Individual Lab Report - Progress Review 8

Autonomous Reaming for Total Hip Replacement

HIPSTER | ARTHuR

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Team C:

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1 Individual Progress

1.1 Linear Actuated End Effector

In the previous progress review and individual lab report I talked about the initial design we were thinking of following for our new linearly actuated end-effector and the reasons we were moving forward with the redesign in the first place. The main progress since then has been on fleshing out the CAD and determining methods of sensing the force applied to the acetabulum. As can be seen in figure 1, our CAD has been updated to utilize the linear actuator parts that we purchased, and the rest of the components have been designed to interface with the ServoCity motors that we purchased and with the force sensors we decided to utilize.

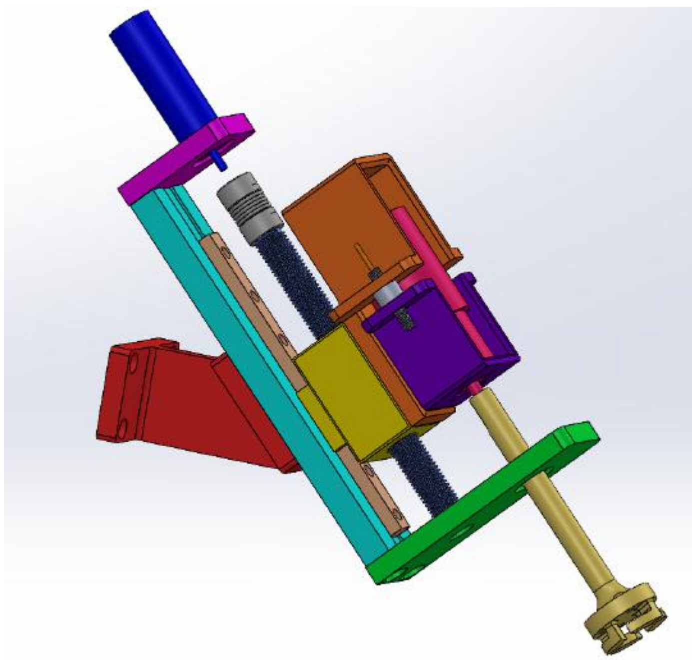

Figure 1: v1 of End-Effector CAD to be 3D-Printed

Specifically for our force sensing we have decided to move forward with using an ATO miniature load cell, which is attached in the image between the orange and purple parts. We decided on using this load cell as our force sensor largely because of it's size, as to be able to measure the axial force we needed to be able to have a force sensors that the motor is pushing back on. Having a larger load cell would lead to that motor carriage beginning to get larger and more bulky, which would cause issues with the amount we're able to actuate and the weight of the end-effector in general. Furthermore, this design specifically helps us to avoid a problem if we decided to put the load cell in between the motor shaft and the reamer shaft (which makes most logical sense). If we did that, then the load cell would be rotating as well and as such we would need a slip ring or some other method of constraining the wire coming out of the load cell, otherwise it would just tangle up on the rest of the assembly. It is also worth noting that this is our best design for directly measuring the axial force applied to the acetabulum, and there is a much easier indirect way of measuring that force, which would be sensing the current applied to the motor actuating the ballscrew. Knowing the current being applied to that motor would allow us to determine the torque that it is applying to the ballscrew, and with that we could correlate the applied rotational torque to a linear force utilizing a ballscrew equation. While getting rid of the load cells and just using current sensing for our force sensing would simplify our design, for the sake of safety during surgery, it made more sense to us to directly measure the applied force rather than indirectly. That being said, our sponsor thinks either method of measuring the force is valid and as such we might move to current sensing if we see little benefit in the ATO force sensors.

With our design finalized in CAD, it was time to move onto actually 3D-printing our new design. Using my personal Ender 3 Pro, with a white filament (to better match the color scheme of the Kinova), we printed all components with 30% infill and holes that were undersized slightly for tapping. It is worth noting that this printer required some significant maintenance to get it to begin consistently succeeding on prints, so a good amount of work went into getting the printer itself functioning. While we required some reprints to change dimensions and such of the parts, we were eventually able to get functioning parts and assemble the end-effector (without a attached reamer shaft and bearings) for the progress review, which can be seen in figure 2. This design passed all of the validation criteria we specified for Test 1, as it is capable of actuating greater than 50 mm, it rigidly attaches to the end-effector, and it has minimal vibrations while the arm is being moved.

Figure 2: 3D-Printed End-Effector Attached to Kinova Arm

1.2 Electrical Subsystem

Most of my time this progress review went into the end-effector design, but I did spend an hour or so thinking through how our electrical subsystem needs to be redesigned to interface with the new end-effector successfully. A block diagram of our new proposed electrical subsystem can be seen in figure 3.

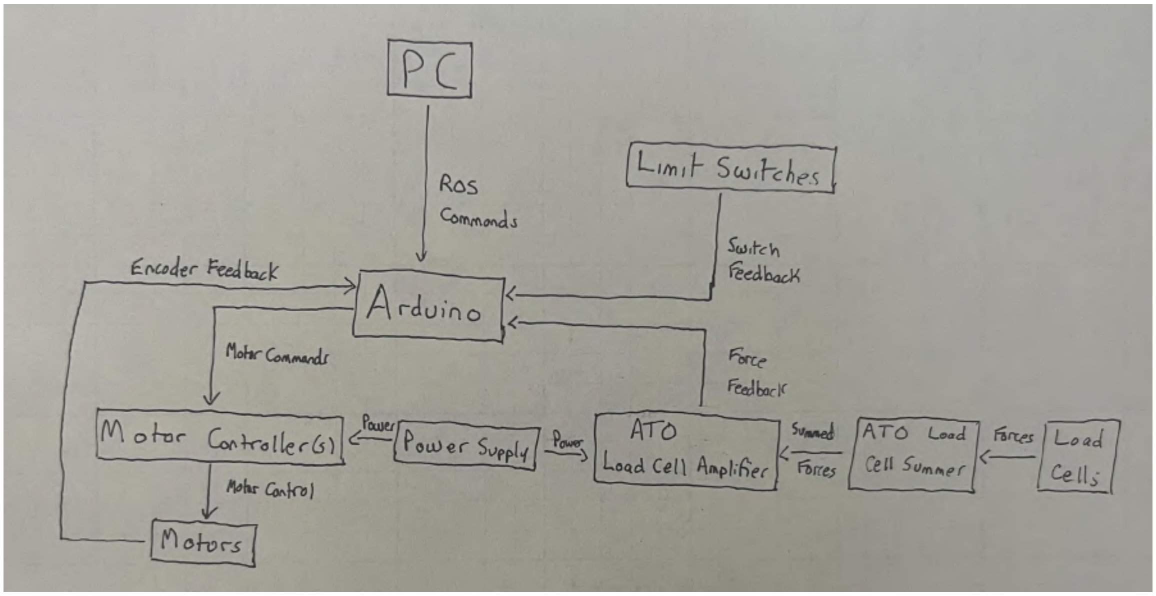

Figure 3: Redesign Electrical Subsystem Block Diagram

Currently we are using an Arduino Nano connected to a PCB and a Cytron motor controller to control the reaming motor, and our ATI force-torque sensor is communicating with ROS via a telnet session. Given the state of our PCB and the overall messiness of that system, we decided to completely redesign our electrical subsystem to be much simpler. From the top, we want our PC and Arduino to be able to communicate, but we don't want ROS to have to send continuous commands to the Arduino throughout the procedure. Ideally we would like ROS to send the Arduino a command to start reaming, and then have the Arduino stream back important data to ROS during the procedure, while the Arduino itself determines whether it is functioning or in error. As a result of this, we need all sensor inputs to be flowing into the Arduino, which means any sensors, like the ATO load cells, the motor encoders, and potential limit switches would have to be connected to the Arduino. The ATO load cells would also need to be amplified to have their output be between 0-5V, as such we need to utilize a load cell summer (to sum the values from the two ATO load cells in the design) and an amplifier before the resulting signal can be passed to the Arduino.

We already have a lot of the necessary components for this system, like the motors, motor encoders, load cells, and power supply, which leaves us with needing to find an Arduino, limit switches, and motor controllers to use. Looking to the MRSD inventory, there are plenty of Arduino Uno's that we could use for this system which would work perfectly for our needs. Furthermore, there are plenty of motor controllers, like the Cytron that we are already using, that would work perfectly for our needs. Using the Cytron would require us to use two separate motor controllers (one for each motor in the design), which is a little clunky. As such we were also considering using an Arduino motor shield to control both DC motors with the same package, like this one (https://www.pololu.com/product/5036) from Pololu. Our goal is to utilize the Cytrons and Arduino Uno from inventory for now and get the electrical subsystem and end-effector integrated before making potential upgrades to the motor controllers.

1.3 ROS Familiarization

One more slight thing I worked on for this progress review was familiarizing myself with the ROS code even further, as I have been working pretty far from the software for the majority of my time on this project. Thankfully Kaushik was willing to walk me through our entire codebase and get me up to date with how our code is structured and functions in general. I spent some time on my own picking through the code (specifically looking at how we're doing registration) and learned a lot about ROS, C++, and interfacing with outside libraries. I hope to continue learning more ROS and being more involved in the software side of things in the future.

2 Challenges

2.1 Linear Actuated End Effector

The biggest challenge for the end-effector redesign came from the linear actuator that we bought off Amazon having some weird dimensions, leading to a lot of the parts we designed to interface with it not fitting, necessitating reprints. This slowed down our progress in 3D-printing the end-effector significantly, as several parts had to be printed multiple times. Furthermore, there were some issues with hole sizing that largely came from human error, as parts were printed with the wrong hole sizes and the shrinkage of 3D-printed material was not accounted for well at times. We were also unable to get the two bearings that we ordered for the assembly integrated into the design as then can be seen missing in figure 2, as the holes we dimensioned for a press fit were very small and we could not manage a press fit with just our hands. Given that we were unconvinced that the current part would be part of our final design, we did not want to press fit the bearings in quite yet, leading to us eliminating them from the design.

One challenge not mentioned just yet was that we got stuck on our design for a while for how to support the reaming shaft using a bearing. If we use a rotational bearing to support the reaming shaft, then the reaming shaft would not be able to move through the bearing without significant friction. If we use a thrust bearing to support the shaft's linear motion, then we would prevent the shaft from rotating easily as there would be no bearing support for it. We decided to utilize a rotational bearing that is loosely fitted for our purposes, as the rotational motion of the reamer shaft would be supported, but the loose fit would allow for translational movement to still occur.

2.2 Electrical Subsystem

There weren't really many challenges with regard to the electrical subsystem as we have not started working with the physical parts quite yet. I anticipate that there may be issues with using parts from inventory that may be burned out and replaced without saying anything, or issues with general integration of the ATO load cells into the Arduino circuit. By utilizing the oscilloscope and power supply in the lab we can avoid a lot of integration issues by understanding what signals the ATO load cells output. However, those issues will be documented in the next ILR.

3 Team Work

- Anthony: Worked with Kaushik to implement a basic joint velocity controller on both simulation and on the real arm, implementing inverse kinematics, singularity damping, and joint limit avoidance algorithms. He also worked with Kaushik to test the performance of this controller, testing how well it could track a pelvis marker and tuning the PID gains to do so. In addition, Anthony worked on the task prioritization framework, creating a more detailed UML diagram that outlines classes, class members, and class functions and how they will interface with each other. Furthermore, Anthony worked with Parker to help finalize the CAD design, sourcing key components such as the motor, load cells (and load cell electronics), and the linear motion mechanism. He also helped Parker calibrate his 3D printer. Lastly, Anthony also put together a knowledge sharing session with the team to explain the math and algorithms behind the Task Prioritization controller to be implemented.

- Gunjan: Developed the necessary script to convert STL-filetype pelvis scans to PCD format to facilitate usage in the current system pipeline. Further she worked on assessing the feasibility of using RQt and Open3D for the UI development. Gunjan also began development on the watchdog module.

- Kaushik: Set up a simulation environment to serve as a testbed to implement and validate the working of the velocity controller. He then worked closely with Anthony in implementing the new joint velocity controller in simulation with singularity damping and joint limit avoidance. He further helped validated the controller's performance and tune the gains for the real robot arm.

- Sundaram: Worked on finalizing the watchdog architecture and started implementing features for the watchdog. He made changes to the architecture based on the feedback provided by our sponsors. He worked on creating the wireframes for the User Interface and conceptualized the critical components that need to be visualized on the UI. He also assisted Parker in finalizing the design for the end-effector and helped evaluate the performance of the 3D printed assembly.

- Would like to add a side note that Anthony, Kaushik, and Sundaram ran the Pittsburgh Tough Mudder with me on 9/24/2022 largely on a whim. Great teammates :)

4 Plans

4.1 Integrate End-Effector with Electrical Subsystem

The biggest task for the next progress review for me is to integrate the end-effector with the electrical subsystem. This would involve first completing the end-effector itself by reprinting the reamer shaft and the bottom of the reaming motor holder, as well as pressing the bearings into the part. Secondly, it would involve gathering the materials necessary for the electrical subsystem and utilizing a breadboard and jumper wires to connect all parts of the system together. The goal would be to demonstrate the end-effector's ability to actuate the ballscrew motor and reaming motor while taking input from the load cells. For this point in the progress it does not need to be a formalized controller or connected to ROS, however that would be the step after initial integration.

4.2 User Interface

In an effort to increase my time spent working on the software side of things, I plan on helping Gunjan work on the user interface for the next progress review. This initial prototype of the user interface would not utilize any graphical elements yet, but would focus on displaying important variables to the screen during the procedure in RQt. The goal is for this first prototype to allow us to move away from using terminals to monitor all important variables during execution and instead read all the variables from one window.

4.3 Ballistics Gel Experiment

We need to evaluate the use of ballistics gel as a proxy for soft tissue to hold the pelvis during a reaming operation. We all will likely be working together to generate a method for casting the pelvis in ballistics gel and testing the resulting movement of the pelvis during reaming.