Individual Lab Report - Progress Review 7

Autonomous Reaming for Total Hip Replacement

HIPSTER | ARTHuR

Parker Hill

Team C:

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

September 8th, 2022

Carnegie Mellon University
The Robotics Institute

Contents

1 Individual Progress

1.1 System re-familiarization and analysis

The first thing that myself and the team did this semester was re-familiarize ourselves with the project and think through some of the improvements that we brainstormed this summer at our internships. Once Anthony obtained the arm and the camera and the system was set-up and functional, we thought through certain improvements as a team. The change to using a faster dynamic compensation method, the use of a task-prioritization controller, the development of a better end-effector, the re-hauling of the electrical system, and the implementation of a watchdog and user interface were all topics we discussed and divided up.

We also began thinking through our requirements, risks, and system architectures as a team. Changes to our requirements were necessary as we worked to streamline how we're planning the motion of our robot arm and how dynamic compensation functions. Furthermore, we hope to move away from using hand-eye calibration to correlate the frame of the camera to the base link of the Kinova arm, and instead fix a fiducial marker to the end of the arm such that the camera and arm can be calibrated to one another while the system is running. This would help with a large problem we had in the system, which was if the camera was hit or the table moved during a procedure, the calibration would be thrown off, leading to a need to re-calibrate the arm to the camera.

We also decided to overhaul how we are going about managing our work on the project and are using a to-do list with sticky notes to do so. This can be seen in Figure 1. This should be an improvement over Jira for organizing our work as we often struggled with using Jira and it became more of a burden than a help.

Figure 1: Team To-Do List

Figure 2: Linear Actuator from Amazon

1.2 End-effector redesign

The task that I focused on at the beginning of this semester was thinking through and getting some initial CAD together for a new linearly actuated reamer assembly. Anthony and I are planning on using this project for our Medical Robotics class project and Sundaram is helping with analyzing the design and providing feedback. The justification behind a new end-effector design is that our previous design was too long and relied on the axial force which would be applied to the acetabulum be generated by the robot arm. This led to shaking during the procedure and the arm had to often move through awkward positions to ream the acetabulum. We believe that a linearly actuated design would improve the performance of our system as the arm itself will not be applying force to the acetabulum, but rather our linear actuating end-effector. Furthermore, having the reamer in line with the final joint of the arm was reducing our maneuverability, and as such we wanted our new design to have the reamer at an angle or perpendicular to the last link of the Kinova arm.

To begin, Anthony, Sundaram and I kicked around some ideas for how we wanted to redesign the end-effector. We all landed on the use of a lead or ballscrew for actuating a platform which would hold a motor attached to the reamer shaft. This would allow for the platform to rise up and down as the reamer was spinning, providing the linear actuation into the acetabulum that we desired. There were some kinks to figure out about this design, as we would need to constrain the platform attached to the leadscrew such that it moves linearly rather than around the screw itself. Anthony found a great linear actuator off of amazon which can be seen in figure 2. This actuator has a stroke length of 100mm and uses a Nema 23 stepper motor to actuate a ballscrew. The only issue with this design is the Nema 23 stepper motor. We hope to utilize admittance control to control the force applied to the acetabulum, and as such the motor actuating the ball screw would need to be able to be controlled via a PID controller. As such we would need to replace the stepper motor with a DC motor. We are already looking at some motors from ServoCity for this, but are still undecided on which motor to get.

With this actuator as a base, I got started with creating a CAD model of the end-effector. Some interesting notes on the design which can be seen in figure 3 are summarized here:

- A custom part is attached to the linear actuator's platform to couple with a DC motor.
- Attached to the DC motor is a longer version of the reamer shaft/coupler
- The reamer shaft is supported via a rotary bearing which would need to be oversized and not press fit onto the shaft or else we could potentially over-constrain our system
- The weight of the original linear actuator was a bit high and lacked connections, so we would replace some parts with our own to negate this issue
- An angled component would be added to the back of the linear actuator to connect with the end of the robot arm. The angle for this attachment could be changed as necessary if we desire different angles

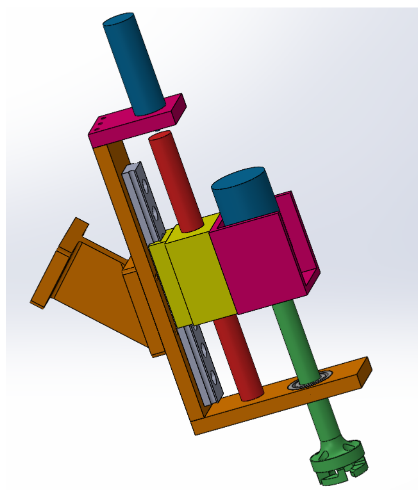

Figure 3: Linearly Actuated Reamer Assembly v1

This model is a very rough approximate of what I imagine our final reamer assembly will look like. We hope to manufacture most structural components out of aluminum and then user injection molded or 3D printed plastic parts to cover up the assembly and make it look more professional. Our goal is to first finish a 3D printed prototype by the end of September and begin converting the design to be manufactured from aluminum to be finalized by mid October.

2 Challenges

2.1 System re-familiarization and analysis

There were no real challenges with this aspect of the project. It was great to be with the team again and we all came up to speed quickly.

2.2 End-effector redesign

There were some minor design related problems with redesigning the end-effector that slowed down our progress. Finding a relatively cheap linear actuator and leadscrew system took a while and we had some internal disagreements over whether we needed a rotary bearing or a linear bearing to support the reamer shaft. We realized that it would be best to move forward with a rotary bearing that is undersized and lubricated, as that would support the shaft as it moves linearly through it and support it in rotation should there be a cantilever applied to the reamer head via contact with the pelvis. One challenge we still need to address is how we are measuring the force applied to the pelvis. One method is to measure the current drawn by the ballscrew motor and correlate that to the force applied by converting the current into torque and the torque into axial force. However this is an indirect measurement and it would be better to directly measure the force via a force sensor in-line with the reamer shaft. We still need to spec an appropriately sized sensor and determine how it would be fixed to the shaft however.

3 Team Work

- Anthony: Worked with the team to re-familiarize and rebuild the workspace. He also contributed to updating the requirements, risks, and roadmap for the system. In addition, we has been working with Sundaram and Parker to brainstorm ideas for the end-effector and source components to use in the design. And lastly, he has been compiling algorithms into one document for a new controller architecture for a Kinematic Task Prioritization Controller for the team to read through and understand for implementation.

- Gunjan: Worked on assisting in bringing up the system for re-familiarization and conducting the project management review. Gunjan and Sundaram also brainstormed the watchdog module.

- Kaushik: Helped restore the system to the same working condition as demonstrated during the SVD encore. He then brainstormed ideas for the online camera to robot arm extrinsic calibration. He was involved in the team discussions regarding overall system enhancements, potential upgrades to the controls sub-system, reevaluating requirements, and the roadmap for the fall semester. He updated and started tracking the project's ongoing risks and updated the cyber-physical architecture.

- Sundaram: Worked on reassembling the workspace and revisiting previous implementation with the team. He also assisted Parker and Anthony in brainstorming ideas for the new end-effector design. He contributed in setting up the new project management methodology and re-evaluating the system requirements, risks and project roadmap. He spent time with Gunjan to ideate the Watchdog module's functionalities.

4 Plans

4.1 End-effector redesign

The next major step for the end-effector redesign is to iterate upon this first version and make improvements to the overall structure. Integrating a force sensor into the reamer handle is critical and once that is done and the dimensions are cleaned up we can move forward with 3D printing some prototype parts and ordering the necessary motors, shaft couplings, and bearings for the design. Ideally by next PR an initial 3D printed prototype is either completed or close to being completed.

4.2 User interface

I intend to aid with the software aspects of our project a lot more this semester as I was relatively uninvolved in it in the past. I hope to work with Gunjan to create a wireframe of what we want our user interface to look like and begin working with the Qt to bring it to fruition.

4.3 Better familiarization with ROS

I need to spend some time looking through all the code that has been written so far and get better familiarity with how everything has been structured. Hopefully Kaushik will be able to help me get a better understanding of how our ROS is setup between now and next PR.