Individual Lab Report 6 - Progress Review 7

Autonomous Reaming for Total Hip Replacement

HIPSTER | ARTHuR

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Team C:

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Carnegie Mellon University
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1 Individual Progress

Several tasks were completed since the start of the semester, including collecting the Kinova Gen 3 Arm and Atracsys 300 Camera from our company sponsor, helping setup our workspace, updating the current wrench controller for better dynamic compensation, brainstorming end-effector designs, and compiling algorithms for designing a new controller architecture.

The first week, I went to our company sponsor to pick up the Kinova Gen 3 Arm and Atracsys 300 Camera, and then helped setup the system workspace the next day, mounting the arm and camera, as well as booting up and re-familiarizing myself with the system.

One of the major goals of the semester was to improve the dynamic compensation of our system. This requires two steps. First, the end-effector needs to be redesigned to have a prismatic joint for reaming, eliminating the need for motion planning, which was a bottleneck in our controller speed for dynamic compensation. Second, the controller rate needs to be increased and PID gains tuned better. Therefore, I spent time modifying the underlying state machine to remove planning, increased the controller speed, and tuned the PID gains of the wrench controller. This resulted in much better tracking of the pelvis in real-time, but there are some bottlenecks that can't be solved with the current controller architecture, which will be discussed in the challenges section.

Since a new end-effector is another goal for this semester, I spent time brainstorming end-effector designs. The new end-effector is going to be a prismatic joint, which could be driven by a ball screw linear motion system. This would eliminate the need for planning in the software architecture, which slows down the controller, and could allow for more consistent reaming forces since alignment and reaming are now kinematically decoupled. An initial sketch of the end-effector design can be shown in Figure 1.

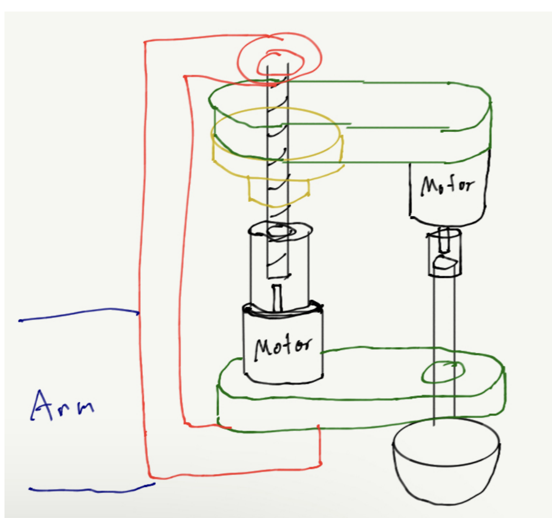

Figure 1: An Initial Sketch of the New Prismatic End-Effector Design

Because the current controller has bottlenecks in the controller rate, a joint velocity controller was chosen as the new controller since Kinova Kortex API supports rates up to 1 kHz. Therefore, the last task this week was designing a new controller architecture. The new controller will be a Kinematic Task Prioritization Controller. This not only allows for better tracking with the improved controller rate, but also allows for multiple tasks to be accomplished at once, including a reaming alignment task, camera-marker alignment task, singularity avoidance task, and joint limit avoidance. Avoiding singularities also positions the arm with maximized manipulability, allowing for more resistance to vibrations from reaming. An initial software architecture, controller architecture, and task prioritization algorithm can be seen in Figures 2, 3, and 4.

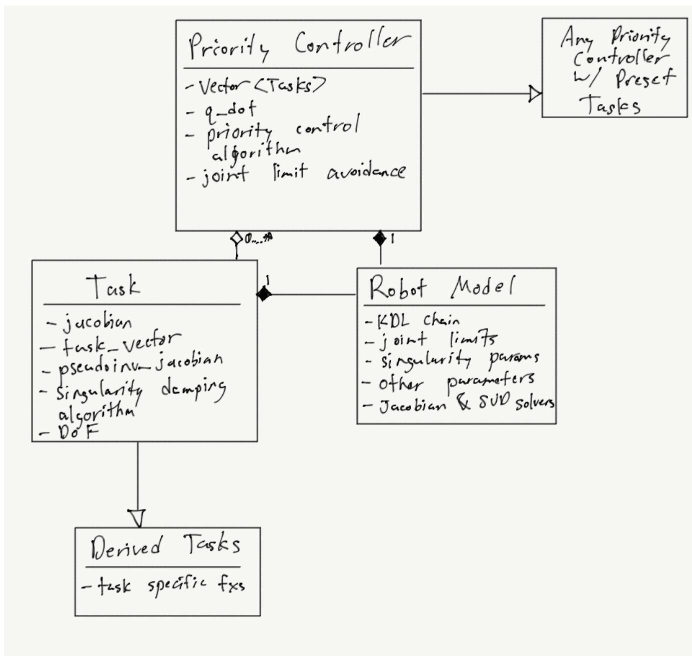

Figure 2: An Initial UML Diagram of the Kinematic Task Prioritization Controller Software Architecture

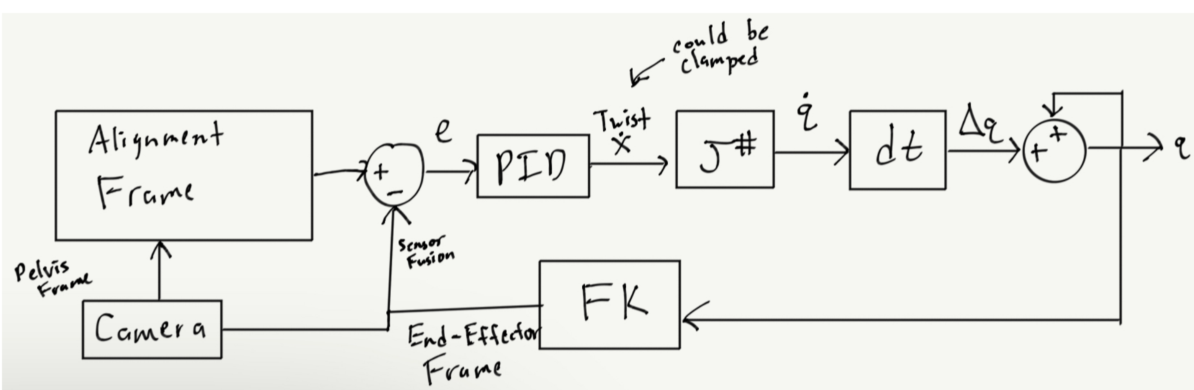

Figure 3: Control Block Diagram of the Inverse Kinematic Controller

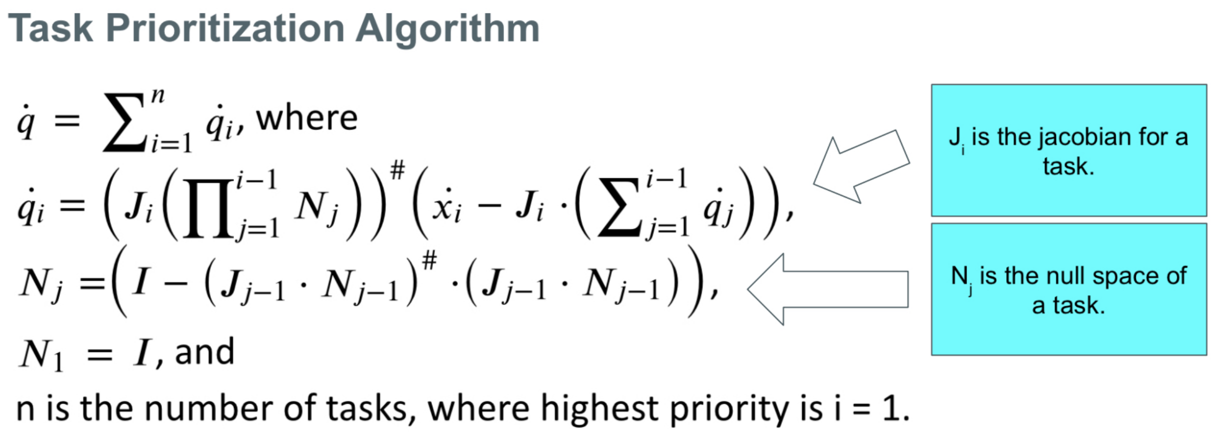

Figure 4: The Task Prioritization Algorithm: Prioritizes Which Tasks Take Priority When Executing Multiple Tasks Simultaneously

2 Challenges

The major challenges for this progress review were in improving the controller to track the pelvis more dynamically and with less latency. To do this the PID gains for the PID wrench controller were tuned more aggressively, and the planning module was removed, allowing for more responsive tracking. However, the controller would still have some latency, and with high gains, the system would overshoot and oscillate. This is likely due to the low frequency that the controller is constrained to.

Kinova's API for wrench control is through a service-client interface. This means that the ROS node for the PID wrench controller has to send a request to this service and wait for a response, which creates a bottleneck for the controller. After some testing, it was confirmed that the controller was limited to 40 Hz. Therefore, other API's were explored, and a joint velocity API was found that would run at 1 kHz because it runs on a publisher-subscriber interface instead. This will allow for a faster-responding controller.

Another challenge for the current controller is that it doesn't allow for multiple tasks to be performed simultaneously. One potential aspect we wanted to add to the controller was the ability for it to point the end-effector marker probe towards the camera during the operation to allow for better end-effector tracking and accuracy. This would not be possible with the wrench controller, since we are not controlling individual joints through that API. A joint velocity controller will enable us to take advantage of redundant joints to accomplish this task.

3 Team Work

3.1 Anthony Kyu

Anthony worked with the team to re-familiarize and rebuild the workspace. He also contributed to updating the requirements, risks, and roadmap for the system. In addition, he has been working with Sundaram and Parker to brainstorm ideas for the end-effector and source components to use in the design. And lastly, he has been compiling algorithms into one document for a new controller architecture for a Kinematic Task Prioritization Controller for the team to read through and understand for implementation.

3.2 Parker Hill

Parker helped with re-evaluating the requirements, risks, and roadmap of the system and took helped to setup our new project management method. He also relocated his 3D printer to the lab and began brainstorming ideas for a new linearly actuated reaming end-effector with Sundaram and Anthony.

3.3 Sundaram Seivur

Sundaram worked on reassembling the workspace and revisiting the previous implementation with the team. He also assisted Parker and Anthony in brainstorming ideas for the new end-effector design. He contributed to setting up the new project management methodology and re-evaluating the system requirements, risks, and project roadmap. He spent time with Gunjan to ideate the Watchdog module's functionalities.

3.4 Kaushik Balasundar

Kaushik helped restore the system to the same working condition as demonstrated during the SVD encore. He then brainstormed ideas for the online camera to robot arm extrinsic calibration. He was involved in the team discussions regarding overall system enhancements, potential upgrades to the controls sub-system, reevaluating requirements, and the roadmap for the fall semester. He updated and started tracking the project's ongoing risks and updated the cyber-physical architecture.

3.5 Gunjan Sethi

Gunjan worked on assisting in bringing up the system for re-familiarization and conducting the project management review. Gunjan and Sundaram also brainstormed the watchdog module.

4 Plans

For the next progress review, I plan on working with Kaushik to set up a simulation environment to test the new controller and develop a simplified version of the controller to test and determine if we want to pursue this new controller architecture or fall back on the wrench controller. I will also be brainstorming and co-designing the new end-effector, providing feedback on and helping with the CAD models, and 3D printing the models. Once 3D printed, these designs will be tested and iterated upon.

If time permits, I will also start implementing the more complex task prioritization framework in C++, which will allow for much more robust and complex behavior of the system, such as executing multiple tasks simultaneously. Since I have done a similar implementation before, I do not foresee this being a challenging task, but still time-consuming.