Individual Lab Report - Progress Review 11

Autonomous Reaming for Total Hip Replacement

HIPSTER | ARTHuR

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Team C:

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November 17th, 2022

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1 Individual Progress

1.1 End-Effector Hardware

Our manufactured components finally arrived during the last two weeks, and as such we were able to start putting together the final assembly for our end-effector. Assembly went relatively smoothly, as Xometry did a good job with the screw holes, machining all the clearance and tapped holes well such that we had no alignment issues with the print. With the hardware fully assembled we were then able to take a look at our acetabular reamer shaft that we received from our sponsors. I determined how we needed to machine down the reamer shaft, and we all went to Tim and helped him with lathing and cutting the shaft to size. When it was finished it was perfectly manufactured to fit inside our couplings and had the exact specifications we needed. We were able to then couple it with the manufactured end-effector, making for the first time our fully functional reamer operational. The end-effector can be seen in figure 1 without any covers on it. While this was

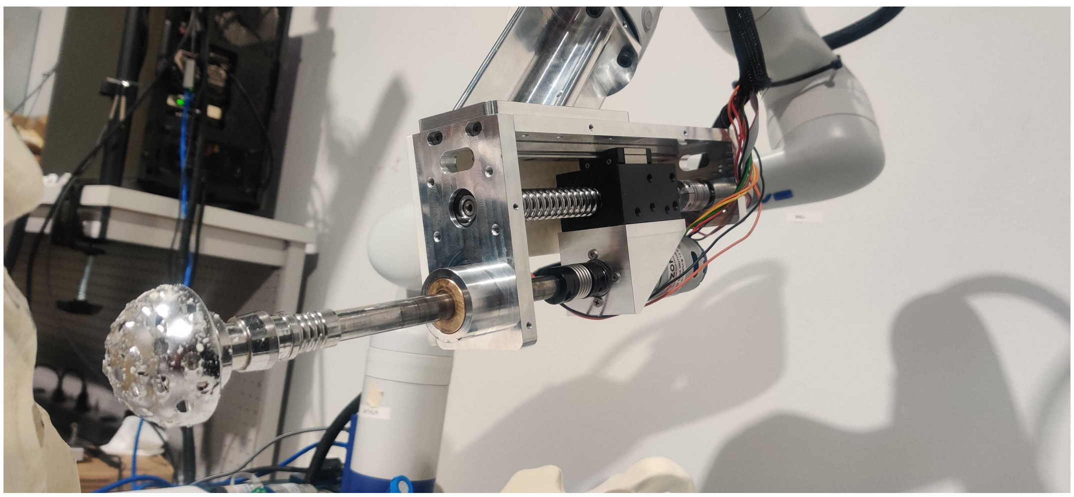

Figure 1: Manufactured Reaming End-Effector

great to see, we still had some changes to make to the end-effector to make it function perfectly. Thankfully we the end-effector to be adaptable to a number of different motors from ServoCity, so when we decided to change to using motors with different speeds and torques it was relatively easy to switch between them. I also spent some time adjusting the alignment of parts in the end-effector to verify that everything is as aligned as possible. Anthony is largely handling printing the cover, but Sundaram and I are helping him with checking alignment on the end-effector, and analyzing the resulting fit of components.

1.2 Electrical Redesign

So, we had to do another quick electrical redesign to fix the rat's nest of wires that had existed below our robot for some time. This was necessitated less by a need for cleanliness (cleanliness was just a byproduct), but more from a need to change motors wires and be able to verify that connections are stable and not causing issues while debugging during integration. As such I printed an electrical system adapter, which we could screw all the different components down to in order to better organize the system. I also decided to utilize a protoboard as opposed to a breadboard to make more stable and permanent connections. The resulting electrical system can be seen in figure 2. We also got new motors that we wanted to integrate with the electrical system, however

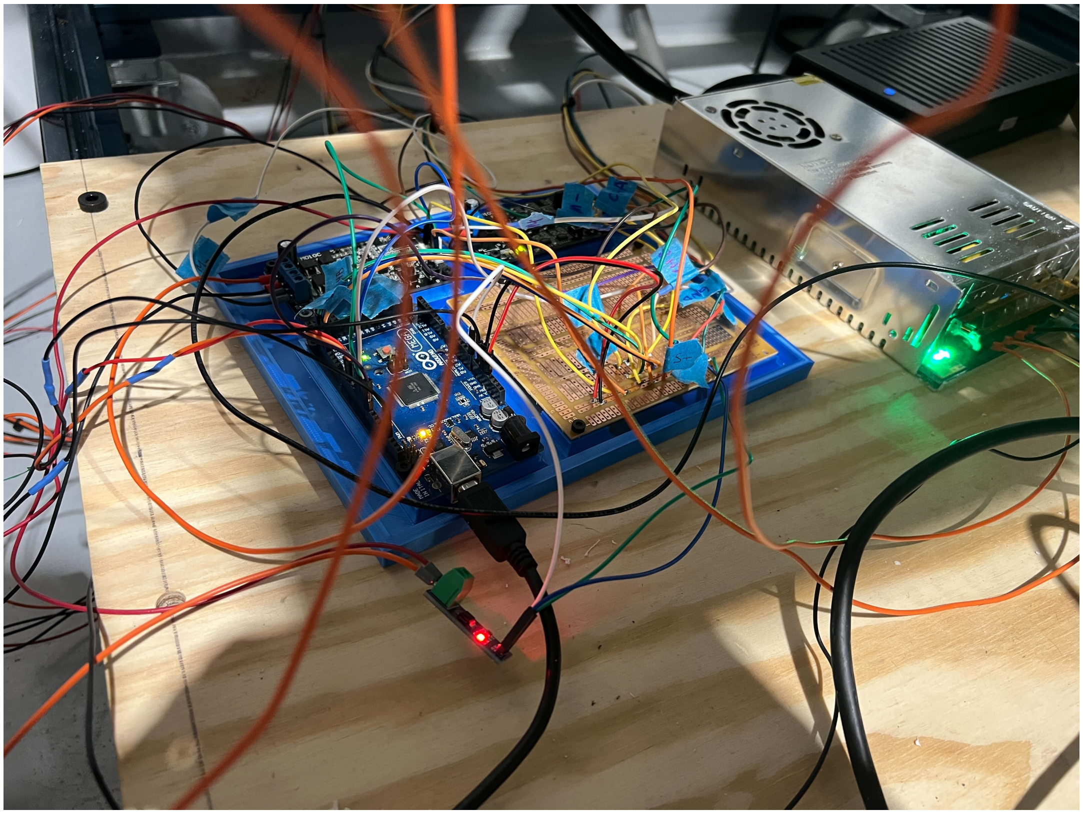

Figure 2: Electrical System Redesign (I promise it's less messy

our previous motors were connected directly to the system via soldered wires, so we needed to make new extension wires for the motors. Furthermore, instead of just soldering long wires to the motor wires, we decided to instead utilize connectors such that we could easily disconnect the motors from the electrical system and also that we could switch out motors quickly. We wanted to use molex connectors in order to do so, but they have taken a while to arrive, and as such we decided to make our own connector by using solid AWG wires which were taped together and then inserted directly into the connector that was pre-existing on the motor. While this sounds like a "MacGyver'd" solution, it does work well and allows us to maintain our connection to the electrical system while disconnecting the motor, allowing us to switch out motors with ease. This system's ease of use was proven when we were struggling to determine what was happening with a stalling motor not being able to be turned back on, which we were able to disconnect the motor to individually test it, and disconnect wires from one Cytron MD10C and attach those wires instead to a Cytron MD30C.

1.3 Integration

By far the largest sink of time for me these past two weeks was aiding in the integration of the total system. Generally during these integration sessions I focused on the end-effector and electrical systems, verifying that they were working within desired parameters and there was no resulting issues with communication to the controls systems. One major thing that Anthony, Sundaram, and I determined was with regard to our misalignment as a result of our hand-eye calibration, which we worked to hand tune the resulting position of the base of the robot such that our detected end-effector position was accurate to reality. I also worked to make things easier for Gunjan and Sundaram for working with the pelvis and acetabular cup meshes by adjusting the origin of the pelvis and cup to specified locations in Blender allowing them to perform alignment and the final registration easier. Finally, I went with the team to our sponsors and scanned the final reamed pelvis' and then worked with Sundaram to determine the difference between what we wanted and what we actually reamed.

2 Challenges

2.1 End-Effector Hardware

One issue we saw when we assembled the full manufactured was that the reaming handle was getting caught on our bushing and causing an issue when we linearly actuate forward, leading to the shaft jittering forward. We fixed this by fixing some alignment issues in the end-effector and by spraying WD40 on the shaft and bushing, leading to completely smooth motion. There were also some issues with motors, as we realized that our linear actuator motor had too much torque and that our reaming motor had too little torque. This conclusion was drawn as the linear actuator motor didn't need to press as hard against the pelvis to cut it, and having it have such high torque narrowed the band of currents we could detect contact from, and for the reaming motor, we realized we didn't need as much speed and that the torque was too low leading to the motor stalling too often. We swapped these motors out, decreasing the linear actuator torque by around four times, and increasing the reaming torque by around two times.

2.2 Electrical Redesign

Another problem we faced was that our current sensor was not reading well enough. We tried debugging this issue in several ways on the electrical side of things, believing connections and the Arduino to be the issue, until we realized it was just a matter of the linear actuator motor having too much torque. One of the largest and most annoying problems we faced was with respect to our systems performance whenever our reaming motor stalled out. As we understood, when our reaming motor stalls out the current sent to the motor should be continuously trying to move the motor, even if it cannot at the moment. However, in practice we were noticing that when we stall the motor, even if we remove the pelvis which was causing the stalling, the motor would not return to spinning. We eventually isolated this issue to the MD10C motor controller, which turned off as soon as the motor stalled. Our theory for why this happens is that the motor controller is rated for 13A continuous and 30A peak (10 second duration). Our motor should be drawing at most 20A when stalled, however it is likely that the current spikes before reaching that 20A number. This likely causes the Cytron to turn off to protect the circuit and motor when it detects this current spike. We fixed this by sourcing an MD30C from the lab inventory which has a 80A peak current, leading to us not running into the same issue.

2.3 Integration

We noticed that when we calibrate our system and then touch defined points on the robot with our probe, the exact transformations do not match up. In fact these transformations were often off by 3-4 mm in x, y, and z dimensions. Through some testing, Anthony, Sundaram, and I were able to isolate this issue to the hand-eye calibration, which consistently misaligned the base frame of the robot. We were unable to determine what was causing this error and decided to fix the issue for now by manually adjusting the base position until we determined a better alignment. Moving forward we'll need to use online calibration instead of offline hand-eye calibration, as if someone knocked the camera currently we would have to work to calibrate the camera again in a arduous process. Another issue we noticed was that while reaming the system often would not cut significantly less from the bone than we anticipated. This is from a variety of factors, including the end-effector controls, the urdf of the end-effector, perception misalignment, and most importantly flex in the system. Our shaft coupling was slightly compressible which leads to the reamer shaft not cutting as deeply as we want, but more pressingly, the pelvis itself was flexing in the vice, moving away from the reaming head. By supporting the back of the pelvis during reaming we were able to cut much deeper into the pelvis. We will likely need to test in ballistics gel to mitigate this issue further.

3 Team Work

- **Anthony**: Collaborated with Sundaram and I to finalize the end-effector. Worked with Sundaram to integrate the watchdog and controller. Aided Kaushik to integrate the end-effector controls and controlled. Worked with me to determine misalignment issues in the system. Finally, collaborated with the entire team to obtain reaming results for validation.

- **Gunjan**: Completed UI integration with Watchdog with Sundaram. Worked to debug issues with UI and pointcloud collection with Kaushik. Worked with Sundaram to get data for post implant alignment datea for performance evaluation. Finally, worked with entire team to debug system and perform dress rehearsal.

- **Kaushik**: Worked to set up end-effector controls, setting up a state machine and individual controllers for both motors. Worked with Sundaram and Anthony to integrate end-effector controls with Watchdog and controls. Also worked with Gunjan to get a correct reaming transformation. Finally, worked with entire team to do dry runs and validate performance.

- **Sundaram**: Finalized the development of the Watchdog and worked with Kaushik, Gunjan, and Anthony to integrate it with the UI, controls, and end-effector controls. Assisted Anthony and I with mechanical design tasks. Worked with me on developing a pipeline for validating our reaming. Worked on getting a ballistics gel model set up. Finally, worked with entire team to integrate all subsystems.

4 Plans

At this point we are in the final sprint to get everything set up for FVD, and as is always the case with big projects such as ours, there is a huge list of tasks to complete before we start our final demonstrations. The following is a sampling of all the tasks that we still have to accomplish:

- Fix all bugs and inconsistencies with the end-effector controls
- Set-up online calibration
- Create a poster for FVD
- Fix issues with faults in Watchdog
- Set up and check all microphones and cameras for the zoom recording
- Acquire sandbags and cast more pelvis’ in ballistics gel
- Integrate Watchdog with RMSE error
- Determine what is causing our inconsistency with reaming depth
- Test how the UI is integrated with our hardware
- Perform another dry run, scan the resulting cut, and analyze compared to desired cut
- Create a tabletop for our Vention table
- Print a new electrical system adapter with a lid