Individual Lab Report - 2

Autonomous Reaming for Total Hip Replacement

HIPSTER | ARTHuR

Kaushik Balasundar

Team C:

Kaushik Balasundar | Parker Hill | Anthony Kyu
Sundaram Seivur | Gunjan Sethi

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1 Individual Progress

For this week, my focus was primarily on tackling the registration problem. The registration problem can be defined as the process of finding the rigid transformation parameters g (rotation matrix $R \in SO(3)$ and translation vector $t \in R3$) which best aligns the point cloud X to Y. The best alignment can be determined using a predefined distance metric d. Based on the nature of the distance metric used, there are variations of the ICP algorithm.

$$\underset{R \in \mathcal{SO}(3), t \in \mathbb{R}^3}{\arg\min} \|d(X, g(Y))\|_2^2$$

Figure 1: Registration Problem Definition

I started by researching the various available methods for performing registration. I realized the approach to be used depends significantly on whether the pointclouds that need to be registered are coming from the same source or from different sources. If they are from different sources, the following challenges are to be expected:

1. Noise and outliers: Due to different sensor types and acquisition environments, there will be discrepancies in the two pointclouds created.
2. Partial Overlap: It is only possible to retrieve the surface of the acetabulum, and hence will be only a small subset of the pelvis model stored.
3. Density Difference: Due to different imaging resolutions of the sensors capturing the pointclouds

Since in our case the sources are from two different sensors, my research lead me to believe that the best way to perform registration will be using optimization-based approaches. The various other approaches are summarized in the flowchart below.

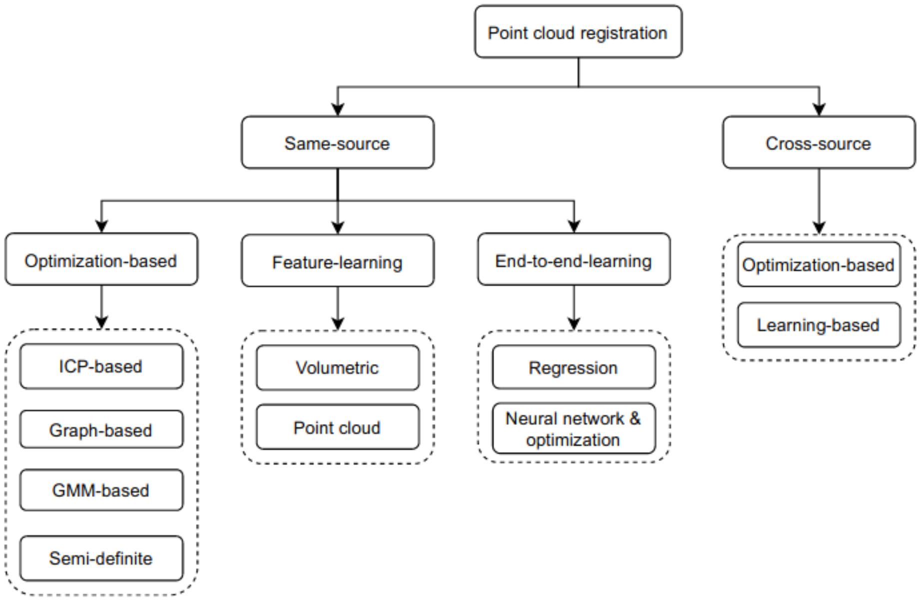

Figure 2: The various registration approaches based on the sources[1]

The most widely documented and used optimization-based registration method is called the Iterative Closest Point (ICP) algorithm. It is also well supported and documented in the pointcloud library we chose for this project, Open3D. I integrated this library with ROS, and also converted a pelvis model to its corresponding pointcloud while extracting out feature points of interest. This algorithm involves two main steps, the first being correspondence matching and the second being the determination of the transformation between the points from pointset A to B. This is summarized in the image below.

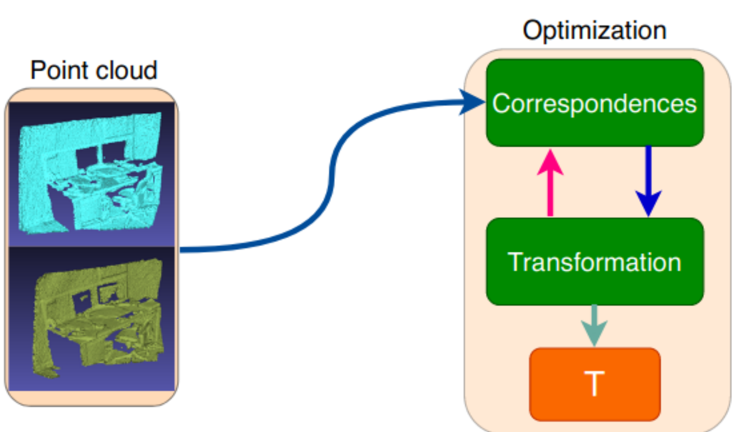

Figure 3: Main steps involved in registration [1]

It is also common practice to involve a RANSAC algorithm to remove outliers from the final registration as a refinement step. The following images show preliminary results of the registration algorithm.

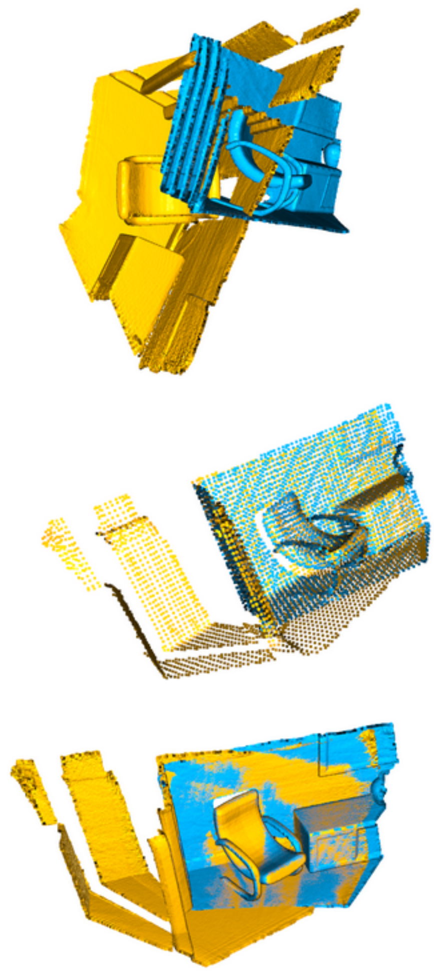

Figure 4: Preliminary registration results showing initial and final pointclouds

2 Challenges

2.1 ICP Registration

While I was able to have ICP working with some toy examples that come with the tutorials, the challenge will be to get it to work in a scenario where the two pointclouds are from different sources and have different properties as mentioned in the previous section. There needs to be a significant amount of post-processing and hyperparameter tuning that needs to be done for the registration to work reliably with two different point clouds of varying density, noise, and resolution. The following two images depict the difference in scale and density:

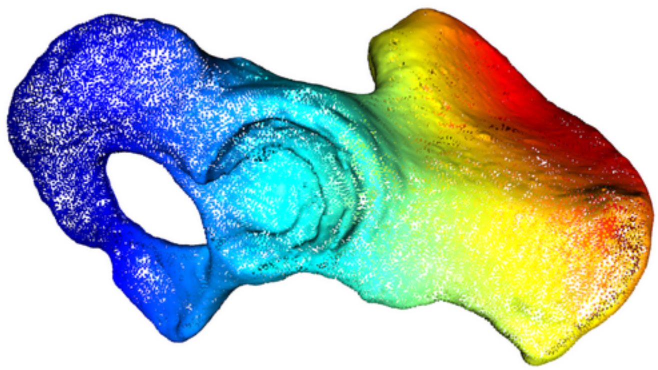

Figure 5: Pelvis model converted to pointcloud

Figure 6: Points extracted from the surface of the acetabulum

2.2 Simulation

Unfortunately, our robot arm was deemed unsuitable to use due to the lack of API support. As a result, most the work I did with the simulation leading to this point is redundant, and needs to be re-done either for the UR5-e robot arm or the Kinova Gen3 robot arm. This is going to be a challenge to complete in the short amount of time before the next progress review. However, there were several things I learned during my previous setup which I hope will save me some time in setting up a similar simulation with a different arm.

3 Team Work

Sl No	Team Member	Contribution
1	Kaushik Balasundar	I worked on the registration problem - researched various types of registration algorithms, integrated Open3D with ROS, wrote a script for converting a mesh file to a point cloud, implemented a preliminary ICP registration algorithm with Open3D for local and global registration, and tested ICP with some toy examples to verify its functionality.
2	Parker Hill	Parker picked up the reamer handle, and elicited motor requirements for the reaming assembly. He created a rough Solidworks CAD model of the reamer and end-effector adapter for use in the preliminary design. He also worked on all aspects of the Power Distribution Board PCB assignment (schematic, board layout, CAD/drawing, and analysis).
3	Gunjan Sethi	Gunjan worked on further developing the ROS package for the Atracsys camera- adding marker pose detection. She is currently trying to resolve some challenges with code reliability during market detection. She tested the camera discovery and geometry file loading functionality for robustness. She also prepared for the progress review #1 by compiling all the progress so far into a presentation.
4	Sundaram Seivur	Sundaram collaborated with Anthony in conceptualizing the optimal control problem for the system. In addition, he went through a significant amount of literature to decide between model-predictive control and hybrid force position control. He also was the primary point of contact in facilitating a new arm for the team to use.
5	Anthony Kyu	He worked on the high level controls architecture, designing the block diagram, defining constraints for our controls system, and creating the linear dynamics for our model predictive control. When designing this, he collaborated and brainstormed a lot with Sundaram.He collaborated with Parker on the PCB, sanity checking his circuit and pointing out some key issues that may have led to shorts. He also brainstormed a few ideas for mechanical design with Parker to mount the reamer to the end-effector. It should be noted, however, that Parker took lead on both the PCB and mechanical design.

Figure 7: Contributions by each team member

4 Plans

In the next couple of weeks leading up to the progress review 2, I plan to work on the following:

1. Pointcloud Registration: I will be working on further improving the results and reliability of the ICP registration process when dealing with cross-source pointclouds. I will explore various post-processing methods and hyperparameter tuning to do this.
2. Simulation Environment: I will also take lead in ensuring that my team has a reliable URDF and simulation environment of the new arm so that motion planning and controls work don't get delayed any further. This will also involve me setting up the IKFast inverse Kinematics plugin for the arm since I have some prior experience doing this.
3. I also plan to be the presenter for the next progress review, and thus will be working on ensuring that all the tests planned for the next review are executed promptly.

References

[1] Huang, Xiaoshui, et al. "A comprehensive survey on point cloud registration." arXiv preprint arXiv:2103.02690 (2021)