Individual Lab Report - 5

Autonomous Reaming for Total Hip Replacement

HIPSTER | ARTHuR

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Team C:

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1 Individual Progress

I was the owner for the point-cloud registration test on the real point cloud for this week's progress review. As a result, my time was devoted to ensuring that the registration pipeline was refined to meet this target. To meet this goal, we first needed to obtain the geometry of the acetabulum. Previously, although we obtained a pointcloud using a marker, it was from the marker's center and not from the tip. So, we needed a way to determine the tip of the marker given the readings of the marker center. The next challenge was to determine the initial transformation for the ICP registration. Finally, the parameters for registration had to be tuned. I also helped in the integration of the planning and controls pipeline in simulation.

1.1 Acquiring Acetabulum Pointcloud

Previously, Gunjan and I had written the preliminary code to acquire the acetabulum geometry using a registration probe. However, the points acquired were with respect to the center of the registration probe, not its tip. In order to get points at the tip, we needed the marker geometry which was given to us by our sponsors. We used this information to attach a frame at the tip of the marker. We then experimented with the number of points to be collected and the frequency at which they need to be collected. Figure 1 shows the frame attached to the tip of the marker, and Figure 2 shows the registration probe used to acquire the pointcloud.

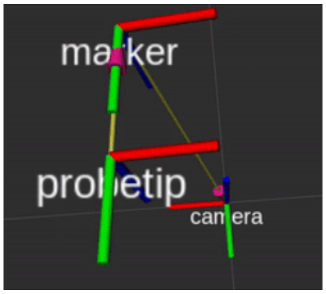


Figure 1: Frame attached to probe tip

Figure 2: Registration probe used for pointcloud collection

1.2 Initial Guess and ICP Registration

To acquire an initial guess for the transformation to feed into ICP, we wrote a script to match correspondences between the acetabulum in the real world and the 3D CAD model of the pelvis that was laser scanned. Figure 3 shows the process of correspondence matching using a simple GUI provided by Open3D. We needed a minimum of 3 corresponding points to solve for the translation and rotation between the two sets of points. This was then converted to a homogeneous transformation matrix and used as an initialization of the ICP algorithm. Since the ICP algorithm was previously tested and I had some experience in understanding the parameters to be tuned, getting registration to work was fairly straightforward. Figure 4 shows the two pointclouds prior to registration and figure 5 shows result after registration.

1.3 MPC Commander Node

One of our PR goals was to test out the MPC node in Gazebo. I helped Anthony and Sundaram integrated their pipelines by writing a torque commander interface. This involved setting up virtual effort controllers in simulation. After this, I wrote a simple python script that subscribed to the torque commands coming in from the MPC node and published this to the appropriate topics that actuated the joints.

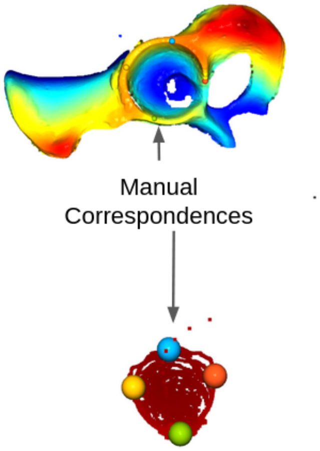


Figure 3: Manual correspondence matching for initial guess

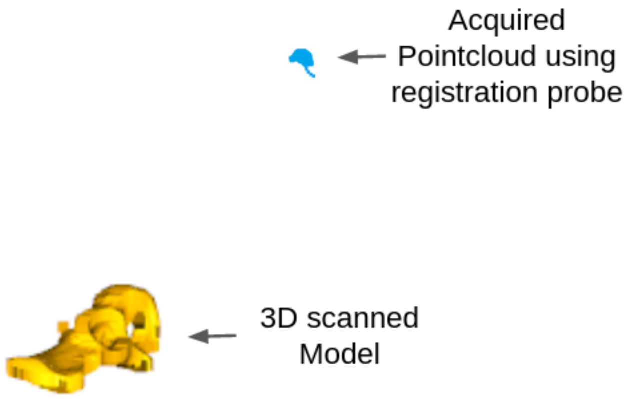


Figure 4: Result prior to registration

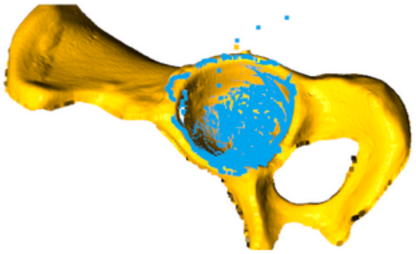


Figure 5: Result after registration

2 Challenges

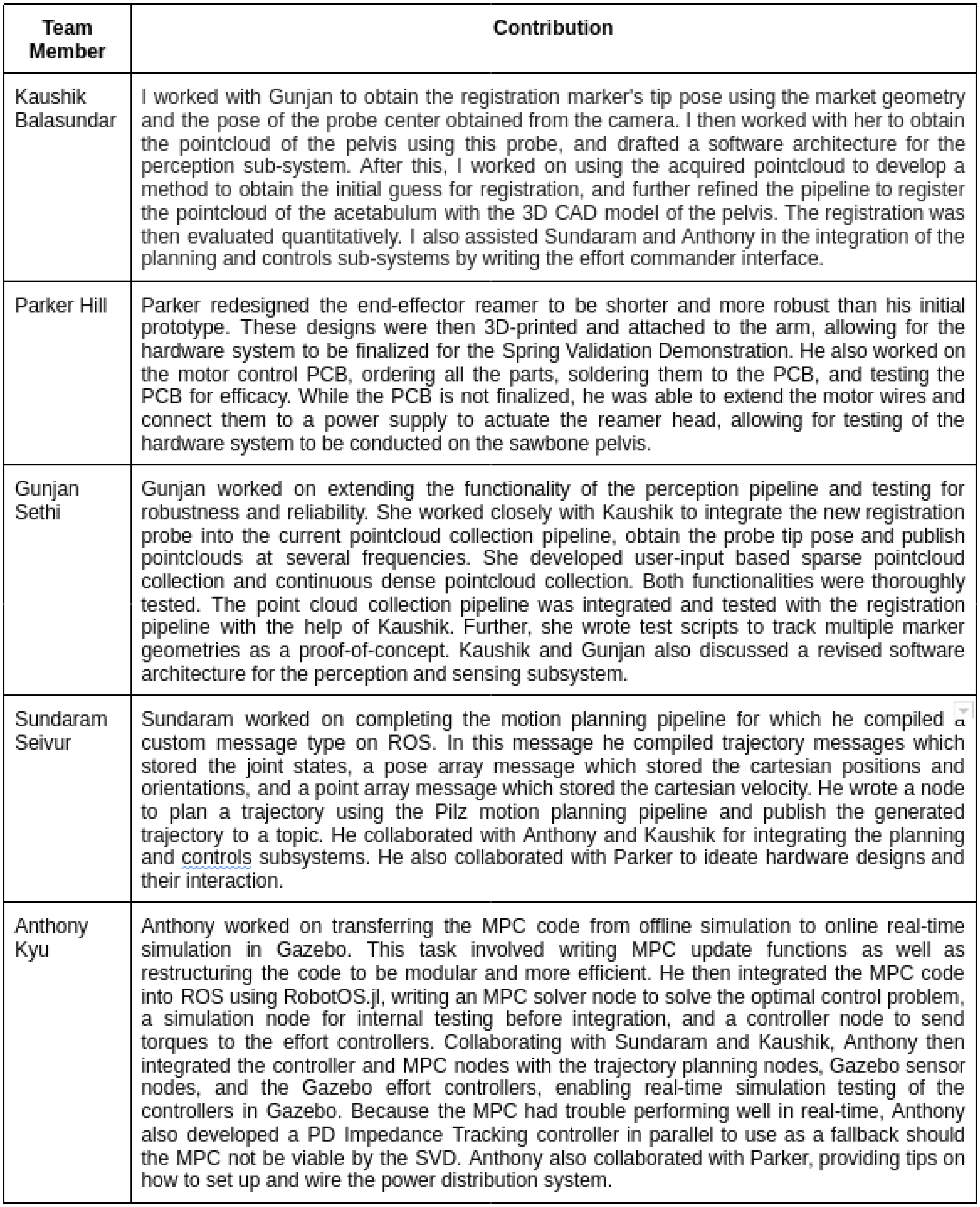
2.1 Registration

The acetabulum surface is a hemisphere and the symmetry makes it difficult for correspondence matching. We still need to finalize a stable method for acquiring points from the acetabulum surface such that matching the correspondences is accurate. The better this initial guess, the better the registration result. The point cloud obtained using the registration was a scaled down mesh (since the units used for distance in ROS is in meters). The 3D scan of the pelvis model was in millimeters, which was giving us issues with registration initially. Once I realized this and scaled both meshes to millimeters, the registration results were much better.

2.2 Integration of Planning and Perception

We need to determine the transformation between the marker attached to the robot arm and the end-effector link. Subsequently, using the transformation tree in ROS, we need to determine the tranformation to the base-link of the robot - which is used as the global frame for planning. Acquiring this transformation accurately is a vital step in our performance requirements. We are exploring different ways to do this including using a CAD assembly, and other online calibration methods.

3 Team Work



Team Member	Contribution
Kaushik Balasundar	I worked with Gunjan to obtain the registration marker's tip pose using the market geometry and the pose of the probe center obtained from the camera. I then worked with her to obtain the pointcloud of the pelvis using this probe, and drafted a software architecture for the perception sub-system. After this, I worked on using the acquired pointcloud to develop a method to obtain the initial guess for registration, and further refined the pipeline to register the pointcloud of the acetabulum with the 3D CAD model of the pelvis. The registration was then evaluated quantitatively. I also assisted Sundaram and Anthony in the integration of the planning and controls sub-systems by writing the effort commander interface.
Parker Hill	Parker redesigned the end-effector reamer to be shorter and more robust than his initial prototype. These designs were then 3D-printed and attached to the arm, allowing for the hardware system to be finalized for the Spring Validation Demonstration. He also worked on the motor control PCB, ordering all the parts, soldering them to the PCB, and testing the PCB for efficacy. While the PCB is not finalized, he was able to extend the motor wires and connect them to a power supply to actuate the reamer head, allowing for testing of the hardware system to be conducted on the sawbone pelvis.
Gunjan Sethi	Gunjan worked on extending the functionality of the perception pipeline and testing for robustness and reliability. She worked closely with Kaushik to integrate the new registration probe into the current pointcloud collection pipeline, obtain the probe tip pose and publish pointclouds at several frequencies. She developed user-input based sparse pointcloud collection and continuous dense pointcloud collection. Both functionalities were thoroughly tested. The point cloud collection pipeline was integrated and tested with the registration pipeline with the help of Kaushik. Further, she wrote test scripts to track multiple marker geometries as a proof-of-concept. Kaushik and Gunjan also discussed a revised software architecture for the perception and sensing subsystem.
Sundaram Seivur	Sundaram worked on completing the motion planning pipeline for which he compiled a custom message type on ROS. In this message he compiled trajectory messages which stored the joint states, a pose array message which stored the cartesian positions and orientations, and a point array message which stored the cartesian velocity. He wrote a node to plan a trajectory using the Pilz motion planning pipeline and publish the generated trajectory to a topic. He collaborated with Anthony and Kaushik for integrating the planning and controls subsystems. He also collaborated with Parker to ideate hardware designs and their interaction.
Anthony Kyu	Anthony worked on transferring the MPC code from offline simulation to online real-time simulation in Gazebo. This task involved writing MPC update functions as well as restructuring the code to be modular and more efficient. He then integrated the MPC code into ROS using RobotOS.jl, writing an MPC solver node to solve the optimal control problem, a simulation node for internal testing before integration, and a controller node to send torques to the effort controllers. Collaborating with Sundaram and Kaushik, Anthony then integrated the controller and MPC nodes with the trajectory planning nodes, Gazebo sensor nodes, and the Gazebo effort controllers, enabling real-time simulation testing of the controllers in Gazebo. Because the MPC had trouble performing well in real-time, Anthony also developed a PD Impedance Tracking controller in parallel to use as a fallback should the MPC not be viable by the SVD. Anthony also collaborated with Parker, providing tips on how to set up and wire the power distribution system.

Figure 6: Contributions by each team member

4 Plans

In the next couple of weeks leading up to SVD, I plan to work on the following:

1. Building a test-rig to validate the marker detection accuracy: One of our tests for marker detection is the accuracy constraint in translation and orientation. For this, we will 3D print a model of known geometry and measure the distance and rotation between known key-points on the model using the camera and markers. We will then validate this against the ground truth to validate our performance requirements.
2. Gunjan and I will integrate the perception and planning pipelines by using the registration transformation result and converting the end-point for reaming to the base frame of the robot for planning a trajectory.
3. I will also help Sundaram and Anthony set up the trajectory evaluation package to validate if the actual trajectory followed by the arm matches the trajectory provided by the Pilz Planner.
4. I will further work with the team in setting up the hardware demonstrations in preparation for SVD.