Robot Control With Simulation In the Loop

Computer Integrated Surgery II
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Introduction

- To create a virtual environment in a simulation environment, and to synchronize the movements between the surgical robots in the virtual and actual states during a mastoidectomy.
- To provide feedback (constraints) to the robot based on the context situation simulated in the simulator to prevent the robot from invading patient critical anatomy.
- Providing various visual and haptic feedback to the surgeon is important due to the challenging nature of a mastoidectomy. In a wider context, the communication established between the physical robot and a simulated environment serves as a platform for future development of other conceivable virtual and physical feedback modalities to improve surgical performance in any surgery covered by a cooperative robotic system.

The Problem

- Surgeries (like Mastoidectomy) operates near a patient's critical tissue.
- Surgical robot does not know the context of the surgery hence cannot provide safety constraints during the surgery.

The Solution

High Level Controller

1. Update AMBF simulator visuals based on sent joint state from robot.
2. Calculate distance d from tool tip to nearest constraint surface. Other distance functions may be used here as well.

Payload: Distance Vector d →

AMBF Plugin: ROS interface, Model State Update

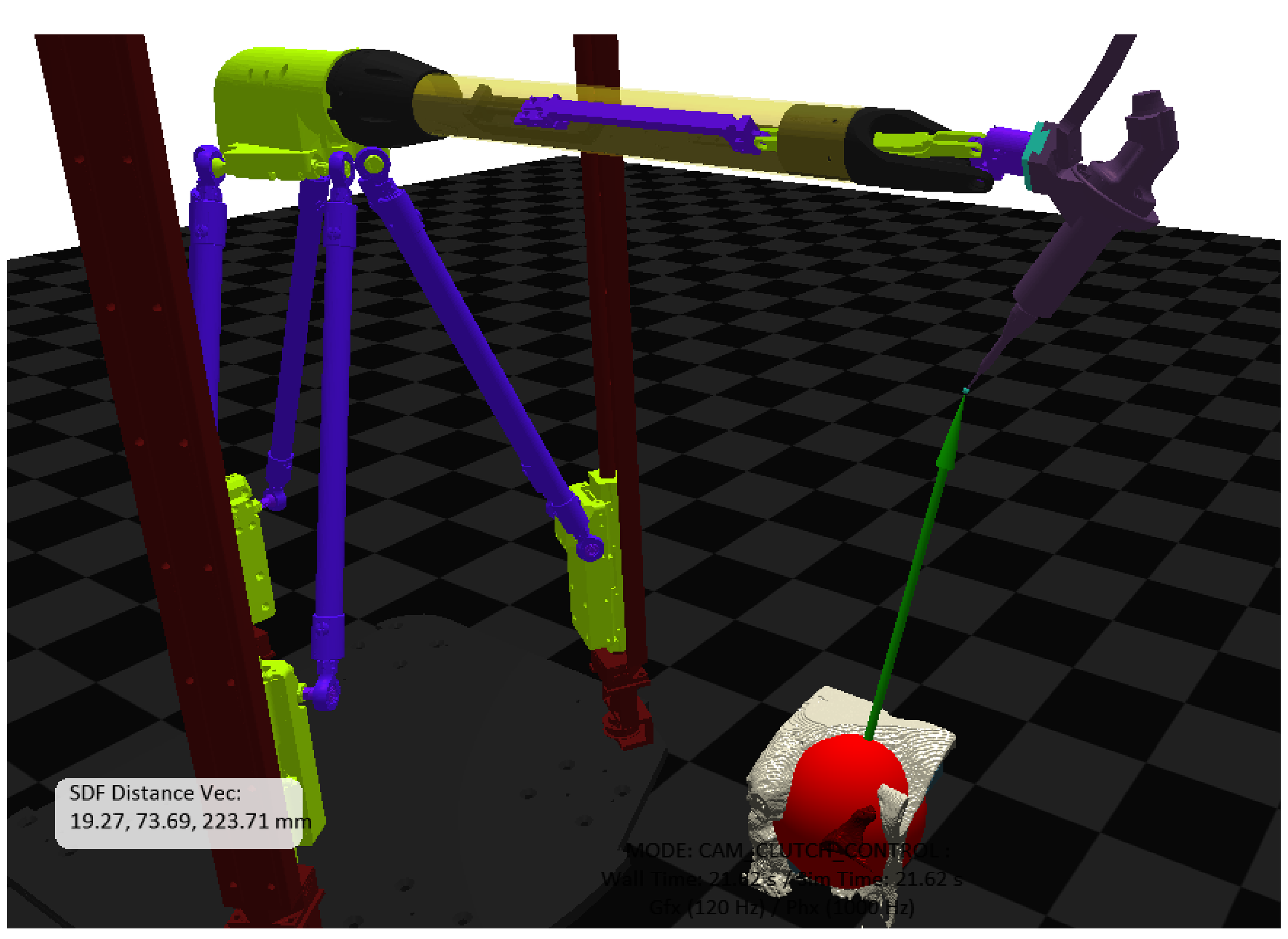
← Payload: Robot Joint State

Force Resolution

1. Resolve distance as a **spring-damper** force from the sphere surface
2. Transform force to End Effector frame
3. Resolve pseudoforce to force applied by surgeon on handle.
4. Send force through Galen force control sequence to move robot.

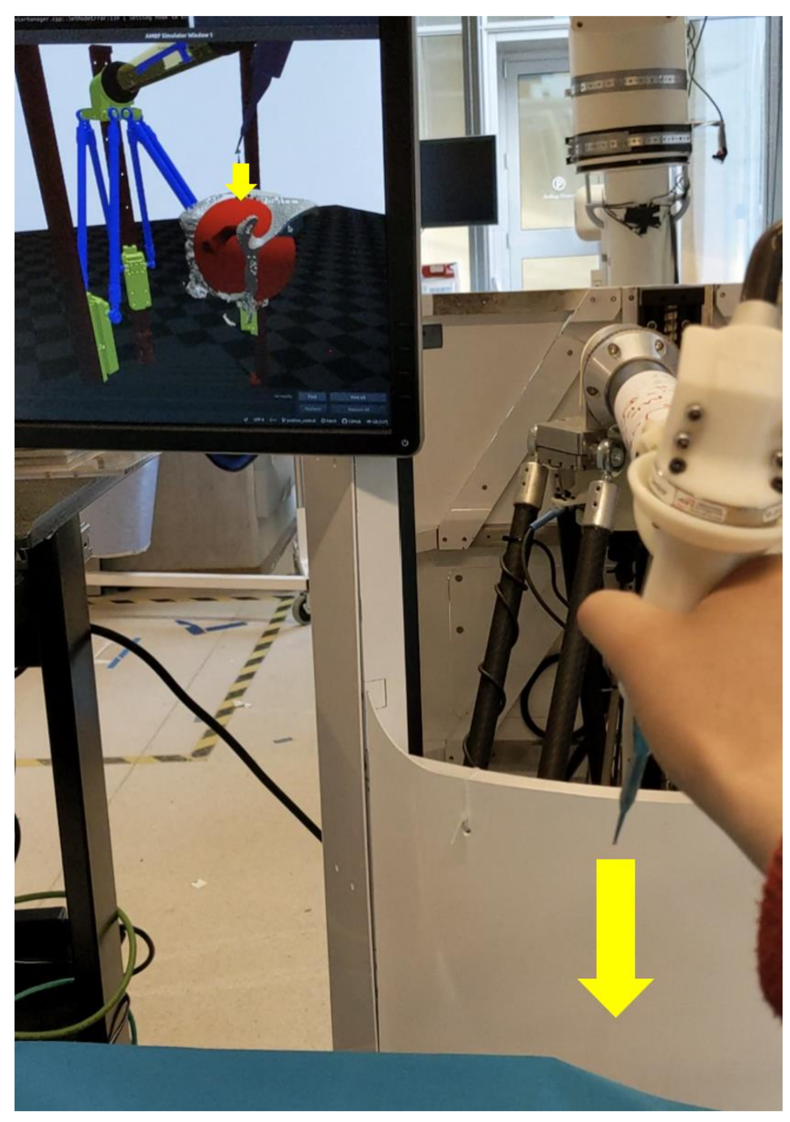
Spring-Damper Model

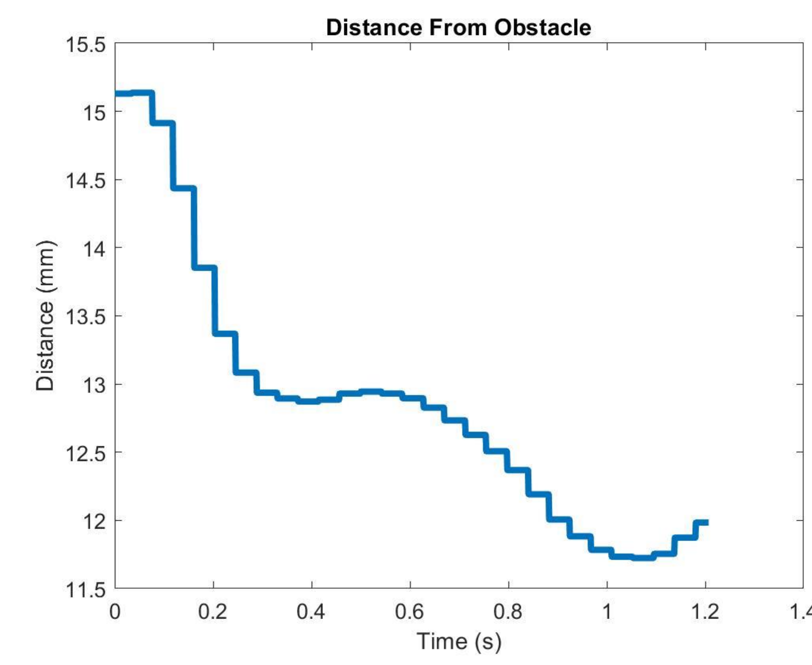
$$f_{sim} = (\beta - \|d\|) * k_p * norm(d) + k_d * \dot{d}$$

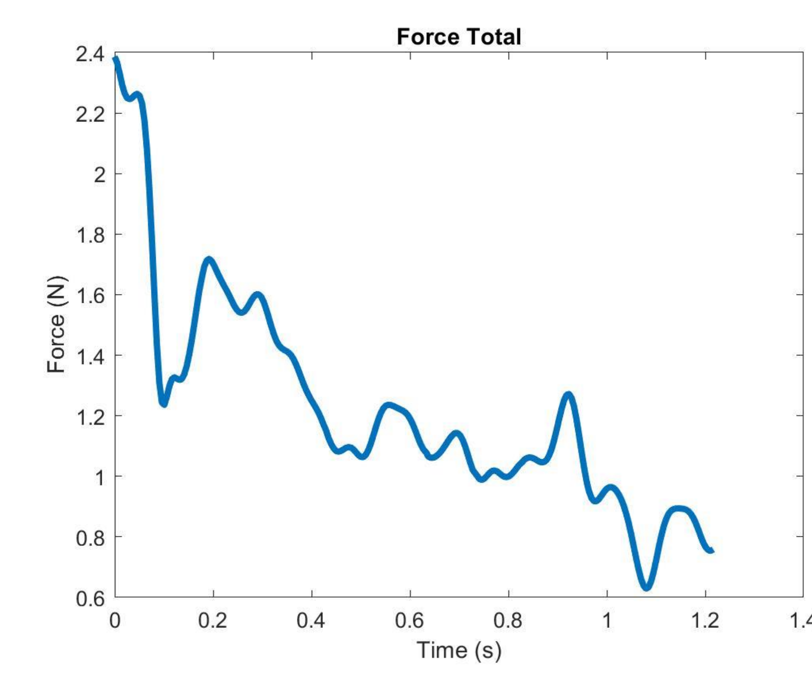


Outcomes and Results

We recorded the data (distance, forces) from a motion where the user moves the drill towards a constraint. The plots below show the magnitude of the distance to constraint, and the total force magnitude, where the total force is determined by subtracting the simulator constraint force from the surgeon handle force. The key trend of note here is that as the distance magnitude to the constraint drops below the 15 mm threshold, the total force magnitude can be observed to approach 0 N. This makes sense because we reach an equilibrium where the force applied by the surgeon is directly cancelled by the force from the simulator.







Future Work

We will combine our work with the SDF and registration pipelines and run user studies on a Phacon skull-base model to validate the system. This will also require us to replace the current CT-scanned model in the simulation with a model of the Phacon.

Lessons Learned

We have learned handle delays. A functional Galen system was pivotal to the full success of our project. However, the system was out of commission for much of the semester, so we had to work around these delays, and adjust our deliverables accordingly.

Credits

- Tommy Liang: Galen Force Control Pipeline
- Jintan Zhang: ROS interface, Simulation Control
- Hongyi Fan: Surgical Environment setup in Simulation

Publications

[1] A. Munawar and G. S. Fischer, "An Asynchronous Multi-Body Simulation Framework for Real-Time Dynamics, Haptics and Learning with Application to Surgical Robots,"
[2] A. Munawar, Z. Li, P. Kunjam, N. Nagururu, A. S. Ding, P. Kazanzides, T. Looi, F. X. Creighton, R. H. Taylor, and M. Unberath, "Virtual reality for synergistic surgical training and data generation,"

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