Individual Lab Report - 8

Autonomous Reaming for Total Hip Replacement

HIPSTER | ARTHuR

Kaushik Balasundar

Team C:

Kaushik Balasundar | Parker Hill | Anthony Kyu
Sundaram Seivur | Gunjan Sethi

October 13th 2022

Carnegie Mellon University
The Robotics Institute

Contents

1 Individual Progress

1.1 Framework for task prioritization

With a single task of aligning the robot arm's tool frame with the pelvis frame accomplished, Anthony and I moved to build modular classes for task prioritization. Previously, while we had implemented singularity damping, we had not implemented singularity avoidance. Firstly, we created a UML diagram depicting the required classes their relationships. We used this as a backbone for further development. We then restructured our code to incorporate singularity avoidance into the framework and allow scaling to multiple tasks. We used an ordered map data structure with the key being the task priority, and the value being the pointer to the task at that priority level. This allows easy swapping of task priorities when needed. As a risk mitigation strategy, we first tested the framework we developed in simulation. The new restructured framework was able to avoid singular configurations while being able to achieve similar performance.

1.2 Assisting with the electrical sub-system

Since I did not have any PR deliverables this week, I assisted Parker to get the electrical subsystem integrated with the newly 3D printed end-effector. It involved soldering new wiring to the new Cytron motor drivers and incorporating the additional motor, limit switches, and programming them accordingly to validate the functionality of the overall end-effector. We then integrated this setup with ROS and were able to send commands using topics. In the near future, we will integrate the load cell and implement admittance control.

1.3 Frequency analysis of collected surgical data

A few weeks back, the team had the opportunity to observe a real surgery at our sponsors' surgical lab. In the process, we collected data during the actual reaming of the acetabulum as a reference for the motion of the pelvis. I post-processed the raw data and used a fast Fourier transform to extract frequency domain information. We collected similar data with the pelvis immersed in the Ballistics gel and on the vice. Figure 1 below shows the plots of the frequency spectrum for displacement and rotation of the pelvis during reaming in the actual surgery, when encased in ballistics gel, and finally when mounted on a vice.

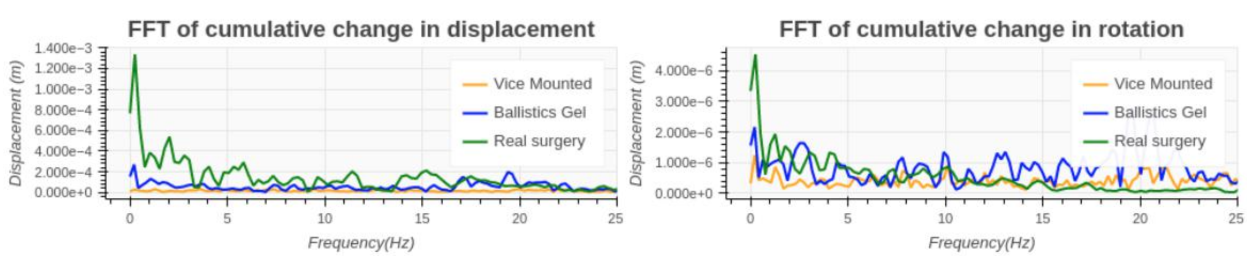

Figure 1: Linear frequency spectrum of displacements and rotation during actual surgery

1.4 Ballistics Gel Experiment

I assisted Sundaram in creating a ballistics gel encasing for the pelvis. This is intended to simulate the dynamic motion of the pelvis during surgery when cushioned by soft tissue. The process involved mixing food-grade ballistics gel in water, and mixing it until a syrup-like consistency was obtained. We then removed any lumps in the mixture by running the mixture through a sieve. Once completed, we set the solution in the fridge for a few hours, reheated it in a water bath, and allowed it to set for an additional 24 hours. Since the solution can be re-set multiple times, a previously reamed pelvis can be replaced with ease. The image below shows the set pelvis within the ballistics gel. We evaluated the efficacy of this setup in simulating soft-tissue properties by carrying out a reaming operation and comparing the frequency spectrum of displacement and rotation obtained with the data gathered from a real surgery.

Figure 2: Ballistics gel solution before removal of lumps and setting

Figure 3: Ballistics gel after setting for 24 hours

2 Challenges

2.1 Switching between simulation and real-world during controls testing

For the last couple of weeks, Anthony and I were testing the controller framework in the real system. This required some changes to be made to the URDF as well as changes to the communication interface. Switching back to testing in simulation required some reverting of those changes. Moving forward, we will ensure that we have a simulation and real-world branch in our GitHub repository to save time and effort.

2.2 Ballistics gel storage, maintenance and evaluation

As we worked with the Ballistics gel, we realized that it is the best set when fully refrigerated. Since this is a food-grade biodegradable product, it is susceptible to bacterial growth. We realized that we need to use a preservative in addition to proper cooling temperature, such as peppermint oil. We also realized that the evaluation of the Ballistics gel as a proxy for soft tissue was dependent on other variables. The evaluation is susceptible to the amount of input force applied during reaming, and since we did not measure this during the surgery, it is likely to introduce variability in our results. Moreover, the discrepancy in dynamic reaction between foam bone and real bone is another reason for the the differences in the frequency spectra obtained.

3 Team Work

Team Member	Contribution
Kaushik Balasundar	I worked with Anthony in setting up the task-prioritization framework and tested it in simulation. I assisted Parker with wiring the electronics and programming the reamer end-effector. I also assisted Sundaram in setting up the ballistics gel encasing for the pelvis. Finally, I post-processed raw surgery data and conducted frequency analysis of the vibrations during reaming to validate the use of Ballistics gel as a proxy for soft tissue.
Gunjan Sethi	Gunjan continued development on the UI module. She set up the basic wireframe of the UI on Open3D. She then completed the Image Alignment tool development that is able to display multiple point clouds and transform the implant pointcloud using UI-based controls. Further, she collaborated with Parker and Sundaram to facilitate the integration of the watchdog module with the UI. Finally, she worked with Kaushik to calibrate the new end-effector marker and test its detection and tracking.
Parker Hill	Parker continued working on the end-effector, integrating a new motor plate for indirect force sensing, limit switches, and a marker holder into the design. He 3D-printed these new parts and assembled the end-effector to a functional state. Working with Kaushik, he then set up the electrical system and integrated it with the end-effector, allowing for the end-effector to be controlled by ROS. Finally, he collaborated with Gunjan and Sundaram to determine how to receive information from the watchdog so that it can be displayed in the user interface.
Anthony Kyu	Anthony worked with Kaushik to set up the task-prioritization framework, creating several new classes based on the software architecture, further setting up the simulation environment, and finally testing the framework in simulation. Anthony also worked with Parker to design the end-effector marker mount, providing feedback on the design, and helping 3D print some parts. Anthony also helped Sundaram to debug some of the Watchdog Module code, providing suggestions for code structure and CMake. And lastly, Anthony helped collect data for reaming on the pelvis encased in ballistics gel.
Sundaram Seivur	Sundaram worked on developing the watchdog module by setting up a C++ node and successfully compiling the CMake file with the necessary dependencies. For this, he worked with the owners of all the subsystems to finalize the functionality of the watchdog and the features that need to be developed. He made a decision tree that helped with the development of the subsystem and rigorously tested the inputs and perception subsystem working. He also worked on creating the ballistics gel mold for testing the pelvis model. He worked with Kaushik and Anthony to collect data by reaming the pelvis model submerged in the gel and analyzing the results generated. He discussed with Parker the integration of the Watchdog module with the User Interface and assisted him with evaluating the performance of the 3D-printed end-effector.

4 Plans

In the next couple of weeks, I plan to work on the following:

1. Collaborate with Anthony to transfer both pelvis and camera alignment tasks from simulation to testing them on the real arm.
2. Work with Parker in setting up an end-effector online calibration routine with the newly 3D printed marker geometry.
3. Collaborate with Parker to write the end-effector admittance controller.