Individual Lab Report 10 - Progress Review 11

Autonomous Reaming for Total Hip Replacement

HIPSTER | ARTHuR

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Team C:

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1 Individual Progress

Several tasks were completed since the last progress review, which included fixing collision detection in the arm controller, integrating controls with the watchdog and end-effector control subsystems, redesigning the end-effector marker geometry, redesigning the end-effector cover and 3D printing it, helping develop the end-effector controls, and determining sources of misalignment in the system.

The first task I worked on was fixing the collision detection in our arm controls. This was simply done by creating larger environmental objects in the URDF for the MoveIt package to look at during detecting collisions. The reason why it failed earlier was that the table was too small, and the arm in the URDF went over the table's edge, so it never collided. Making a larger table and a wall behind the arm should and did resolve this.

The next task I focused on was integrating the Arm Controls subsystem with the Watchdog and End-Effector Control subsystem. Integration with the Watchdog subsystem required adding subscribers and publishers, as well as some additional logic for fault-checking and disabling the controller when the system goes into fault. For integration with the end-effector, this required only publishing when to start reaming and when to start dynamic compensation.

After integration, and with the manufactured end-effector coming in (Figure 1), I turned my attention to getting that up and running. First, I redesigned our end-effector geometry since our last geometry was both too linear and too long. The new geometry (Figure 2) is shorter and much closer to those used in industry (asymmetrical). Second, I also designed a cover. The cover designed previously was very bulky and left a lot of empty space, potentially limiting our workspace. I redesigned the cover to be more form-fitting, to have magnets for easy attachment and removal, and to have a wire strain-relief port in the back since we were having issues with wires pulling out through the back (Figure 3). After designing it, I have been 3D printing it and adjusting for tolerance as needed.

The next task I worked on was to help end-effector controls tune gains and swap out necessary hardware to have more robust force-sensing. For this, I mainly helped tune PID gains for force and position controllers, and also determined a new linear actuator motor that provides less force to allow for a greater range of currents for the current sensor to read for force control.

Lastly, I worked on determining sources of accuracy errors in our system. The main sources were in our hand-eye calibration, as the location of the base was constantly off even after calibration, so we had to hand-tune the base position and verify with a pointer probe (which we knew was correct). The second source of error was the end-effector position control is still a little inconsistent. This was also tuned to have less variability.

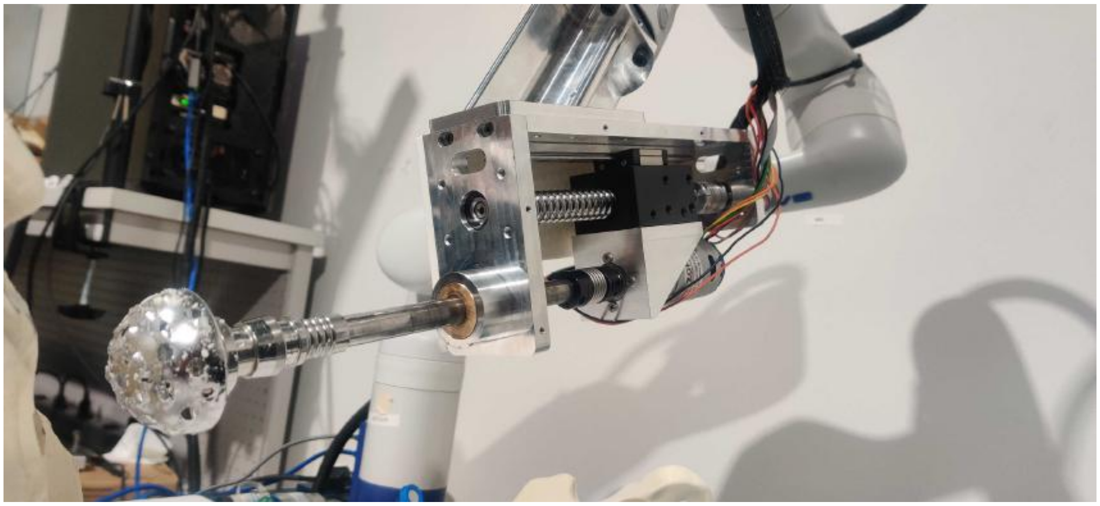

Figure 1: Manufactured Components of End-Effector Assembled

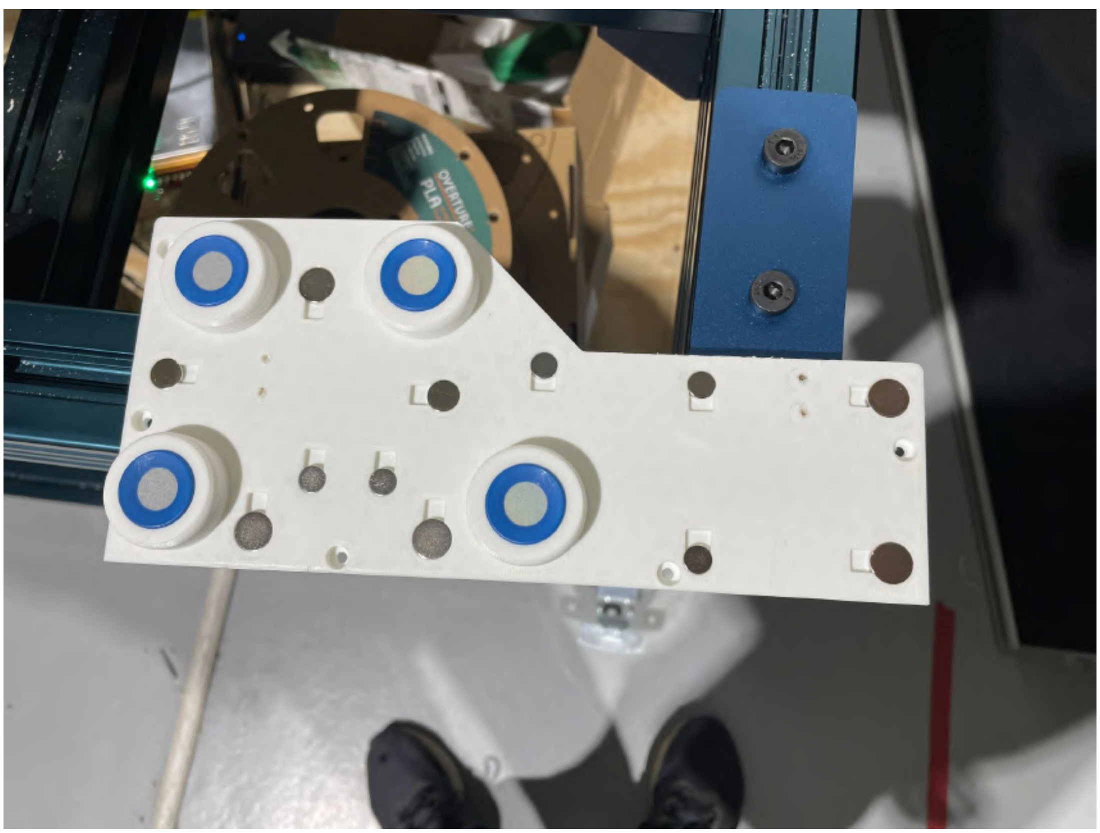

Figure 2: End-Effector Geometry

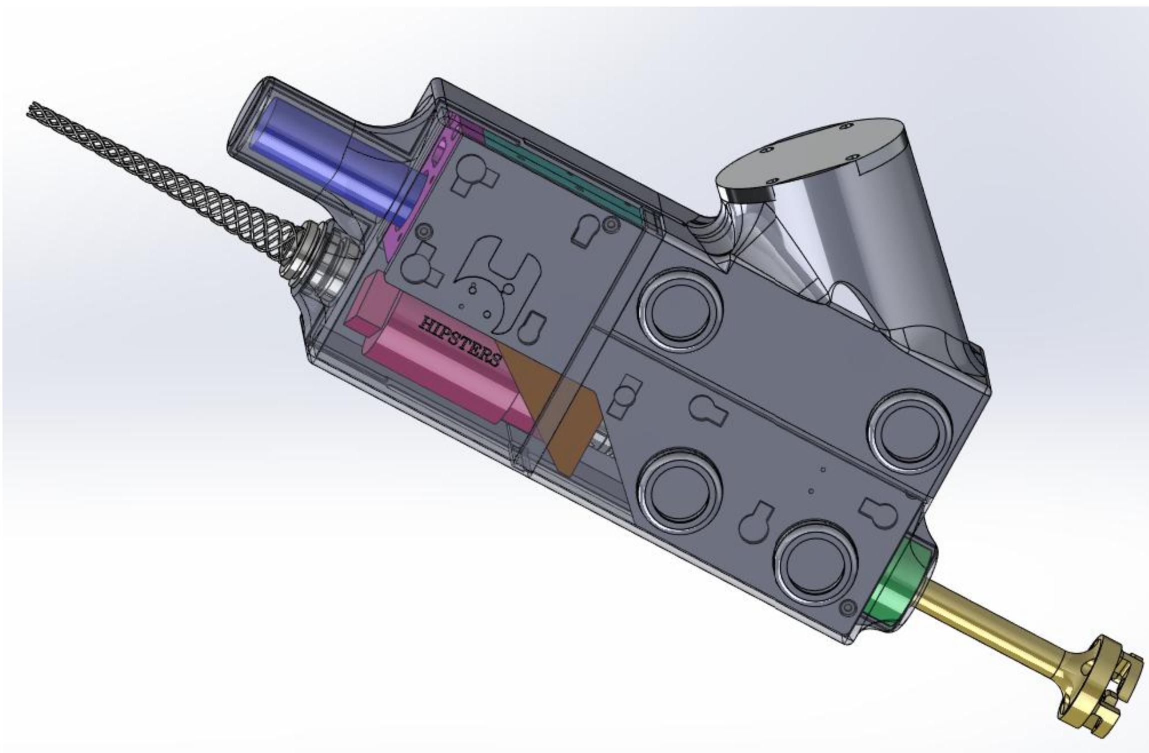

Figure 3: The final cover design of the End-Effector with wire strain-relief on the back.

2 Challenges

The major challenges for this progress review were integrating the arm controller with the rest of the system, adjusting the end-effector cover for 3D printing tolerances, and determining sources of misalignment and failure in the system.

The first challenge, the integration of the arm controller, was because of several reasons which largely stemmed from the fact that there were a lot of moving pieces, all of which are prone to bugs and logical errors. After testing numerous times and checking logic over and over, this challenge was overcome.

The second challenge was also overcome by just 3D printing the cover, seeing what was different between the print and the CAD model, and adjusting those dimensions accordingly. This was, however, a major time-sink.

The last challenge was determining sources of misalignment and failure in the system. This required a lot of testing, and looking at where the error occurs through RVIZ by using our pointer-probe and determining ground truth versus what was visualized. Through this, we determined the main sources of error were the base positioning (from calibration), and end-effector controls being inconsistent. Determining system failures was also a major challenge. Our reamer motor would shut off when too much force was applied to it. We initially thought this was our motor being too weak, but after swapping motors, we determined the source of the problem was that the motor driver would shut off during spikes of current. We swapped out the motor driver with one with a higher peak current, and the problem was solved.

3 Team Work

3.1 Anthony Kyu

Anthony worked with Sundaram to integrate the Watchdog Subsystem with the Arm Controller, and worked, similarly with Kaushik to integrate with the end-effector controls, and tune those controls. Anthony also worked with Sundaram and Parker to design and 3D print the cover, starting prints, determining offsets, and reprinting. Furthermore, Anthony worked with Parker to determine the sources of misalignment errors in the system, verifying ground truth and hand-tuning the calibration process to fix misalignment for the reaming procedure. Lastly, Anthony worked with the rest of the team to obtain acetabular reaming results for system validation, so that they could compare desired bone removed versus actual bone removed.

3.2 Parker Hill

Parker worked with Anthony and Sundaram to assemble the end-effector hardware and helped design and 3D print the end-effector. In addition, Parker redesigned the housing for the electrical subsystem to reduce risk of the subsystem failure from external sources. He also worked with the team to integrate subsystems and worked with Anthony to find sources of misalignment. He worked with Sundaram to validate system performance by comparing meshes, and adjusted mesh origins to enable validation.

3.3 Sundaram Seivur

Sundaram worked with Gunjan to integrate the Watchdog subsystem with the UI to display all critical metrics. He also worked with Kaushik to integrate the end-effector controls with Watchdog. In addition, we worked with Anthony and Parker to design and 3D print the end-effector cover, and worked with Parker to create an evaluation metric for FVD. He worked on making ballistics gel for testing and FVD too. Furthermore, he worked with the entire team to integrate subsystems and tune parameters.

3.4 Kaushik Balasundar

Kaushik worked on implementing the low-level position and velocity controllers for the end-effector as well as the State machine for the end-effector. He worked with Anthony to tune these controllers, and with Sundaram to integrate it with the Watchdog. Furthermore, he worked with Gunjan to transform the reaming pose or surgical plan from the UI to the camera's frame of reference and helped debug the perception subsystem. He also worked with the team to integrate the system and start testing the entire system.

3.5 Gunjan Sethi

Gunjan worked on completing the UI and integrating the UI with several subsystem, mainly with the Watchdog. She worked with Kaushik to fix pointcloud collection integration, and with Sundaram to get transformation data for post-reaming validation of the system. She also worked with the entire team to test the system and prepare for dress rehearsal.

4 Plans

Between FVD and now, I plan on finalizing integration between the controls and other subsystems. Most of the integration is finished, and this is a matter of fixing logical bugs between subsystems.

I also plan on creating an online calibration node which will improve the accuracy of our system greatly. In addition, I will be assisting end-effector controls to have more accuracy in reaming depth and debugging sources of error there.

Lastly, I will be preparing for FVD itself by preparing a presentation, getting metrics to show, obtaining materials for testing (such as sandbags), and doing dry-runs of our demonstration with the team.