Individual Lab Report - Progress Review 3

Autonomous Reaming for Total Hip Replacement

HIPSTER | ARTHuR

Parker Hill

Team C:

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

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Carnegie Mellon University
The Robotics Institute

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1 Individual Progress

1.1 End-Effector Redesign

As discussed in my previous individual lab report, there were numerous problems with the previous end-effector design. The length of the assembly was the biggest issue to be addressed in a redesign as it led to difficulties in motion planning, unwieldiness, and flexibility in the system which was undesirable. As a result, we decided to go forward with redesigning the end-effector such that the reamer handle was eliminated from the system, allowing the reaming head to be attached directly to the motor shaft. Taking measurements utilizing a caliper and iteratively printing, testing, and updating the design led to the finalized design which can be seen in figure 1.

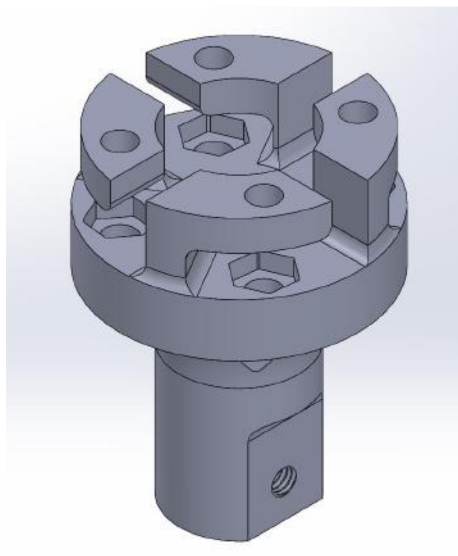

Figure 1: Reamer Head Motor Coupling

This reamer head utilized M4 screws and nuts to lock the reamer head in place in a similar fashion to how the reamer handle did. This motor coupling was designed such that it can work with any size reamer head, allowing the reamer heads to be changed by loosening the set screw to the motor shaft, removing all four screws holding the reamer head in place, then changing the reamer head and replacing all the screws. Testing showed that this coupler was able to attach to the motor shaft and hold up under some of the reverse torques that the part would be experiencing during reaming. The next step was to reprint the motor housing and the force-torque sensor adapter with some slight design changes. The motor housing was shortened and the walls were made much less thick, allowing for the motor to fit more securely inside of it. Furthermore, a marker mount was added to the motor housing, allowing for the marker mount which attached to the reamer handle to be attached instead to our custom geometries. The force-torque sensor adapter was also shortened and some of the holes in the part were adjusted to allow for better connection to the force-torque sensor. Finally, using a power drill, the marker mount for the pelvis was drilled into the sawbone pelvis allowing for registration of the pelvis to occur with reference to a static frame. With all these parts printed we were able to assemble our finalized hardware setup that we would be utilizing in our Spring Validation Demonstration, as can be seen in figure 2.

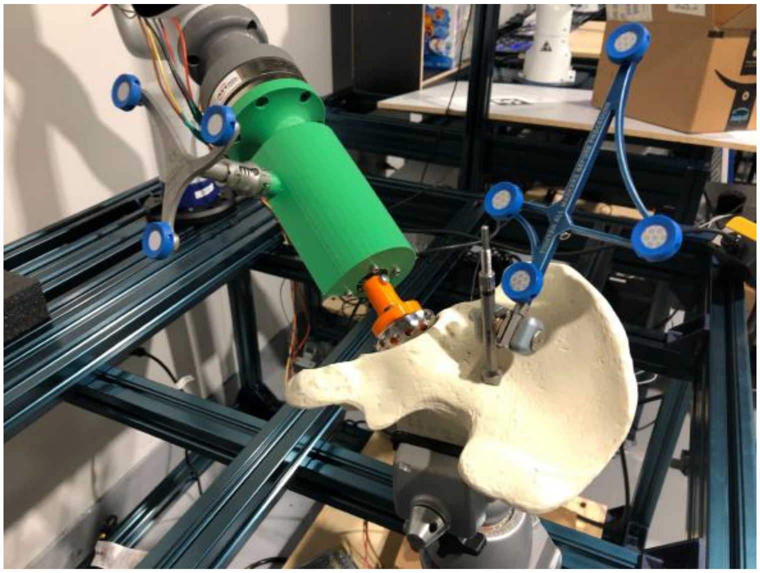

Figure 2: Full Hardware Setup

1.2 PCB Progress

Once the PCB and all the parts arrived, they were all individually tested for connectivity and functionality prior to beginning to solder them onto the board. Once this was verified, I began to solder all the components onto the PCB, testing connectivity as I went. I began with soldering the resistors and LEDs to the board, before moving onto the fuses and the terminal blocks, and finished with soldering the header receptacles. I then soldered header pins onto the arduino and the Pololu motor controller, leading to the finalized result which can be seen in figure 3.

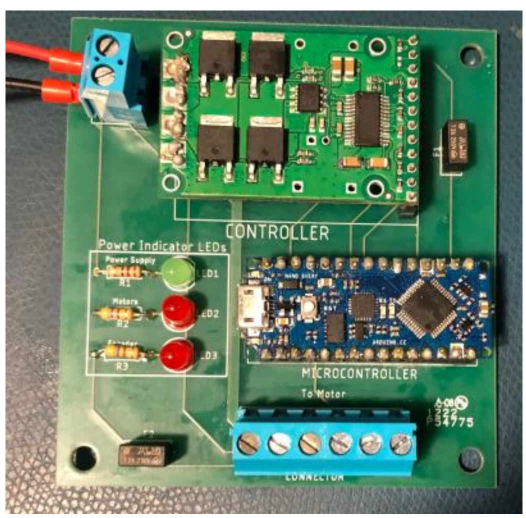

Figure 3: Fully Assembled PCB

Connectivity was verified again and all parts were double checked to verify that their solders looked good prior to testing with the provided power supplies. With the controller and the arduino in the PCB, the PCB was verified to work correctly, as the power supply LED and the encoder

LED light up, showing that the power supply was successfully powering the motor controller, the encoder was correctly being powered by the power supplies 5V out pin, and the motor out on the motor controller was not being powered, leading to the motor LED not lighting up. This success can be seen in figure 4.

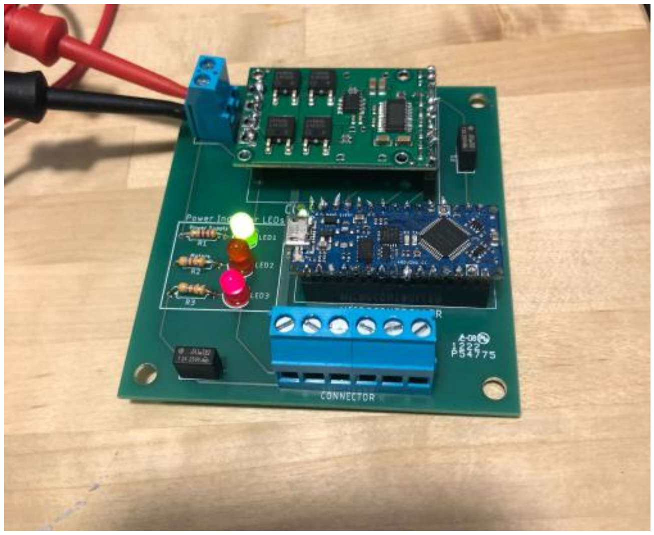

Figure 4: PCB Powered On

The motor wires were then extended by soldering 18 AWG wires onto the current wires, allowing for the wires to be easily and loosely routed along the arm and connected to the PCB.

2 Challenges

2.1 End-Effector Redesign

There were not too many issues with the end-effector redesign outside of the number of iterations of test prints it took to get the reamer head coupling and marker mount fitting correctly to the motor and markers. The reamer head coupling had to be printed on the Ultimakers in lab as my personal Creality Ender 3 printer had difficulties generating supports which could be removed from the print without breaking necessary geometry, while the Ultimakers could use PVA as the support material.

2.2 PCB Progress

While I ended the PCB section above on a high note with the PCB working, it unfortunately all came crashing down as I went about doing a second pass fixing my solders with the aid of flux and some good advice. While my solders largely look better on the board and I have a greater understanding of how to solder in the first place, as a result of this second pass some components on the board got fried while testing them. While testing in the same way as I had prior to the second soldering pass, the motor light came on despite not motor being connected to the PCB and not PWM signal being passed to the motor controller from the arduino. This led to the arduino sparking and becoming fried and the motor controller becoming unreliable. The motor controllers unreliability could be seen in the fact that it's PWMH pin which is supposed to be held LOW, was instead showing voltages between 1 and 3 V, and the resulting current into the motor controller could be seen to be fluctuating on the power supply between 0.1 and 0.6 A. I am still unsure what specifically caused the problem, potentially the reapplication of head caused a solder bridge somewhere on the motor controller, or maybe I didn't remove flux properly enough leading to a short somewhere. Either way, the motor controller has been reordered and should have arrived as of today (4/6/2022) as well as a thinner solder which should be useful for resoldering the motor controller to the header pins.

3 Team Work

- Anthony: Anthony worked on transferring the MPC code from offline simulation to online real-time simulation in Gazebo. This task involved writing MPC update functions as well as restructuring the code to be modular and more efficient. He then integrated the MPC code into ROS using RobotOS.jl, writing an MPC solver node to solve the optimal control problem, a simulation node for internal testing before integration, and a controller node to send torques to the effort controllers. Collaborating with Sundaram and Kaushik, Anthony then integrated the controller and MPC nodes with the trajectory planning nodes, Gazebo sensor nodes, and the Gazebo effort controllers, enabling real-time simulation testing of the controllers in Gazebo. Because the MPC had trouble performing well in real-time, Anthony also developed a PD Impedance Tracking controller in parallel to use as a fallback should the MPC not be viable by the SVD. Anthony also collaborated with Parker, providing tips on how to set up and wire the power distribution system.

- Gunjan: Gunjan worked on extending the functionality of the perception pipeline and testing for robustness and reliability. She worked closely with Kaushik to integrate the new registration probe into the current pointcloud collection pipeline, obtain the probe tip pose and publish pointclouds at several frequencies. She developed user-input based sparse pointcloud collection and continuous dense pointcloud collection. Both functionalities were thoroughly tested. The point cloud collection pipeline was integrated and tested with the registration pipeline with the help of Kaushik. Further, she wrote test scripts to track multiple marker geometries as a proof-of-concept. Kaushik and Gunjan also discussed a revised software architecture for the perception and sensing subsystem.

- Kaushik: Kaushik worked with Gunjan to obtain the registration marker's tip pose using the market geometry and the pose of the probe center obtained from the camera. He then worked with her to obtain the pointcloud of the pelvis using this probe, and drafted a software architecture for the perception sub-system. After this, he worked on using the acquired pointcloud to develop a method to obtain the initial guess for registration, and further refined the pipeline to register the pointcloud of the acetabulum with the 3D CAD model of the pelvis. The registration was then evaluated quantitatively. He also assisted Sundaram and Anthony in the integration of planning and controls sub-systems by writing the effort commander interface.

- Sundaram: Sundaram worked on completing the motion planning pipeline for which he compiled a custom message type on ROS. In this message he compiled trajectory messages which stored the joint states, a pose array message which stored the cartesian positions and orientations, and a point array message which stored the cartesian velocity. He wrote a node to plan a trajectory using the Pilz motion planning pipeline and publish the generated trajectory to a topic. He collaborated with Anthony and Kaushik for integrating the planning and controls subsystems. He also collaborated with Parker to ideate hardware designs and their interaction.

4 Plans

4.1 Hardware

The hardware is largely completed for the Spring Validation Demonstration, and the only thing left to do aside from printing back-up parts would be determining the transformation matrix between the markers mounted on the arm to the last link of the end-effector. Determining this transformation matrix would allow for the arm to be fully localized with respect to the pelvis marker mount. We also hope to mount the power supply and PCB to the bottom of the Vention table by the Spring Validation Demonstration, keeping them from moving while the robot is actuating.

4.2 PCB

There is still quite a bit of work to complete with the PCB prior to the Spring Validation Demonstration. I'll first need to finalize the PCB with the new motor controller and arduino, verifying it's capabilities and stress testing the PCB to verify that it will not break during the demonstrations. I'll then need to develop arduino code which is capable of subscribing to a ROS node which will give it a velocity input to maintain utilizing the PID velocity control code we developed in the sensors and motors lab. Then, I would like to implement a switch to control power to the PCB as well as determine a way in which the E-stop can be used to cut power to the robot arm as well as the reamer motor. Finally, I would like to reroute the motor wires along the arm in a less sloppy manner with motor cable ties and a tighter bundle of wires. I believe all these tasks should be easily be able to be completed by the Spring Validation Demonstration, allowing for our hardware and electrical system to be fully functional.