to the stress-stretch curve for evaluation. The hyper elastic model with the best fit will be incorporated into a mechanics-based needle-tissue interaction model that can predict the behavior of the needle during the base motion. Inverse finite element method will be used to retroactively estimate the tissue parameter, and the estimated parameters will be compared with the experimental value obtained from compression tests.

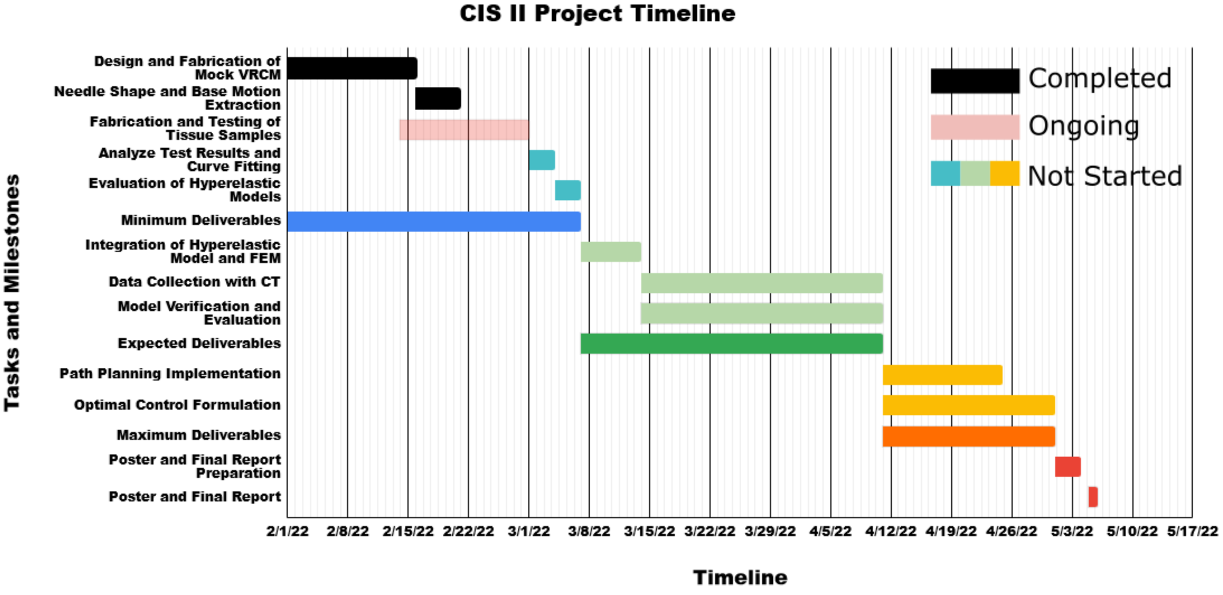


Figure 1: Project timeline and current status.

Finally, a simulation environment will be built in MATLAB, which will visualize the planned needle adjustment behavior provided by a sampling-based planning algorithm. An objective function can also be defined to optimize certain motion parameters, such as the magnitude of the needle base motion so as to reduce tissue displacement.

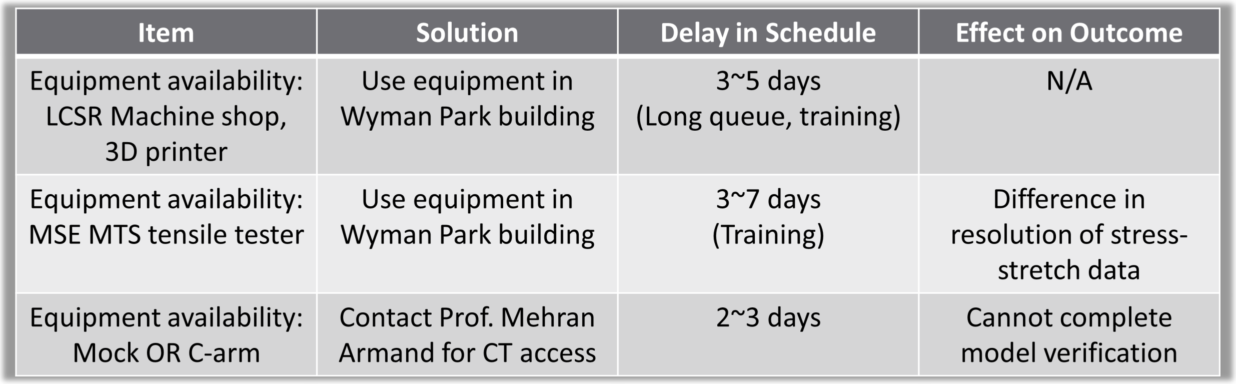
## 3 Deliverables

- Minimum:
    - Hardware setup to mimic freehand needle adjustment motion
    - Algorithm to extract needle shape and base motion from CT
    - Evaluation of hyperelastic models in compression range of tissue phantoms
- Expected:
    - Integration of chosen hyperelastic material model with needle-tissue interaction model
    - Verification/Evaluation of proposed needle-tissue interaction model
- Maximum:
    - Path planning simulation of needle retraction and adjustment
    - Optimal control formulation to minimize tissue displacement
    - Conference paper (ICRA 2023)

## 4 Work Plan and Dependencies

Project work plan is shown in Figure 1 as a Gantt chart.

This project depends a lot on the availability of different equipment, such as 3D printers and the machine shop at LCSR. Luckily there are other ones elsewhere on campus. The C-arm in the Mock OR will be used extensively and it might be difficult to find another one to use; in case the space is occupied, I will just come in early in the morning when there is nobody there.



| Item | Solution | Delay in Schedule | Effect on Outcome |
|---|---|---|---|
| Equipment availability: LCSR Machine shop, 3D printer | Use equipment in Wyman Park building | 3~5 days<br>(Long queue, training) | N/A |
| Equipment availability: MSE MTS tensile tester | Use equipment in Wyman Park building | 3~7 days<br>(Training) | Difference in resolution of stress-stretch data |
| Equipment availability: Mock OR C-arm | Contact Prof. Mehran Armand for CT access | 2~3 days | Cannot complete model verification |

Figure 2: Project dependencies and resolution plan.

## 5 Management

I will have weekly meetings with Prof. Iordachita on Fridays from 11:00 to 12:00, as well as every other Tuesday from 8:00 to 9:00 with Hong Kong MRC members. In addition, progress will be reported during Monday joint lab meetings in the format of a research talk, as well as progress reports according to CIS II schedule.

## 6 Reading List

Priority Medicines for Europe and the World Update, Sec 6.24, p 165, World Health Organization, 9 July 2013.

Reed, Kyle B et al. "Robot-Assisted Needle Steering." IEEE robotics & automation magazine vol. 18,4 (2011): 35-46. doi:10.1109/MRA.2011.942997

Swaney, Philip J et al. "A flexure-based steerable needle: high curvature with reduced tissue damage." IEEE transactions on bio-medical engineering vol. 60,4 (2013): 906-9. doi:10.1109/TBME.2012.2230001

P. Chatelain, A. Krupa and N. Navab, "3D ultrasound-guided robotic steering of a flexible needle via visual servoing," 2015 IEEE International Conference on Robotics and Automation (ICRA), 2015, pp. 2250-2255, doi: 10.1109/ICRA.2015.7139497.

Y. Wang, G. Li, K. -W. Kwok, K. Cleary, R. H. Taylor and I. Iordachita, "Towards Safe In Situ Needle Manipulation for Robot Assisted Lumbar Injection in Interventional MRI," 2021 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), 2021, pp. 1835-1842, doi: 10.1109/IROS51168.2021.9636220.