Individual Lab Report - Progress Review 10

Autonomous Reaming for Total Hip Replacement

HIPSTER | ARTHuR

Parker Hill

Team C:

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

November 3rd, 2022

Carnegie Mellon University
The Robotics Institute

Contents

1 Individual Progress

1.1 End-Effector Hardware

Last progress review we presented our progress on the end-effector, and demonstrated that we had a functional prototype, which actuated as we desired and was controllable. With a working end-effector, the next step for us was to iterate on that end-effector in order to get it ready for being manufactured out of aluminum. Anthony and Sundaram helped me with this, converting a lot of the parts I originally designed to be thinner, use less excessive materials, and have some holes in them for weight reduction. The overall form of the end-effector didn't change much as a result, but the parts are much more optimized, and example being the part which connects the assembly to the end of the Kinova arm, which was redesigned from being an I beam into being two plates connected together via an angled plus geometry. I also began the design of a cover that would encase the end-effector such that the finalized end-effector looks more like a final product as opposed to an open prototype. Figure 1 shows the final end-effector hardware and also the cover which is likely to change more in the future. After reviewing the design, printing out some

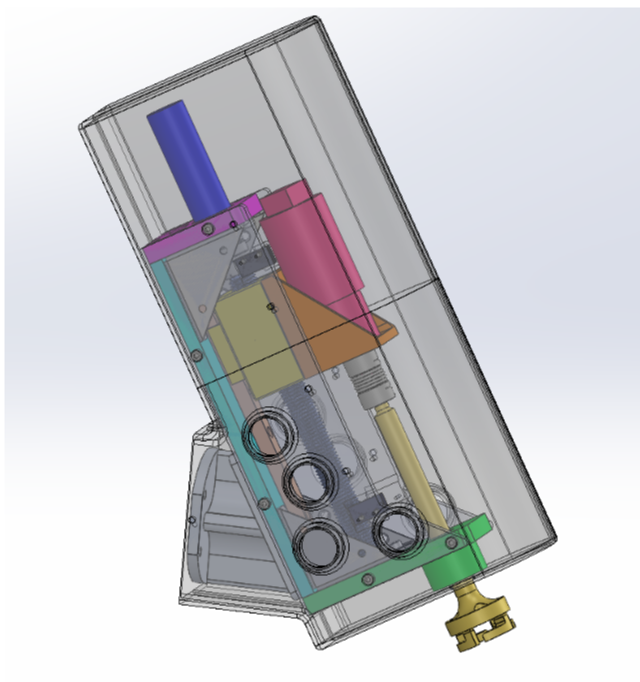

Figure 1: Finalized End-Effector CAD for Manufacturing

prototypes, meeting with Tim, and generating drawings of all the parts which would need tapped holes, we then began the process of receiving quotes for our parts. We decided to use Xometry as they provided relatively fast and cheap manufacturing overseas. To order from Xometry we had to collaborate with Christine Downey, as she was unable to order the parts from our quotes on her end, and as such we needed to aid with ordering the parts. In total we ordered 8 different parts and 12 parts in total for a total of approximately $1300. Figure 2 shows our final orders.

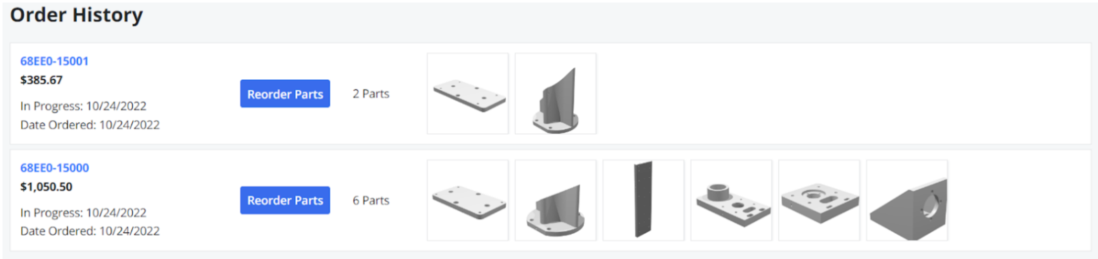

Figure 2: Xometry Order

1.2 End-Effector Controls

Last progress review Kaushik and I had managed to integrate together our electrical system with our prototype of the end-effector to show that we could control the motors using ROS and that our limit switches could be used as interrupts to limit the motion of the linear actuator. For this progress review we decided to begin integrating the final control scheme for the end-effector and revise how the end-effector will be controlled via ROS. We decided that we needed to implement two different PID controllers, one for each motor. The linear actuator motor would be controlled via a PID position controller, where it moves to specified positions that are detected via the encoders. The reamer motor would be controlled via a PID velocity controller, which attempts to maintain a velocity irrespective of the applied torque. With these controllers we could then develop a state machine for the end-effector which would be run on the arduino and the states would be called in ROS. We decided the system needed 6 different states: a state where the end-effector is calibrated, a state where it is waiting for a command, a state where it moves until contact is detected, a state where reaming is performed, a state where the end-effector reacts to dynamic compensation, and a state that occurs after the reamer detects that the operation is completed.

To begin with integrating these states we first had to characterize the performance of the current sensor such that we could then correlate the recorded current to an axial force in the system. To do so we hooked the current sensor up to a power supply and read the resulting analog signal on the serial monitor on an arduino, coming up with the following formula: $Current = (AnalogRead - 510)/14$, to measure the current. We then began integrating some of the states in the state machine, such as the calibration state which needs to touch the top limit switch and then move down 5 mm before coming to a stop, leading to a calibrated initial position for the end-effector. We began coding some of the states but did not get too far into it this progress review.

1.3 User Interface

The last main task that I worked on this progress review was integrating the end-effector and watchdog into the user interface. Gunjan took the lead on designing the user interface in Open3D and made it relatively easy for me to work on. Utilizing ROS subscribers which subscribed to topics which rosserial was publishing from the arduino, I was able to visualize the reamer velocity in the user interface. Similarly, I was able to build a node on the interface which displayed the status of several of the watchdog variables, coloring them green or red based on their status.

2 Challenges

2.1 End-Effector Hardware

There were some issues with the reamer handle that we were 3D printing, as the tapped holes that we were using to hold a set screw were unable to actually hold onto the spinning motor shaft. This led us to need to switch to using the reamer handle that our sponsors provided us coupled to the motor shaft using a flexible shaft coupling. Another challenge with the end-effector came from Xometry, which required a lot of different information from us in order to get our parts manufactured. Even with that information we had some issues with the actual ordering as it was failing to order on Christine's side of things. This was fixed when Christine and I got in a zoom call and ordered the parts off of my account as opposed to hers.

2.2 End-Effector Controls

The biggest challenge for the end-effector controls stemmed from the fact that the code we were attempting to integrate was incredibly bloated and inefficient. This code was developed for our motor controls last semester, with our previous end-effector, so while it was efficient for that system it is considerably hard to work with for our current system, requiring duplicated code for two motors and added state machine functionality. Moving forward we need to refactor a lot of this code. Another challenge with the end-effector controls is that while testing the task prioritization controller on the arm, we accidentally stressed the wires attached to the motor and pulled them off the motor, disconnecting it from our motor controllers. Thankfully we were able to perform some really dicey soldering to reconnect the wires and get the motor working again, however we also ordered two replacement motors which we will integrate into the system as soon as possible.

2.3 User Interface

One weird challenge we're facing with the user interface is that some of the metrics we are displaying, like the reamer velocity, only displays when the mouse is wiggled. This is likely some idiosyncrasy in Open3D, however we were unable to find a solution online or in our experimentation that fixed this. Another issue that we faced is that we set up the user interface external to our ROS workspace, which was initially easier to do as we did not need to worry about properly integrating it with ROS. However this presents a problem when we need to import custom ROS messages into our UI from the watchdog to display the status of several subsystems. The solution to this would be to either get rid of the custom message and instead display all the data on separate topics (booleans) or to instead move the user interface into the workspace so that it can access those messages. We decided to move the user interface into the workspace to solve this problem.

3 Team Work

- **Anthony**:Worked with myself, Sundaram, and Kaushik to finalize the end-effector hardware design and brainstorm the end-effector control architecture. He worked with Sundaram to integrate and test the watchdog and controls. He also implemented self collision checks on the controller and implemented out of range detection.

- **Gunjan**: Worked primarily on the user interface for this progress review, improving the front end to incorporate more widgets, refactoring the code base to make it more maintainable in the process. She developed a point cloud collection tool to display points clouds on the user interface and a landmark selection tool. Finally she helped me with the user interface and watchdog integration.
- **Kaushik**: Worked largely to assist several of the other team members for this progress review, helping Gunjan with integrating the point cloud collection and landmark selection. Also helped me and Anthony with brainstorming and setting up the framework for the end-effector controls on top of helping me to interface with and calibrate the current sensor.
- **Sundaram**: Worked on further development of the watchdog module primarily this review, spending time working with Anthony to integrate the watchdog with the controls and testing that the two systems mesh together well. Also worked with myself and Anthony to redesign the end-effector to be made of aluminum, and also worked with myself and Gunjan to decide user interface functionalities and set up ros topics for the user interface and watchdog integration.

4 Plans

4.1 End-Effector Hardware

Currently we are waiting for our manufactured end-effector parts to arrive, and once they do we need to assemble the final manufactured end-effector. We would likely need to spend some time in the machine shop to do so, as some parts may not have been made properly with correct tolerances. We would also need to spend some time working on making changes to the reamer handle our sponsor gave us, making it shorter, a smaller diameter, and with a different shaft length.

4.2 End-Effector Controls

For the end-effector controls we still need to correlate the axial force to a resulting current such that we can properly report the axial force and utilize it in our linear actuation controls. Once we've finished with that correlation and finished refactoring and writing the end-effector controls we would need to test the controls and verify that it is properly integrated with the ROS code. Some smaller tasks we would also need to take care of would be setting up our new reamer motor and printing a holder for all our electrical components so that the wiring under our table is not so atrocious.

4.3 User Interface

There is still a bunch of work to do with the user interface as the watchdog still needs to be properly integrated, but once the user interface is placed in the workspace it will be relatively easy to read in the booleans for the different subsystems and then color the watchdog terminal with red and green as a result. There are several expansions that could be added on to the user interface as well, as we could potentially pop up a warning if a subsystem goes from functional to non-functional unexpectedly.