Individual Lab Report - 10

Autonomous Reaming for Total Hip Replacement

HIPSTER | ARTHuR

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Team C:

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1 Individual Progress

1.1 Integration between the UI and perception subsystems

I worked with Gunjan to implement the functionality to communicate the reaming end position and orientation from the user interface as a transform in the camera frame. This involved understanding a series of transformations that occur to the pelvis and implant pointclouds as they are manipulated relative to each other in the UI. We then ensured that the reaming endpoint is fixed relative to the pelvis frame such that the reaming endpoint moves when the pelvis marker moves. This allows for dynamic compensation to take place when the pelvis moves more than our error thresholds for position and orientation. The image below shows the result of performing alignment in the UI communicated to RViz as a transform with respect to the base frame.

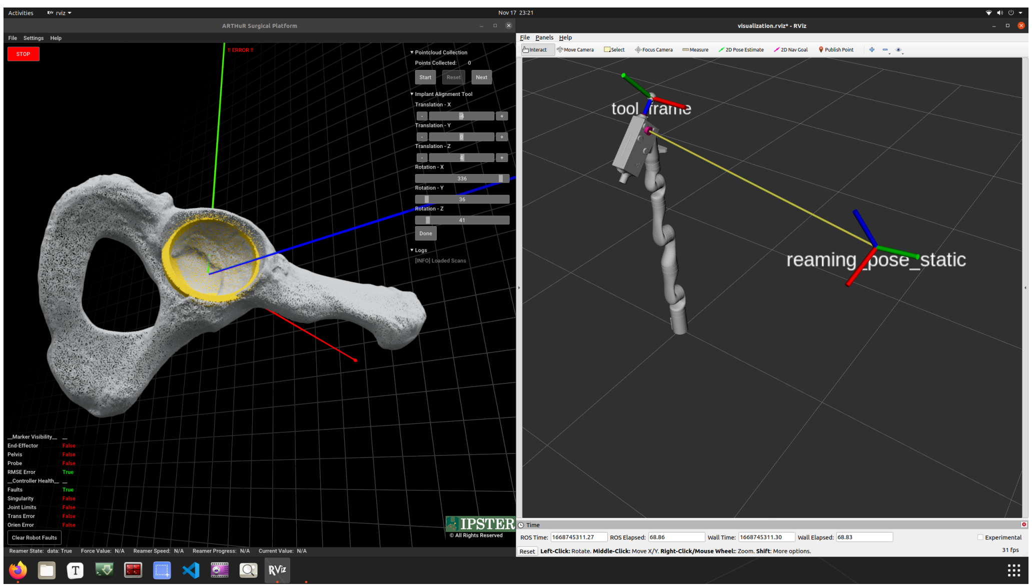

Figure 1: Reaming end-point communicated from the user interface to the robot in the real world

1.2 End-effector controls

A large portion of my time was used in cleaning up our old code for actuating the end-effector and creating a dual loop force-velocity controller to facilitate reaming. I also implemented a motor position controller and a calibration routine wherein the reamer motor moves until it impacts a limit switch to determine its location along the lead screw. I then implemented a state machine that communicates with the arm controller to determine the various stages of the reaming procedure, including moving until sufficient contact with the bone is made, starting the reamer motor, performing dynamic compensation, and finally retracting back when the reaming process is completed. I worked with Anthony to tune the controller to achieve the desired performance.

1.3 Full system integration

I also worked with all of my teammates to integrate the rest of the subsystems and facilitate testing of the system in its entirety. This involved ironing out integration bugs as the various subsystems merged and coming up with different test scenarios where the system might fail. I helped in running the system end-to-end and validating the result of reaming.

2 Challenges

2.1 End effector controls

1. **Encoder interrupt implementation:** With a higher RPM motor that we procured this semester, the encoder interrupt routine we had earlier failed to work properly for our high accuracy requirements. The microcontroller constantly missed counts and we were getting inconsistent results. I switched to using an optimized encoder library that used the full capability of quadrature encoders to fix this problem.

2. **ROS Communication Issues with hardware:** When the watchdog was integrated with the end-effector controls, we noticed a large latency in sending and receiving ROS topics to and from the microcontroller. This was due to asynchronous publishing frequencies between the various sub-systems. We also swapped out our old USB cable, and used a higher bandwidth USB port to make the communication faster. The issue was resolved when we restricted the communication rate of our watchdog to 60Hz.

3. **Issues with malfunctioning hardware:** During testing of the end-effector controls, our microcontroller and one of our motors stopped working. This was difficult to identify, consumed a lot of time to debug. However, since we had replacements in hand, we were immediately able to replace it.

4. **Motor and driver choice:** During testing, we realized that our motor would stall when it makes contact with the bone while applying force on it. We initially assumed that our motor wasn't powerful enough. However, we later realized that the over-current protection on the Cytron motor driver was causing the motor to shut off. We replaced both our motor and driver, doubling their peak torque and current respectively to solve this issue.

5. **Reaming end-pose communication:** We had issues communicating the reaming pose from the UI to the real-world. This was fixed as we spent time understanding the local and global coordinate frames used by the UI, and experimenting with a series of relative and absolute transformations to transform the implant from the UI to the real-world.

6. **Inaccuracies with hand-eye calibration:** We realized that the camera to base link transformation obtained was inaccurate. It was inaccurate by 2-3 mm in each axis. We realized that we had too much translational variance when collecting our calibration poses. In addition to fixing this, we had to do some manual hand-tuning to obtain an accurate robot base to camera transform. In this next couple of days, we will switch to an online calibration routine to fix this issue.

3 Team Work

Team Member	Contribution
Kaushik Balasundar	I implemented a low-level motor position and velocity controller, as well as an outer-loop force controller for the end effector. I worked with Gunjan to communicate the reaming end point from the UI to the real world with respect to the base link. I then worked with Sundaram to integrate the end-effector controls with the watchdog. I worked with Anthony to integrate the arm controls with the end-effector controls.
Gunjan Sethi	Gunjan completed the integration of the UI with the watchdog. She debugged issues with the UI and pointcloud collection integration with me. Next, she provided data for validation of the final reaming endpoint. She also worked with the entire team for the dress rehearsal and debug overall system integration issues.
Parker Hill	Parker designed and 3D printed the end-effector cover. He redesigned the electrical system and cleaned it up to fit into a single 3D-printed part. He worked with Anthony to determine sources of inaccuracies and hand-tuned base positioning. He worked with Sundaram to validate system performance by comparing meshes. He also adjusted the origins of all 3D meshes for ease of use UI and system validation.
Anthony Kyu	Anthony worked with Sundaram to integrate the watchdog subsystem with the arm controller. He worked with me to integrate arm controls with end-effector controls. He also worked with Parker to determine sources of misalignment error and hand-tune base positioning. He then worked with Sundaram and Parker to 3D print the end-effector cover. Finally, he worked with the entire team to obtain acetabular reaming results for system validation.
Sundaram Seivur	Sundaram completed the development of the watchdog after thorough testing. He worked with me to integrate end-effector controls with the watchdog. He worked with Gunjan to integrate and display all watchdog critical functionalities on the UI. He assisted Anthony and Parker with the design and 3D print of the end-effector cover. He then worked with Parker on the FVD evaluation metric. He created a new ballistics gel setup for testing and FVD. Finally, he worked with the entire team to integrate all the subsystems and optimize the performance of the system.

4 Plans

In the next few days leading up to FVD, I plan to work with the team to do the following:

1. **Online Calibration:** Assist in the implementation of end-effector online calibration to ensure there are no inaccuracies in the camera to base-link transformation using the arm's model and inverse kinematics.
2. **System fine-tuning:** Fine-tuning PID controllers: We still have to fine-tune our PID position, velocity and force controls to optimize performance to be within our error thresholds.
3. **Full-system testing:** I will continue to work with the rest of the team to run the fully integrated system to identify and rectify system integration faults and bugs.

5 Closing thoughts

As I finish up my final ILR, I am left with a feeling of immense gratitude towards the rest of the team. Regardless of the outcome of the demo, I believe we worked together extremely well, while learning from each other and supporting each other when the times got difficult. This project and my teammates are without a doubt a highlight of my MRSD experience. I also thank Prof. Dolan, Prof. Apostolopoulos and the TAs across both project courses for their support and feedback.