Augmentation of Haptic Guidance into Virtual-Reality Surgical Simulators
601.446 Computer Integrated Surgery II, Spring 2019

Project Proposal

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Mentors: Dr. Mahya Shahbazi, Dr. Jeremy Brown, Guido Caccianiga

Goal: Investigating the effect of haptic guidance and brain stimulation on motor learning in Virtual Reality surgical simulators.

Clinical Importance: The number of robotic-assisted minimally invasive surgeries (RAMIS) performed annually is rapidly increasing, and new surgeons must be trained to meet this demand. In the current standard of training, novices often spend many hours completing practice tasks which are graded with observational feedback. Getting this feedback requires trained surgeons to spend time going through the videos or watching in real-time, leading to high operational costs and low efficiency. Furthermore, if not corrected early trainees can develop poor habits that will take longer to break after being ingrained over several days of training.

There is a need for new technologies that can lower these mentorship barriers to and speed up training. Current work being done in the space involves building Virtual Reality simulators on daVinci Research Kits (dVRK) for basic tasks such as suturing (see Figure 1). While these tasks are able to provide real-time feedback visually (in the example, the green colored ring indicates a proficient needle entry), they do not provide any corrective guidance for wrong motions. The goal of this project is to incorporate real-time corrective guidance to these virtual simulators with reference to the optimal path for the task. Coupled with the visual feedback, we will be able to work to determine the efficacy of haptic feedback in teaching RAMIS principles.

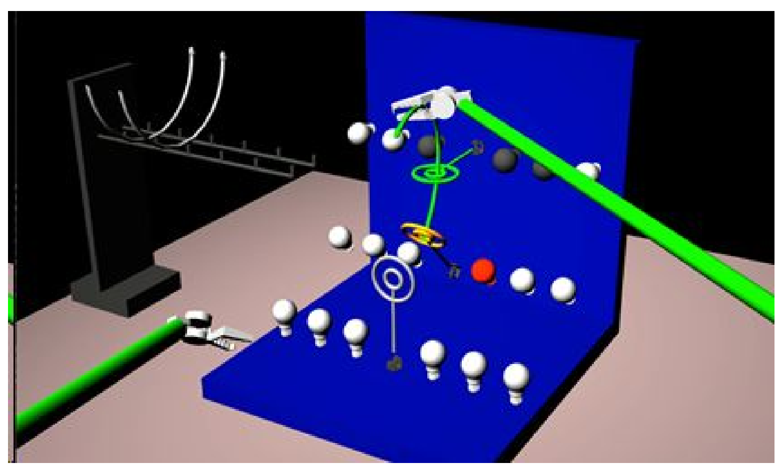


Figure 1: Virtual Reality RAMIS Simulator

Technical Summary: The first phase of this project will include the development and implementation of models for force feedback systems. Previous work has led us to consider two methods, forbidden region (Figure 2) and guidance along the optimal path (Figure 3). Using virtual fixtures, the optimal path will be bounded with an allowable region tunnel that will apply a spring force to the dVRK manipulators should the virtual needle deviate from this region. With guidance, forces will be applied to the dVRK manipulators under certain conditions to encourage users to the optimal path based on the task-space error. Defining the conditions of these forces and tuning the parameters will require significant experimentation and testing.

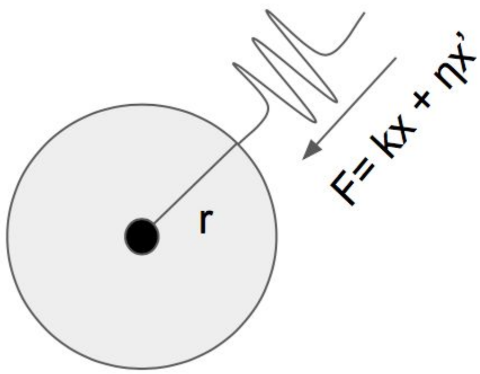


Figure 2: Virtual Fixture visualization

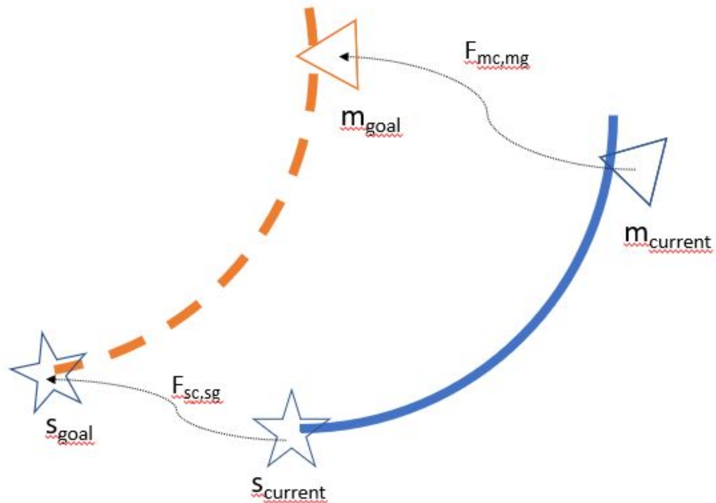


Figure 3: Guidance visualization

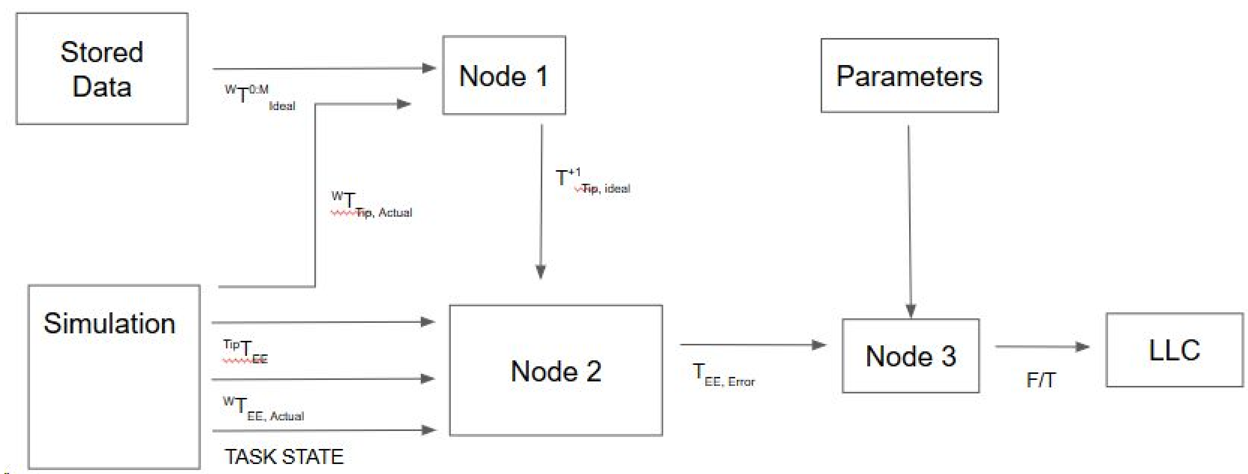


Figure 4: Guidance Data Flow

Node 1: Inputs are list of poses on optimal trajectory and current pose of suturing tip. Outputs a goal pose of suturing tip based on desired velocity.

Node 2: Inputs are transformation from current pose of suturing tip to current pose of end effector, current pose of end effector, task state, and goal pose. Task state is current action of the suture, i.e. insertion, handoff. Calculates the goal pose of the end effector. Outputs the task space error as a transformation between current pose of end effector and goal pose of end effector.

Node 3: Inputs are task space error and parameters about force generation (visco-elastic, non-energy-storing, etc). Outputs forces and torques which are sent to a low level controller.

After these models have been tested and tuned, the second phase of the project can begin (it will have been set up in parallel with the first phase). This phase will involve a pilot user study on fellow LCSR members and other novices on the dVRK. Metrics such as time to completion, accuracy and smoothness will be used to compare the different feedback systems (none, forbidden region, guidance) and their effects on performance and learning. This study can be further extended after to include a study evaluating the effect of brain stimulation on robotic surgery training.

Deliverables:

<u>Minimum (Expected by 4/5):</u>

- C++ code for measuring, computing, and applying force fields to dVRK manipulators while in simulation stored in GitLab
- Documentation of environment including operation, maintenance, and future

<u>Expected (Expected by 4/19):</u>

- Report on user study evaluating the approach(es) taken to implement force field.
    - Goal n = 10
- Data collection protocol and scripts for study extendability stored in GitLab

<u>Maximum (Expected by 5/10):</u>

- Report on user study evaluating the effectiveness of the haptic guidance in the absence and presence of brain stimulation
    - Goal n = 10
- C++ code for integrating brain stimulation into data collection
- Data collection protocol and scripts for study extendability stored in GitLab

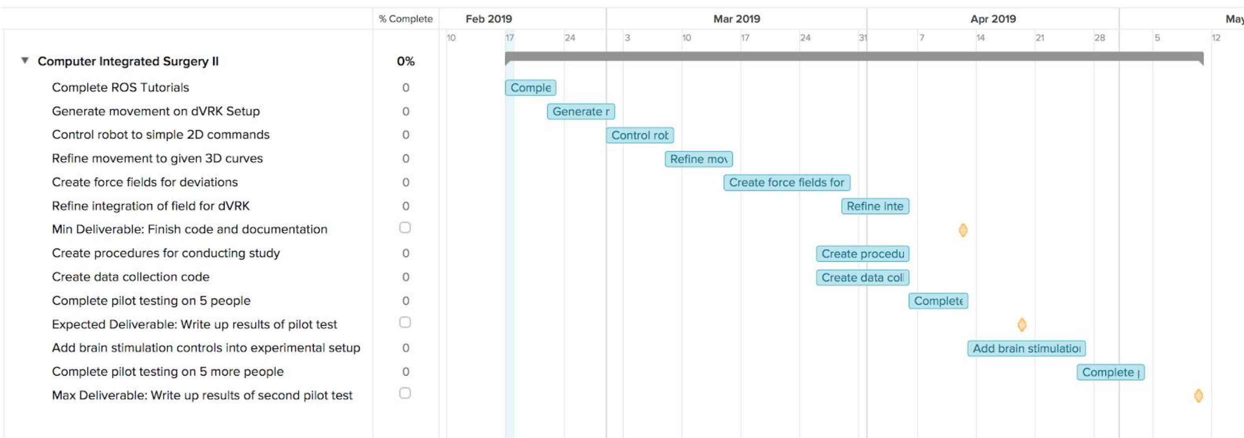
Key Milestones and Tasks:

Minimum Tasks: Implementing repulsive and guidance force fields for the needle-driving task on the dVRK system	**Expected Date**
Complete ROS Tutorials from Clearpath Robotics	2/22
Generate a movement on the existing dVRK setup	3/1
Complete architecture and models for guidance implementation	3/8
Complete code implementation and documentation of guidance model and develop architecture for forbidden region model	3/15
Complete code implementation and documentation of forbidden region model	3/29
Finalize documentation. Create documentation write up.*	4/5

Expected Tasks: Evaluating the approaches in a pilot user study	**Expected Date**
Create procedures for conducting study	4/5
Create data collection code	4/5
Complete pilot testing	4/12
Create write up and edit procedures document*	4/19

Maximum Tasks: Evaluating the effectiveness of haptic guidance in the absence and presence of brain stimulation in a pilot user study	**Expected Date**
Add brain stimulation controls into experimental setup (work with Guido throughout this process)	4/26
Complete pilot testing	5/3
Create write up and edit procedures document*	5/10

***-** Documentation will be produced concurrently and thoroughly with the progress of the project but it will be finalized by the date provided.



Dependencies:

Dependency	Estimated Resolve Date	Needed Resolve Date	Resolution Plan	Fallback Plan
Access to Existing GitLab	2/20	2/22	Contact Guido.	Can begin planning code without access, but will need access before we can test or check integration
Availability of dVRK	2/21	3/1	Create LCSR dVRK schedule	Move project onto a different dVRK or surgical robot.
Availability of accessories	3/1	4/5	Coordinate with HAMR lab for access to brain stimulation measurement tool	Use the brain stimulation tool when other lab members do not need it
IRB update	3/1	3/15	Write an amendment to Dr. Brown's existing IRB and submit for approval as a sub-study	If there is an issue with updating the IRB, we will have to write and submit a new one. We can still evaluate some of our approaches internally until we receive approval - so project progress won't stall completely

Subjects Scheduling	4/5	4/12	Schedule mutually available times with subjects.	If unavailable, we can find more subjects (perhaps in a different population if acceptable to goal of study)

Management Plan:

Meetings:

- Weekly meetings with full mentor team: Fridays 9am-10am
- Weekly meeting with Guido: Tuesday 12pm-1:30pm
- Weekly team check-ins: Thursdays 8pm-11pm and Sundays 3pm-6pm

Storage

- Code Storage: Fork of Existing HAMR GitLab
- Documentation Storage: Google Drive and JHBox

Individual Responsibilities:

All three group members will contribute to all parts of the project, but different team members will take leads on different parts of the project based on interest and strengths to parallelize the effort. Vipul will head creating and implementing the force field models, Brett will be responsible for integration with the VR environment and creating user study procedures, and Eric will lead setting up the brain stimulation aspect of the project.

Reading List:

- Bowyer, S. A., Davies, B. L. & Baena, F. R. Y. **Active Constraints/Virtual Fixtures: A Survey**. *IEEE Transactions on Robotics* **30,** 138–157 (2014).
- Coad, M. M. *et al.* **Training in divergent and convergent force fields during 6-DOF teleoperation with a robot-assisted surgical system**. *2017 IEEE World Haptics Conference (WHC)* (2017). doi:10.1109/whc.2017.7989900
- Enayati, Nima, et al. "**Robotic Assistance-as-Needed for Enhanced Visuomotor Learning in Surgical Robotics Training: An Experimental Study**." 2018 IEEE International Conference on Robotics and Automation (ICRA), May 2018, doi:10.1109/icra.2018.8463168.
- N. Enayati, E. C. Alves Costa, G. Ferrigno, and E. De Momi, *"***A Dynamic Non-Energy-Storing Guidance Constraint with Motion Redirection for Robot-Assisted Surgery***" in IEEE/RSJ International Conference on Intelligent Robots and Systems, IROS, 2016*

- Jantscher, W. H. *et al.* **Toward improved surgical training: Delivering smoothness feedback using haptic cues**. *2018 IEEE Haptics Symposium (HAPTICS)* (2018). doi:10.1109/haptics.2018.8357183
- Kuiper, Roel J., et al. "**Evaluation of Haptic and Visual Cues for Repulsive or Attractive Guidance in Nonholonomic Steering Tasks**." IEEE Transactions on Human-Machine Systems, vol. 46, no. 5, Oct. 2016, pp. 672–683., doi:10.1109/thms.2016.2561625.
- Pavlidis, I. *et al.* **Absence of Stressful Conditions Accelerates Dexterous Skill Acquisition in Surgery**. *Scientific Reports* **9,** (2019).
- Ström, P. *et al.* **Early exposure to haptic feedback enhances performance in surgical simulator training: a prospective randomized crossover study in surgical residents**. *Surgical Endoscopy* **20,** 1383–1388 (2006).