Individual Lab Report 7 - Progress Review 8

Autonomous Reaming for Total Hip Replacement

HIPSTER | ARTHuR

Anthony Kyu

Team C:

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1 Individual Progress

Several tasks were completed since the last progress review, which included coding a new joint velocity controller to align the end-effector with a pelvis frame both in simulation and reality, developing a Task Prioritization Framework, and sourcing and assisting in designing components for the new end-effector.

In the first week, I worked with Kaushik to implement a basic joint velocity controller using inverse kinematics to translate a twist command at the end-effector into joint velocities. The twist command would be an output of a PID controller that translates alignment error into the desired twist. In order to do this, I created a few classes, including a robot model class, which contained the kinematic chain of the robot, jacobian and forward kinematic solvers, SVD solvers, and joint limits, all of which can be constructed from parsing a URDF file. Within the controller, we implemented a pseudoinverse jacobian calculation using SVD, singularity damping algorithms, and joint limit avoidance algorithms. This was tested in simulation first, following a dummy pelvis frame that Kaushik implemented.

In the second week, I worked with Parker to get the end-effector design through a few iterations. I mainly worked on sourcing the critical components for the design to constrain the design to specific off-the-shelf components, such as the linear actuator motor, the load cells, the load cell amplifier and junction box, and the linear motion mechanism (ball screw with linear rail). I also gave advice on how these different components would come together, creating basic drawings of the design for Parker and Sundaram to CAD up.

In the third week, Kaushik and I worked together to transfer our new controller over from simulation to reality. There were a few bugs we needed to fix first, which included issues with joint limit avoidance on continuous joints. Once a dummy pelvis was created from a marker array in the real world, the controller was tested and evaluated on the real arm, plotting the following error of the pelvis over time using rqt as shown in Figure 1. The spikes of error correspond to pelvis movement, and the steady state of error is very close to zero.

In addition, a task prioritization controller framework was created which will further expand the controller that was just implemented, allowing for multiple simultaneous tasks to be executed at once such as pelvis alignment and camera alignment. The framework/UML diagram can be seen in Figure 2.

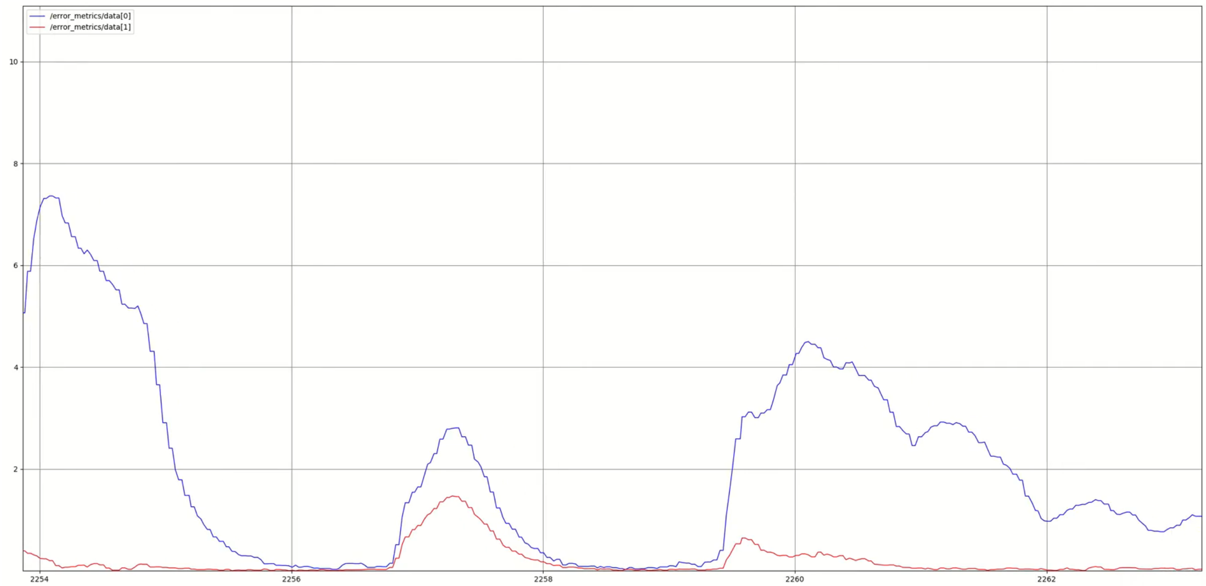

Figure 1: Graph of Position Error (Blue) in mm and Orientation Error (Red) in Degrees Over Time. The Spikes in Error Correspond to Movement of the Pelvis.

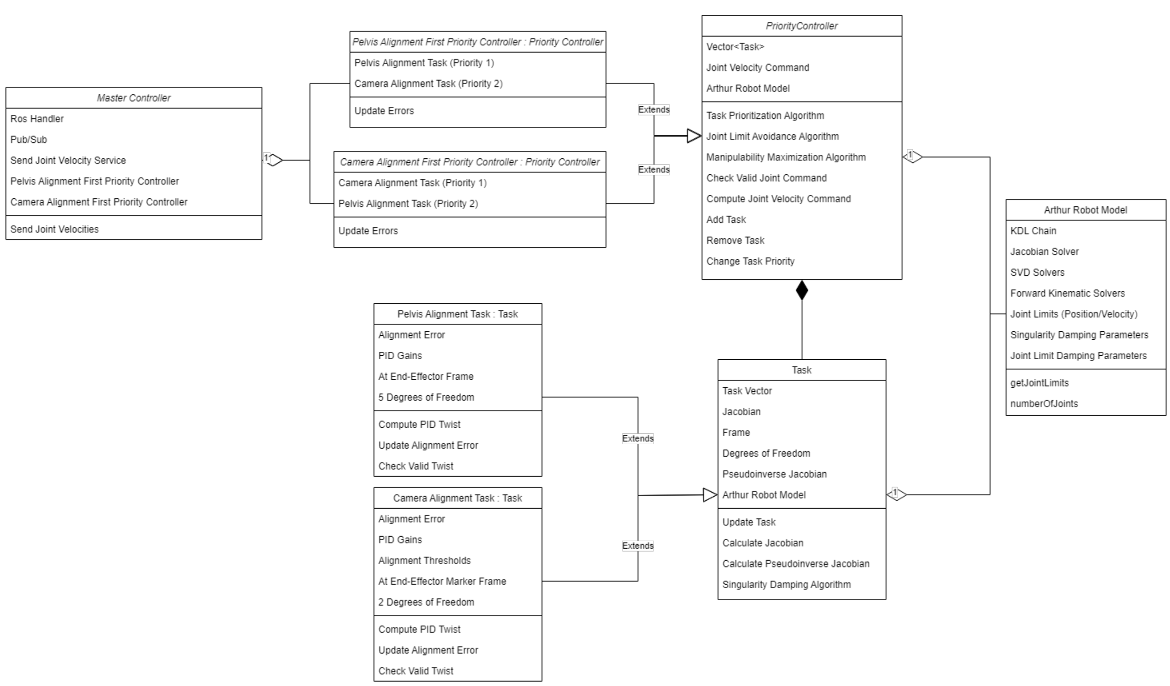

Figure 2: UML Diagram of the Task Prioritization Controller Framework

2 Challenges

The major challenges for this progress review were debugging the new controller, tuning the gains and parameters of the controller, especially when the Kinova ROS API is bottlenecked at 40 Hz, and getting Parker's 3D printer up and running to get the end-effector design 3D printed.

For debugging the new controller, the main bugs were with the joint limit avoidance algorithm. Because certain joints are continuous, they do not have joint limits. This caused odd behavior in the joint limit avoidance algorithm, as the arm would jump around near specific parts of a joint's rotation. After fixing this bug, the behavior became much more predictable.

The other challenge with the controller was that the Kinova Gen 3's control API is limited to 40 Hz, which makes it harder to tune PID gains for a fast and robust controller. In fact, having a derivative term to reduce overshoot seemed to actually introduce instability in the controller because the controller rate is too limited. Therefore, we were left tuning with the Kp term of the controller. The other parameters to tune are the singularity damping coefficient, and joint limit damping factors. Tuning all of these took some time, and slowed implementation.

The last challenge was getting Parker's 3D printer up and running. The printer had gotten severely clogged with filament, and it took a lot of iterative cleaning with various tools to clear the nozzle. In addition, the bed was not calibrated and was very warped as a result of years of use. Getting a new printer bed fixed most issues after some calibration.

3 Team Work

3.1 Anthony Kyu

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. 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.

3.2 Parker Hill

Parker worked with Sundaram and Anthony to finalize the CAD for the new linearly actuated end-effector design and sourced, printed out, and assembled all components for the first version of the design. He also developed an outline and began sourcing parts for the electrical subsystem. Finally, he spent some time with Kaushik learning more about the software aspects of the project to be able to help more with the user interface in the future.

3.3 Sundaram Seivur

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.

3.4 Kaushik Balasundar

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.

3.5 Gunjan Sethi

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.

4 Plans

For the next progress review, I plan on working with Kaushik to implement the Task Prioritization framework that I worked on this past progress review, writing and interfacing all of the classes and class functions, and then developing pipelines to test each individual task like the camera alignment task. After putting it all together, we hope to test the controller in simulation first, and then translate it to the real arm as well. With the 40 Hz rate limitation, if time permits, we may look into using Kinova's lower-level API to increase the rate to 1 kHz.

In addition, I will be assisting Parker in iteratively designing the end-effector, adding limit switches and, if necessary, dampeners to the design. I will also be helping with connecting the electrical system together and designing the separate controller for the end-effector, which will likely use some form of an admittance controller.