April 27, 2022

HIPSTER

Spring Validation Demonstration - Encore

Autonomous Reaming for Total Hip Replacement (ARTHuR)

The Team

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Perception and Sensing Lead

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Mechanical Systems Engineering Lead

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Controls and Actuation Lead

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Trajectory Planning Lead

Contents
(what's changed)

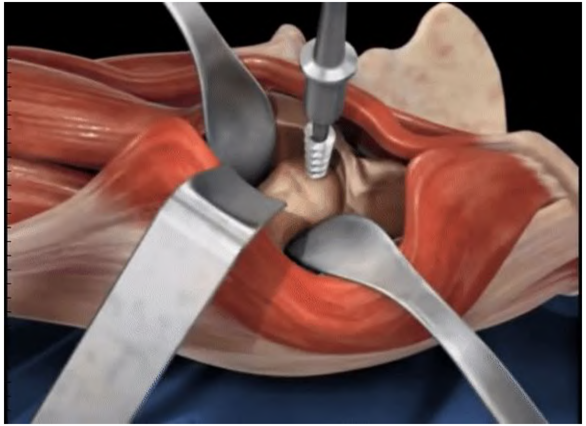
Use Case

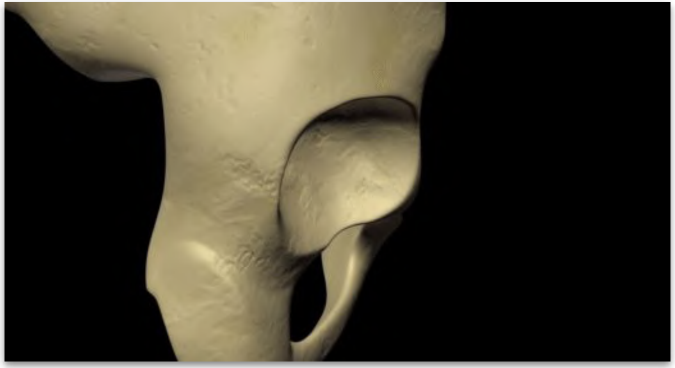
01

Of the 100 manual surgeries, **30-45% of them observed the implant within the Lewinnek safe zone** and of the 100 robotic-assisted surgeries, **77% were within the safe zone.**

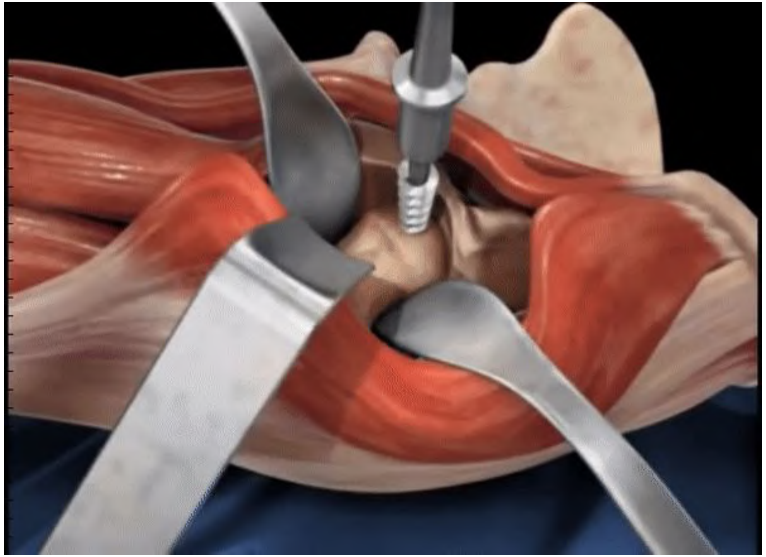
02

Study on the future projections on the number of total joint replacements in the US, show that up until 2040, **we can expect an increase in the requirement of a THR for both sexes by approximately 280%.**





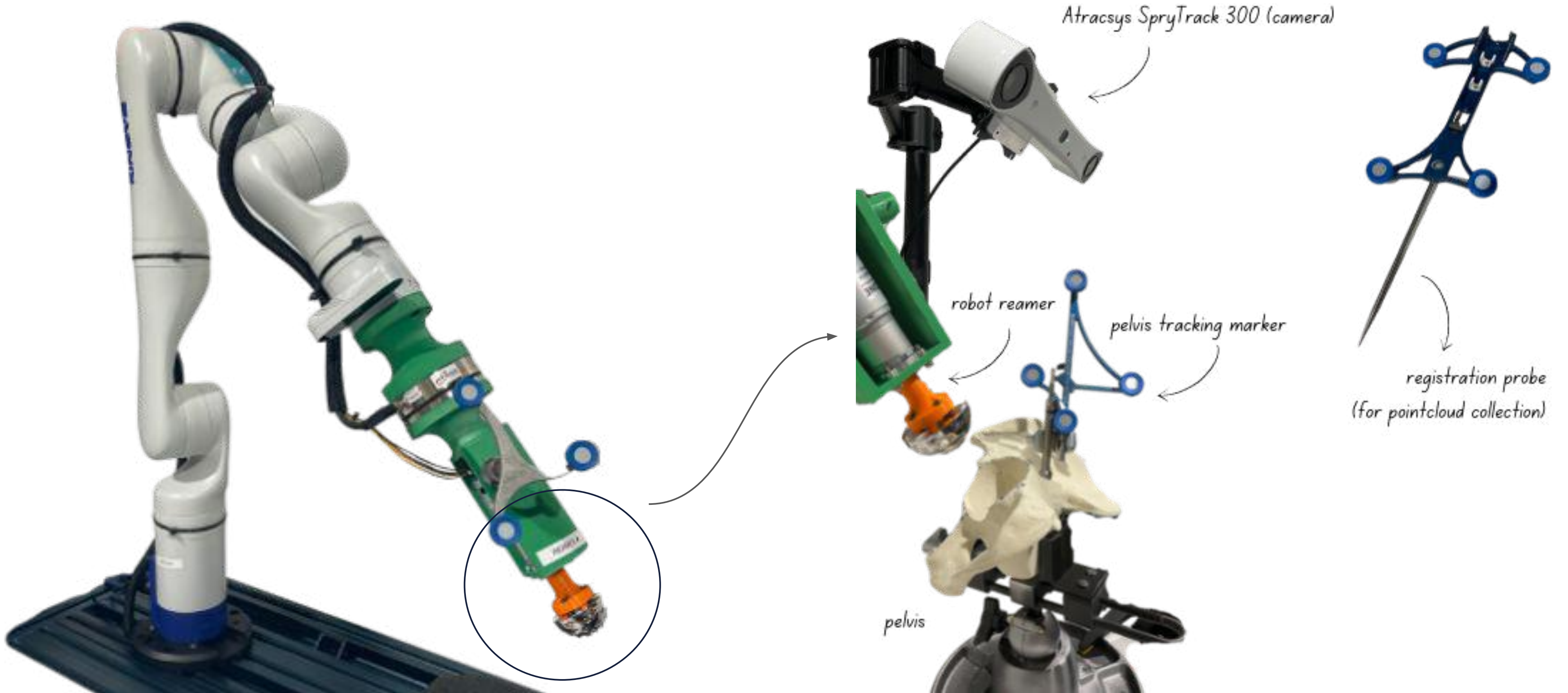
Manual Reaming Demonstration



Overview

A **fully autonomous** robotic arm aimed at performing acetabular reaming with **high accuracy**, eliminating the need of surgeons to use intuition to correctly position/angle the reamer.

Workspace

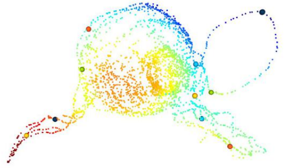


Atracsys SpryTrack 300 (camera)
robot reamer
pelvis tracking marker
registration probe
(for pointcloud collection)
pelvis

Improvements for Encore

Force Feedback

Improved Motor Mount



Sparser Pointcloud for registration (2000 points)

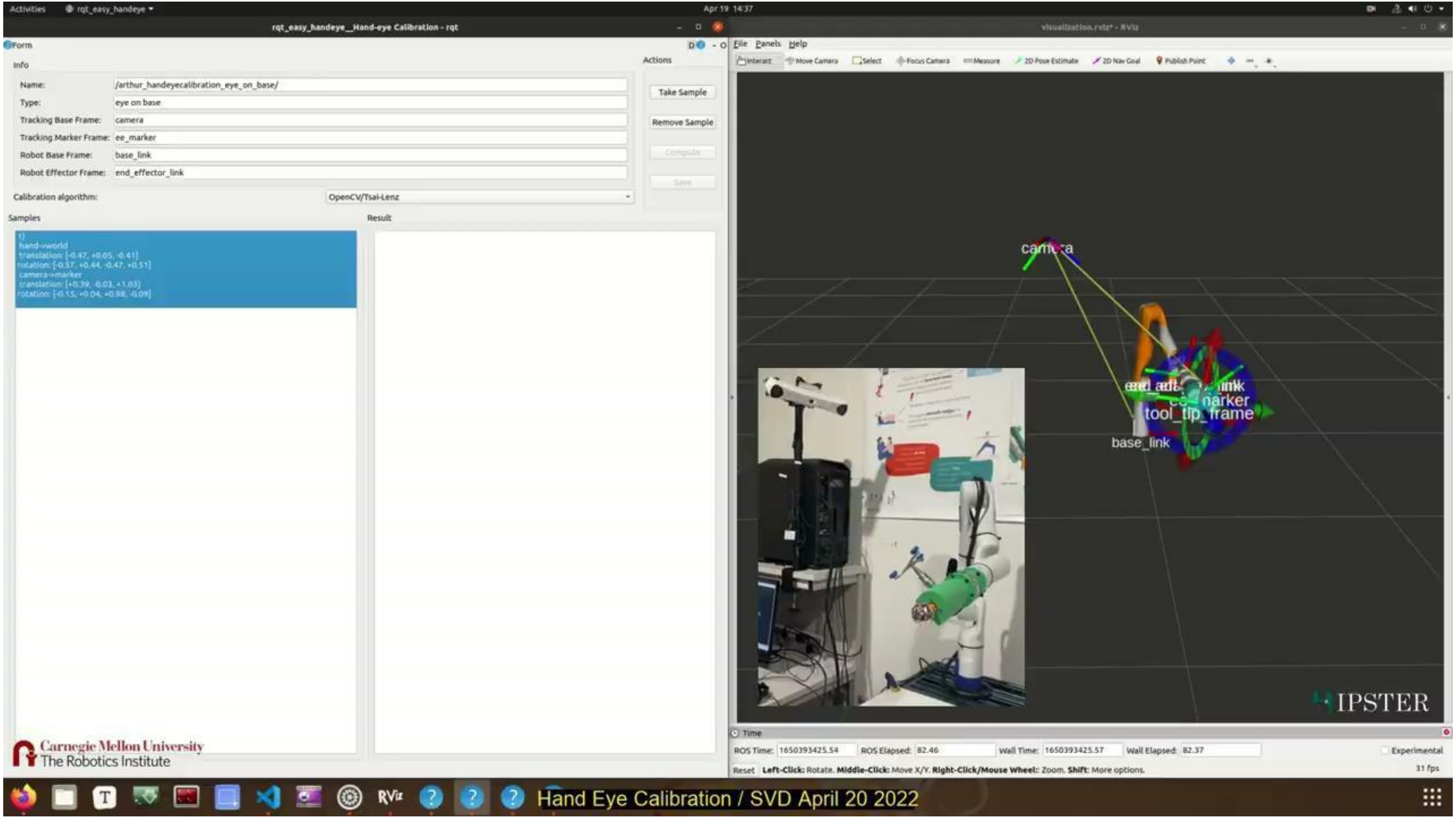
More realistic surgical setting

Tests

- Hand-Eye Calibration (Recorded)
- Free Motion Mode
- Pointcloud Collection
- Landmark Selection + Registration
- Planning
- Controls
- Dynamic Compensation
- Reaming the Pelvis

Hand-Eye Calibration

- **Objective**: Find transformation between /base_link (world) frame of robot and /camera frame
- Eye-on-base problem
- Marker used as calibration target
- Calibration done using OpenCV library's Tsai-Lenz algorithm implementation



rqt_easy_handeye__Hand-eye Calibration - rqt
Info
Name: /arthur_handeyecalibration_eye_on_base/
Type: eye on base
Tracking Base Frame: camera
Tracking Marker Frame: ee_marker
Robot Base Frame: base_link
Robot Effector Frame: end_effector_link
Calibration algorithm: OpenCV/Tsai-Lenz
Actions
Take Sample
Remove Sample
Compute
Save
Samples
Result
1)
hand->world
translation: [-0.47, +0.05, -0.41]
rotation: [-0.57, +0.44, -0.47, +0.51]
camera->marker
translation: [+0.39, -0.03, +1.03]
rotation: [-0.15, +0.04, +0.98, -0.09]
visualization.rviz* - RViz
File Panels Help
Interact Move Camera Select Focus Camera Measure 2D Pose Estimate 2D Nav Goal Publish Point
camera
tool_tip_frame
base_link
Time
ROS Time: 1650393425.54 ROS Elapsed: 82.46 Wall Time: 1650393425.57 Wall Elapsed: 82.37
Reset Left-Click: Rotate. Middle-Click: Move X/Y. Right-Click/Mouse Wheel:: Zoom. Shift: More options.
31 fps
Carnegie Mellon University
The Robotics Institute
Hand Eye Calibration / SVD April 20 2022

Free-Motion Mode

Free motion mode will allow the surgeon to **move the end-effector to the patient's acetabulum** before executing the trajectory. The robot arm stays in place unless the surgeon moves it by hand.


The patient moves due to reaming forces.
The robot automatically aligns with the moved pelvis (dynamic compensation)
Anatomical Terms
KINOVA
Free Motion Mode / SVD 20 April 2022
Carnegie Mellon University
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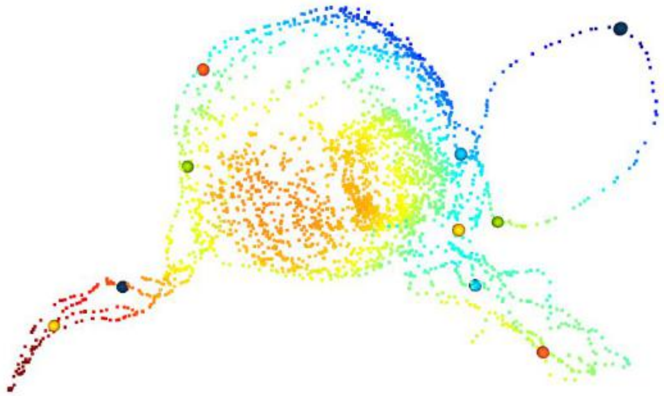
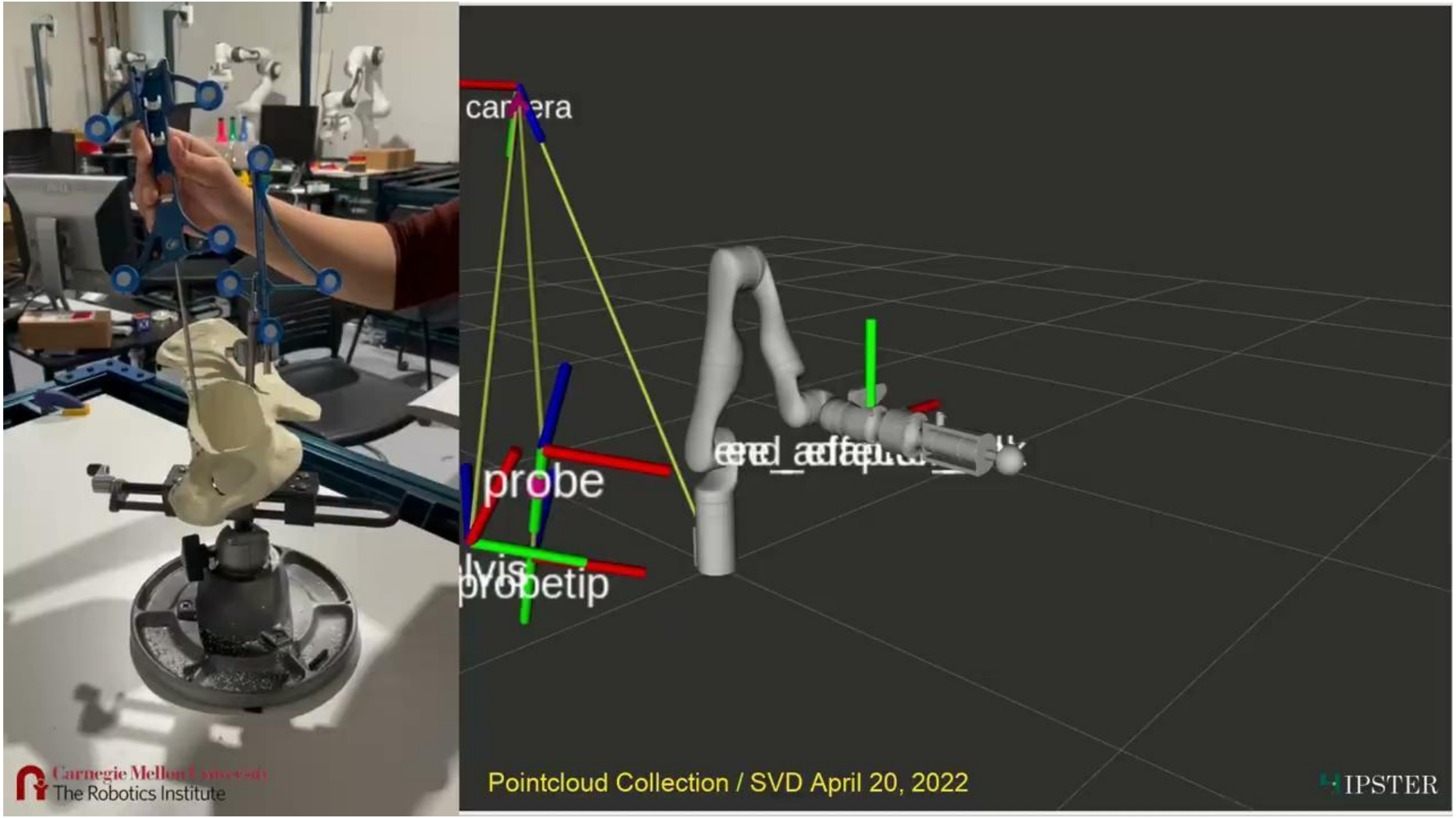
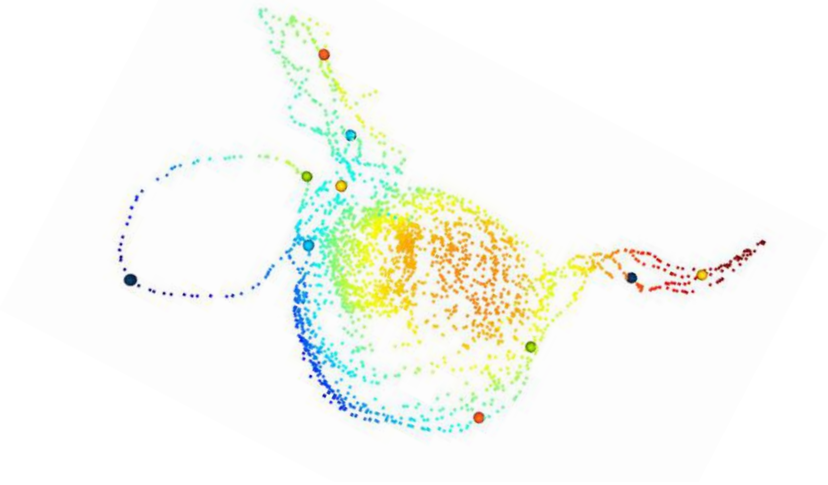
Pointcloud Collection

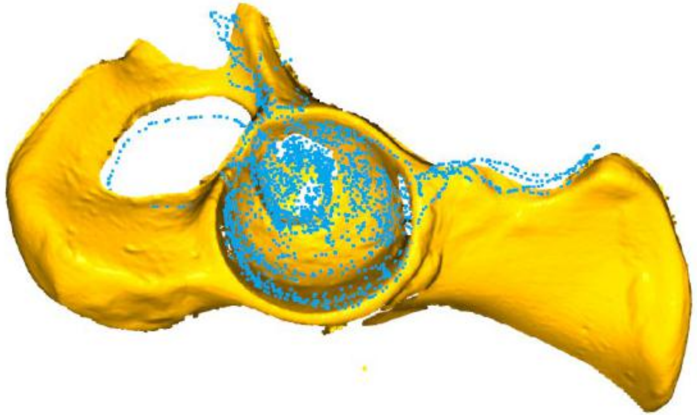


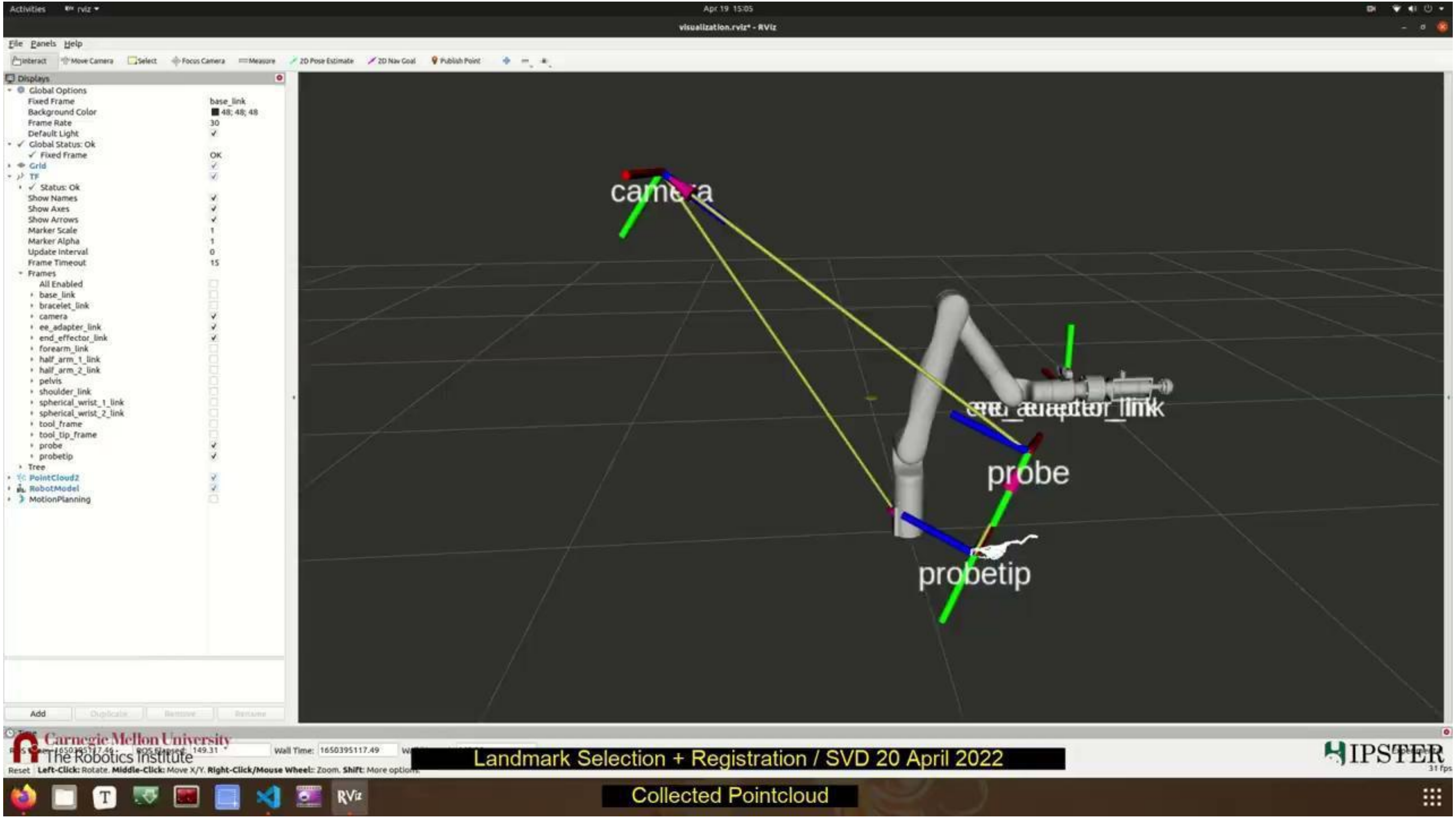


probe
probetip
Pointcloud Collection / SVD April 20, 2022
The Robotics Institute

Landmark Selection + Registration



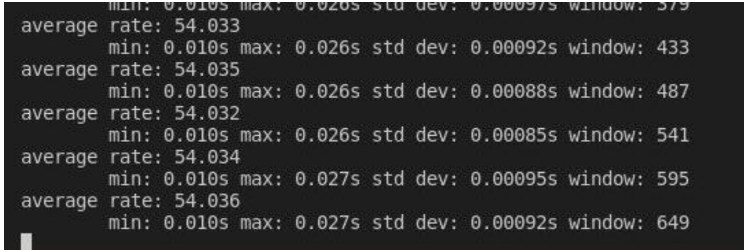


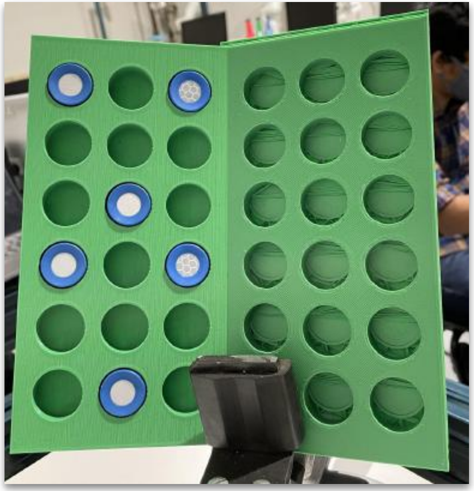


visualization.rviz* - RViz
File Panels Help
Interact Move Camera Select Focus Camera Measure 2D Pose Estimate 2D Nav Goal Publish Point
Displays
Global Options
Fixed Frame base_link
Background Color 48; 48; 48
Frame Rate 30
Default Light
Global Status: Ok
Fixed Frame OK
Grid
TF
Status: Ok
Show Names
Show Axes
Show Arrows
Marker Scale 1
Marker Alpha 1
Update Interval 0
Frame Timeout 15
Frames
All Enabled
base_link
bracelet_link
camera
ee_adapter_link
end_effector_link
forearm_link
half_arm_1_link
half_arm_2_link
pelvis
shoulder_link
spherical_wrist_1_link
spherical_wrist_2_link
tool_frame
tool_tip_frame
probe
probetip
Tree
PointCloud2
RobotModel
MotionPlanning
Add
camera
probe
probetip
Wall Time: 1650395117.49
Reset Left-Click: Rotate. Middle-Click: Move X/Y. Right-Click/Mouse Wheel:: Zoom. Shift: More options.
Carnegie Mellon University
The Robotics Institute
Landmark Selection + Registration / SVD 20 April 2022
HIPSTER
Collected Pointcloud

Latency & Error Detection

- **Latency Test Procedure**
  1. Clamp test model to Vention table.
  2. Place a fiducial marker on the robot's end-effector.
  3. Record the end-effector marker's pose from the camera.
  4. Record time to get end-effector pose.
- **Error Detection Test Procedure**
  1. Place a marker in the initial slot on the test model. Record its pose.
  2. Move the marker to the planar slot. Record its pose.
  3. Move the marker to the slanted slot. Record its pose.
  4. Record computed translation and orientation error for the new marker positions.





Latency & Error Detection

Performance Requirement:

Position Error **<= 3mm**

Orientation Error **<= 3 degrees**

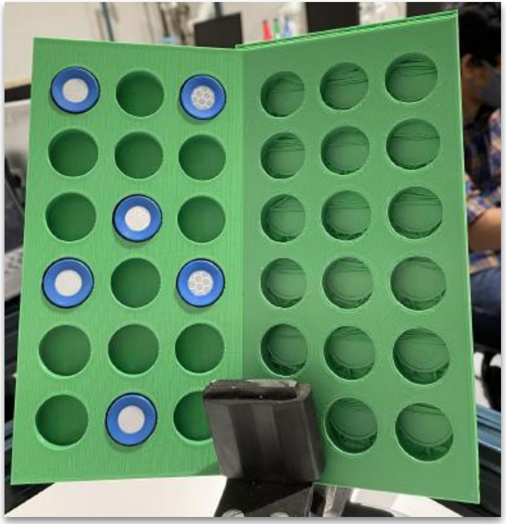
Latency **< 500 ms**

Current System Performance:

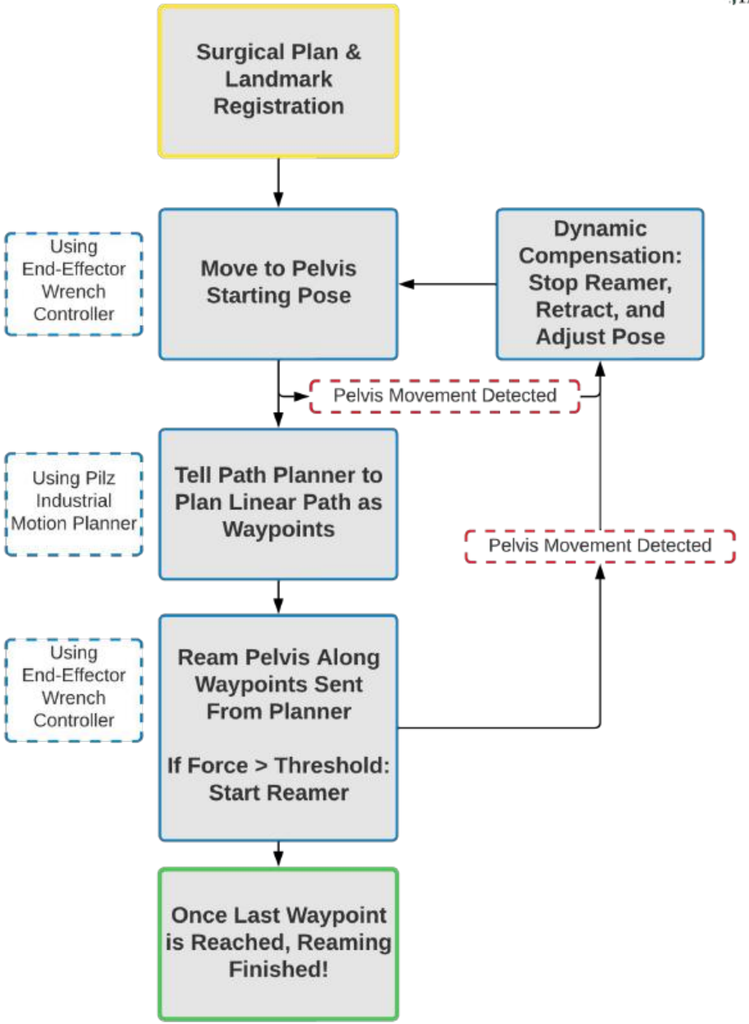
Position Error **<= 2mm**

Orientation Error **<= 3 degrees**

Latency **~ 20 ms**



Planning, Controls and Reaming (Encore)




Reaming Operation
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Dynamic Compensation

ARTHuR constantly **checks for any movement of the patient** above a certain threshold and **re-plans the trajectory** of reaming if that threshold were to be crossed.


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Dynamic Compensation / SVD 20 April 2022
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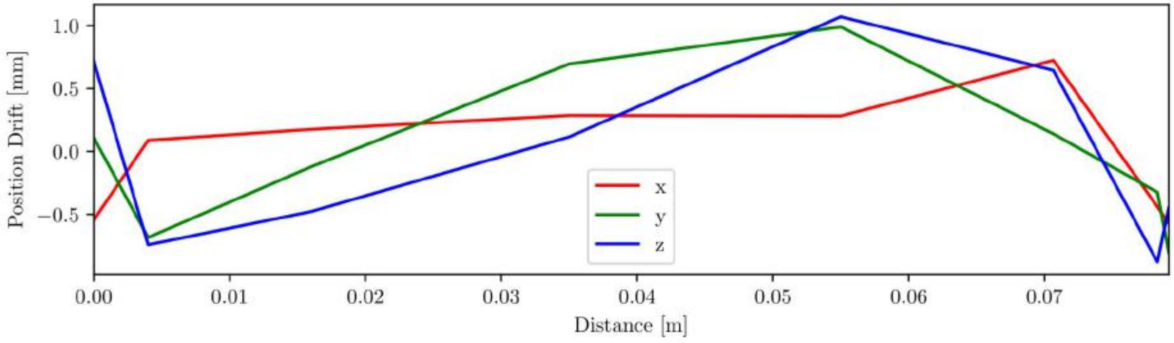
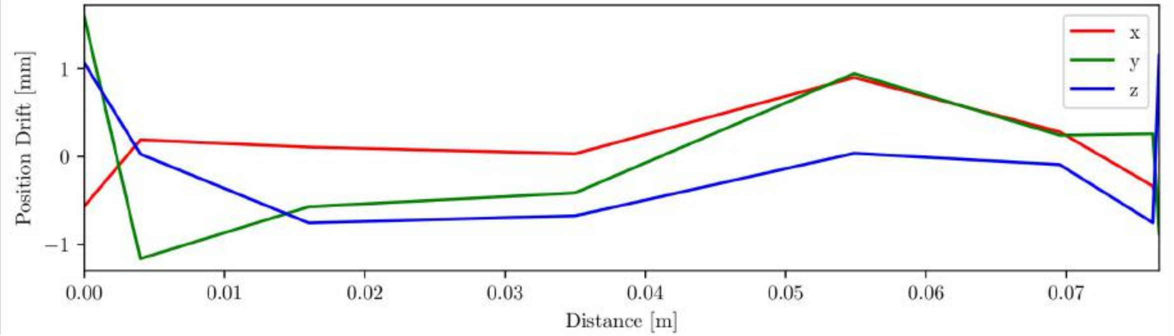
Trajectory Evaluation



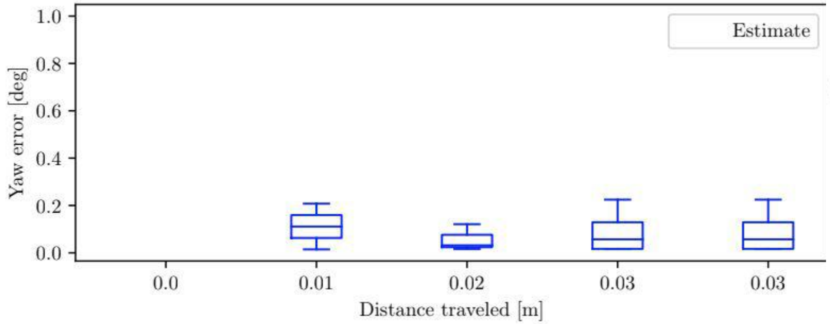
Test 1

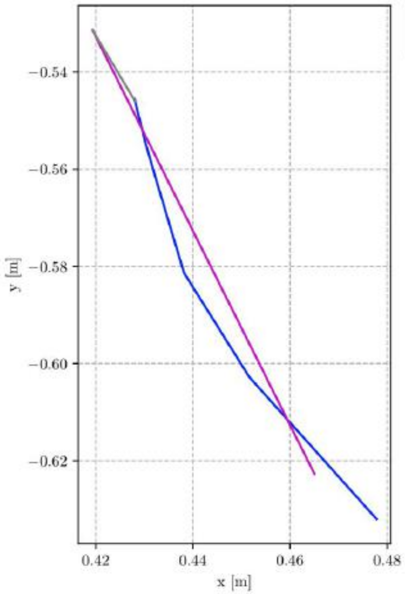


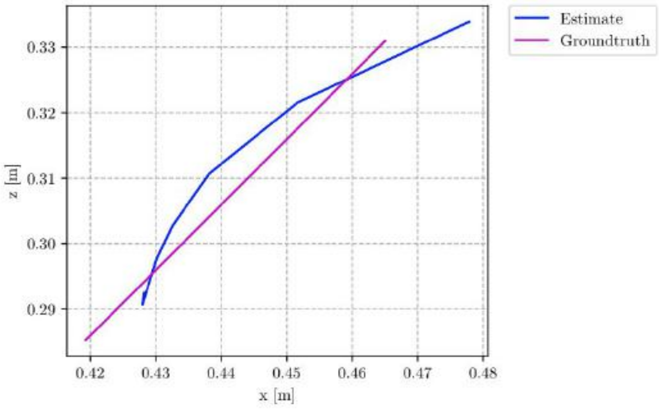
Test 2

	Req	Current
x	3mm	1.5mm
y	3mm	2.4mm
z	3mm	1.8mm

Trajectory Evaluation







Orientations threshold: **3 degrees (rpy)**

Hardware Design

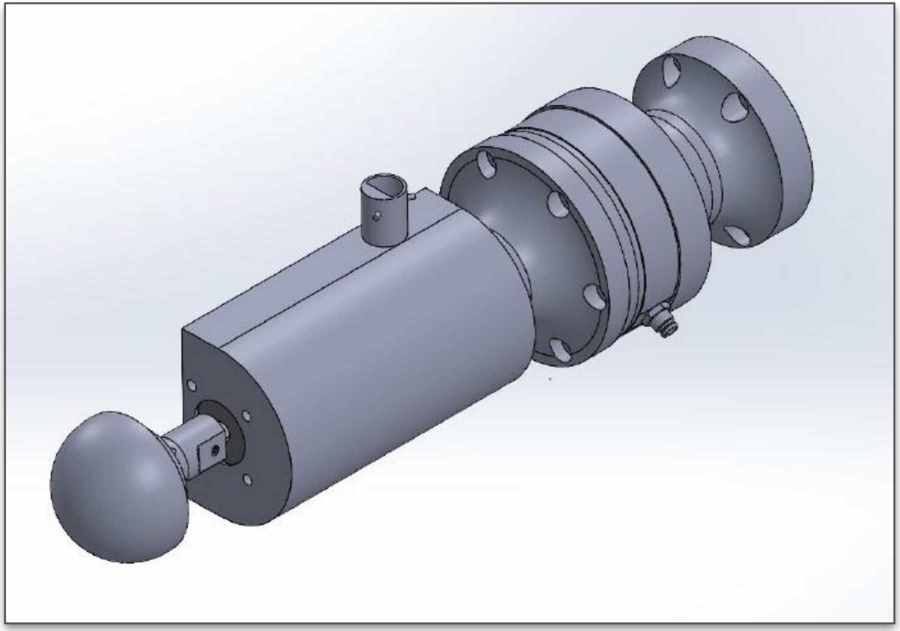
End-Effector Design

Updated Design:

- Shortened original design to increase robustness and accuracy
- Enclosed motor housing for increased sanitization

Parts Necessary for Design:

- Force-Torque sensor
- Motor which can run at 400 rpm while outputting 0.5 Nm of torque
- Fiducial marker mount for camera-base registration
- Reamer head
- Reamer head adapter
- Motor mount
- Force-Torque adapter



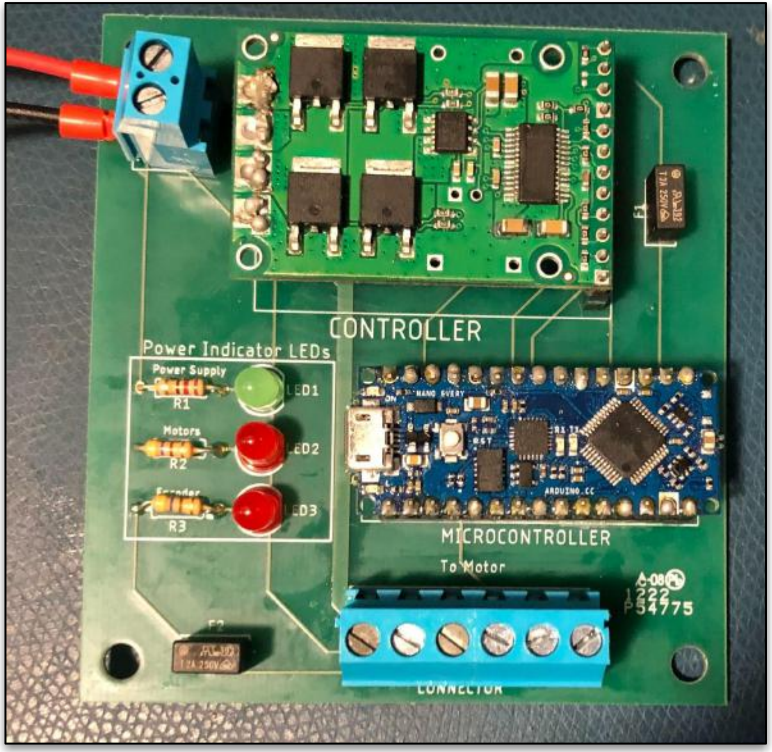
PCB Design

Functionality:

- Needed to be able to turn on and control the motor utilizing ROS
- Further, needed the motor to maintain a consistent rpm during the reaming operation

Parts:

- Pololu 1457 -> Cytron MD10C
- Arduino Nano
- Header Blocks
- Fuses
- LEDs
- Resistors
- Power Supply

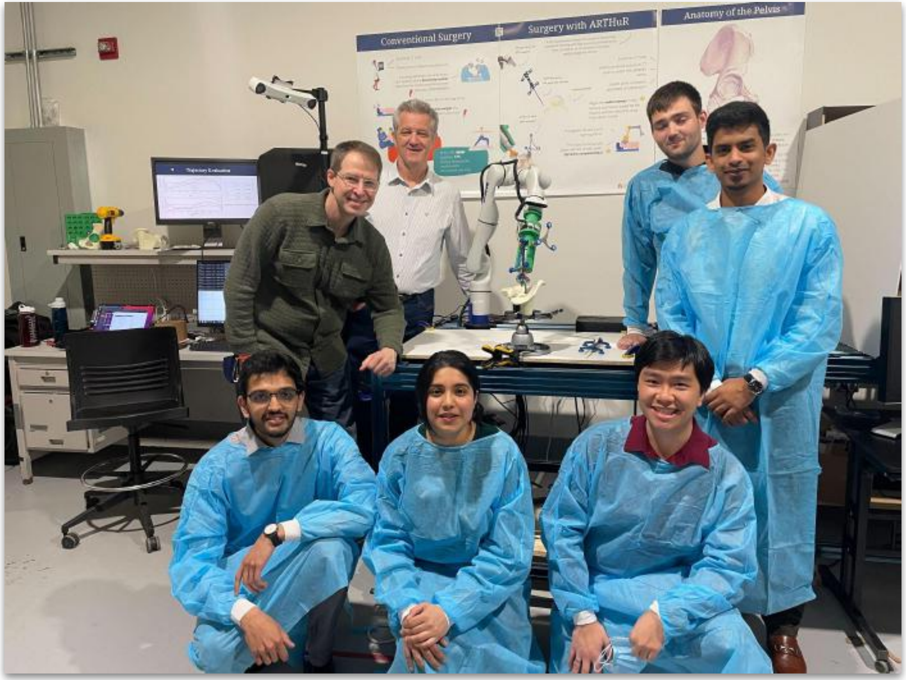


Changes for Fall Validation

Changes for Fall Validation

- Full **User Interface** which allows surgeons to easily interface with the system
- Full **PCB redesign** to integrate all components into one package
- Redesign to the **end-effector**:
  - Want to try different motor orientations (perpendicular orientation)
  - Potentially have stabilization rods
  - Machine out of aluminum or manufacture from plastics
- **Dynamic compensation** which occurs during the reaming operation (no replanning)
- Improved overall performance:
  - Reaming sawbones (closer bone approximate)
  - Faster planning
  - More accurate execution
- If time permits, implement **model predictive control** into our control system

Thank You!
See you next semester :)



Autonomous Reaming for Total Hip Replacement (ARTHuR)