Augmentation of Haptic Guidance into Virtual-Reality Surgical Simulators

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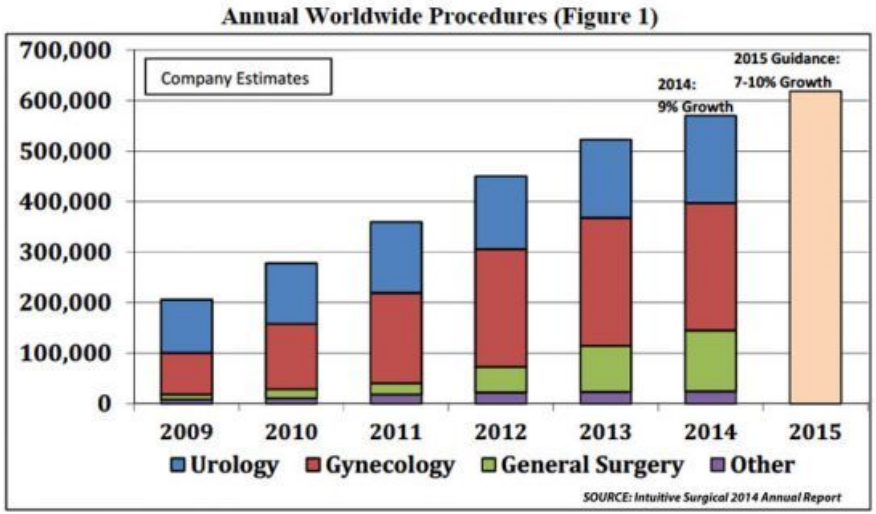
Clinical Relevance

The number of robotic minimally invasive surgeries performed annually is increasing rapidly

Surgeons must achieve proficiency with robotic surgical systems before performing these surgeries

Training takes time and is lacking in real-time feedback



Status Quo and Shortcomings

Trainees complete a practice task and are given observational feedback on metrics like force applied, smoothness, etc.

There is no real-time feedback, so trainees can develop bad practices during training

Expensive Equipment

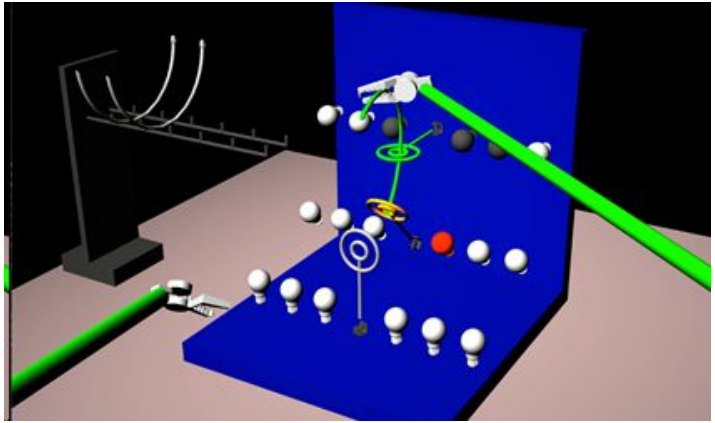
“Observational” Feedback

No Corrective Guidance

Prior Work

Experimental setup and virtual task implemented on dVRK

Provides 2 degrees of visual feedback on deviations from optimal path



Relatively Cheaper Equipment

Limited Real Time Feedback

No Corrective Guidance

Project Goal

Create haptic force feedback using guidance and repulsive force fields

Integrate force fields into existing dVRK experimental setup

Evaluate approach in pilot user studies

Evaluate effect of brain stimulation on training in pilot user studies

Relatively Cheaper Equipment

Full Real Time Feedback

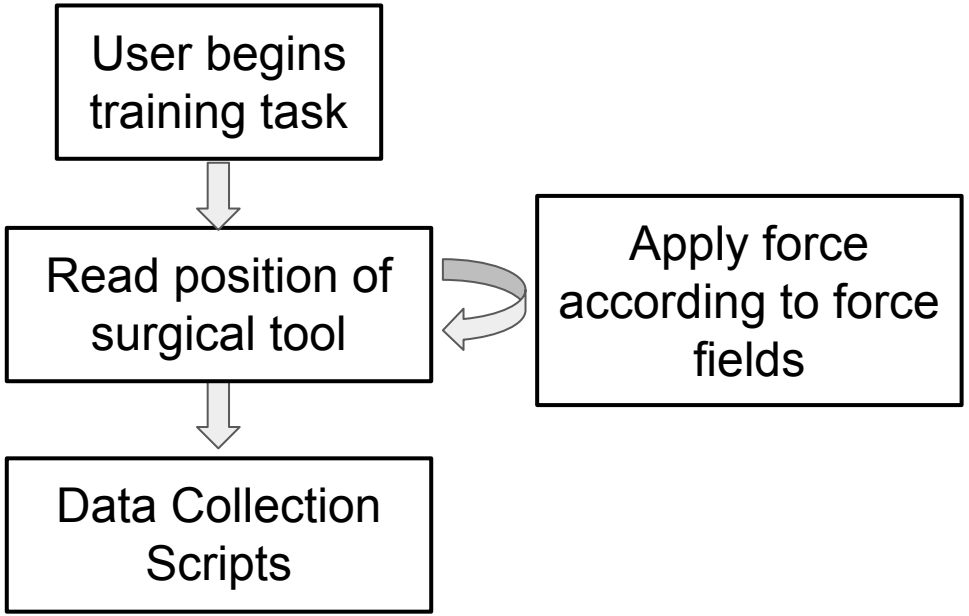
Corrective Guidance

Technical Summary Overview

Pre Study

Define force parameters based on task space error

During Study



Post Study

Change force parameters based on user feedback and metrics

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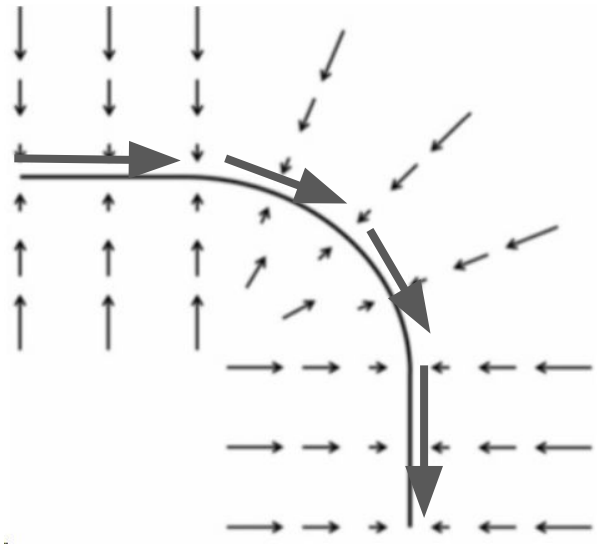
Technical Summary - Force Field Terminology

Repulsive: spring damper pointing towards optimal path

Guidance: forces pointing along optimal path



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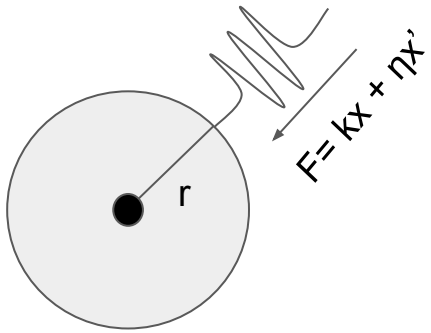
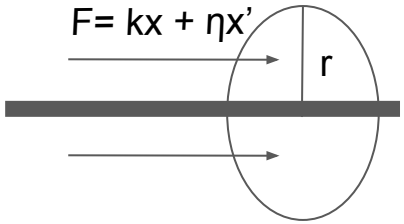
Technical Summary - Force Field Parameters

- $k_{repulsive,\ guidance}$: spring constant
- $\eta_{repulsive,\ guidance}$: damper constant
- $r_{repulsive,\ guidance}$: radius of allowable region
- Scaling on x (linear, quadratic, etc)
- Repulsive, Guidance mixing strategy





Technical Summary - Force Study Outline

What? Evaluate different approaches and parameters for force fields

Why? To determine which approach/set of parameters results in most accurate guidance to optimal path and is least disruptive to the operator

How? Collect user feedback survey data and performance metrics

Who? Internal lab members

Technical Summary - Stimulation Study Outline

What? Evaluate effect of brain stimulation on robotics surgery training

Why? Brain stimulation could have a significant positive effect on training

How? Use existing brain stimulation setup while collecting user feedback survey data and performance metrics

Who? Novice undergrad / grad students

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	3/1	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	4/12	Dr. Brown has previously approved IRB. Add us and dVRK to it	If there is an issue with updating the IRB, we will have to write and submit a new one
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)

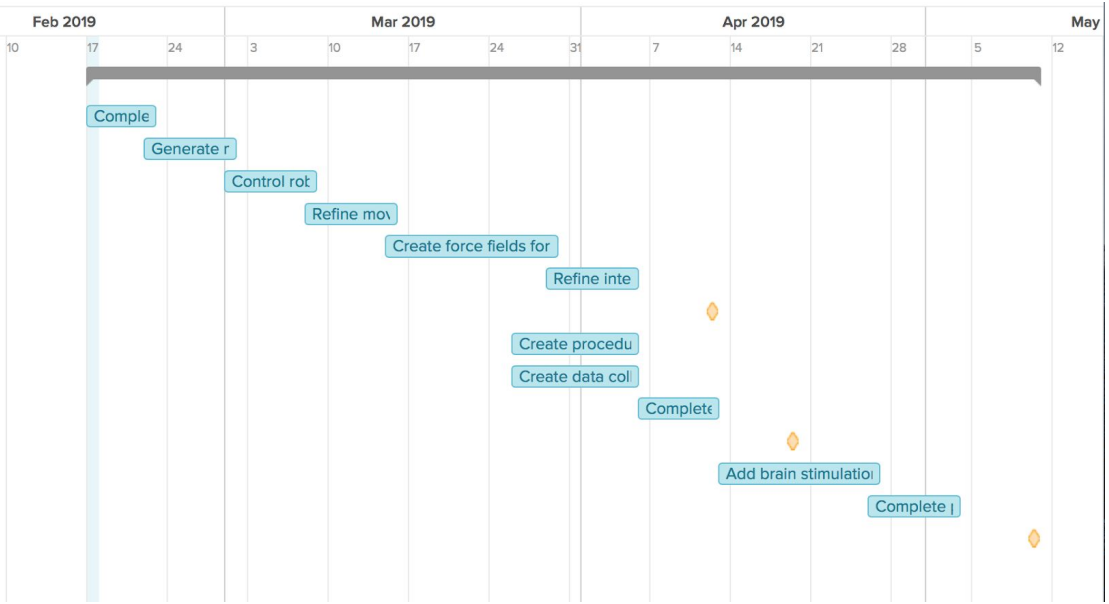
Deliverables

Minimum: (4/12)	• 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
Expected: (4/19)	• 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
Maximum: (5/10)	• 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

More details next slide

Timeline - Overview

	% Complete
Computer Integrated Surgery II	**0%**
Complete ROS Tutorials	0
Generate movement on dVRK Setup	0
Control robot to simple 2D commands	0
Refine movement to given 3D curves	0
Create force fields for deviations	0
Refine integration of field for dVRK	0
Min Deliverable: Finish code and documentation	☐
Create procedures for conducting study	0
Create data collection code	0
Complete pilot testing on 5 people	0
Expected Deliverable: Write up results of pilot test	☐
Add brain stimulation controls into experimental setup	0
Complete pilot testing on 5 more people	0
Max Deliverable: Write up results of second pilot test	☐



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Timeline Details - Development

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
Control movement to follow simple translation and rotation commands with controllable forces and torques	3/8
Refine movement to follow given 3D curve with human interference	3/15
Create repulsive force fields when deviated from given curve	3/29
Refine integration of curve following into dVRK	4/5
Edit / create documentation. Create documentation write up.	4/12

Timeline - Evaluation

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

Management Plan - Overview

Weekly Meeting with full mentor team - Fridays 9am-10am
Weekly Check-Ins with mentor Guido - Tuesdays 12pm
Biweekly Team Check-Ins - Sundays 3pm-6pm, Thursdays 8pm-11pm

Communication: Instant Messaging (Slack), JHU Email
Code Storage: Fork of Existing GitLab
Documentation Storage: Google Drive, JHBox

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Management Plan - Work Breakdown

We will all work on all parts of project. Members will take leads on different sections.

Vipul: Create and implement force field models.

Brett: Integration with VR environment. Creating user study procedures.

Eric: Set up brain stimulation with mentor Guido.

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
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- 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).