April 20, 2022

IPSTER

Spring Validation Demonstration

Autonomous Reaming for Total Hip Replacement (ARTHuR)

The Team

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Trajectory Planning Lead

Contents

Use Case

01

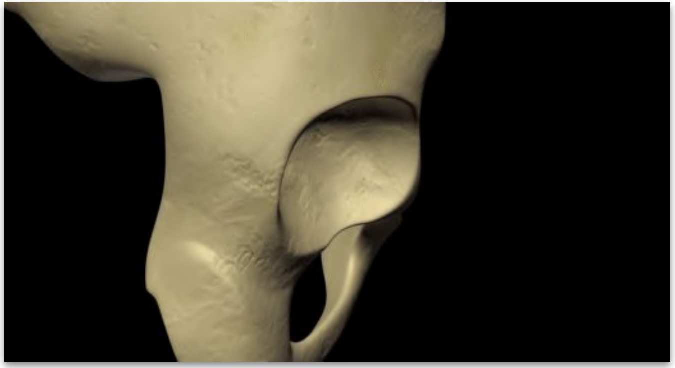
Of the 100 manual surgeries, **30-45% of them observed the implant within the Lewinnek safe zone** and of the 100 robotic-assisted surgeries, **77% were within the safe zone.**

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%.**

A doctor may recommend hip replacement if there exists significant ***pain***, ***inflammation*** and ***damage to the hip joint*** due to conditions such as:

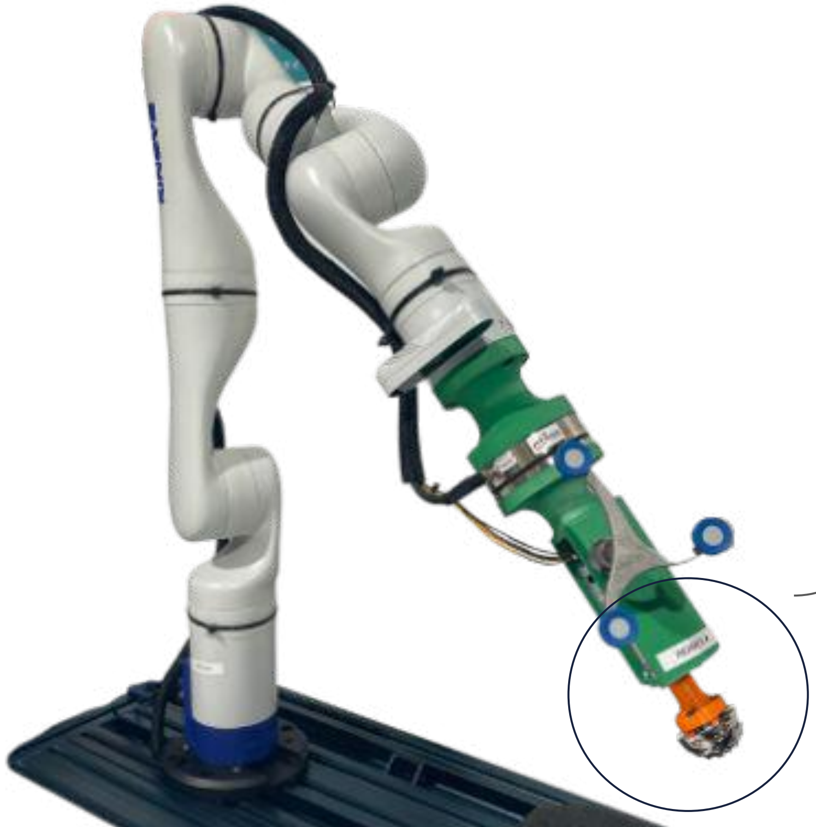
- Osteoarthritis (most common)
- Rheumatoid arthritis
- Osteonecrosis (avascular necrosis)
- Injury such as hip fracture
- Tumor in the hip joint

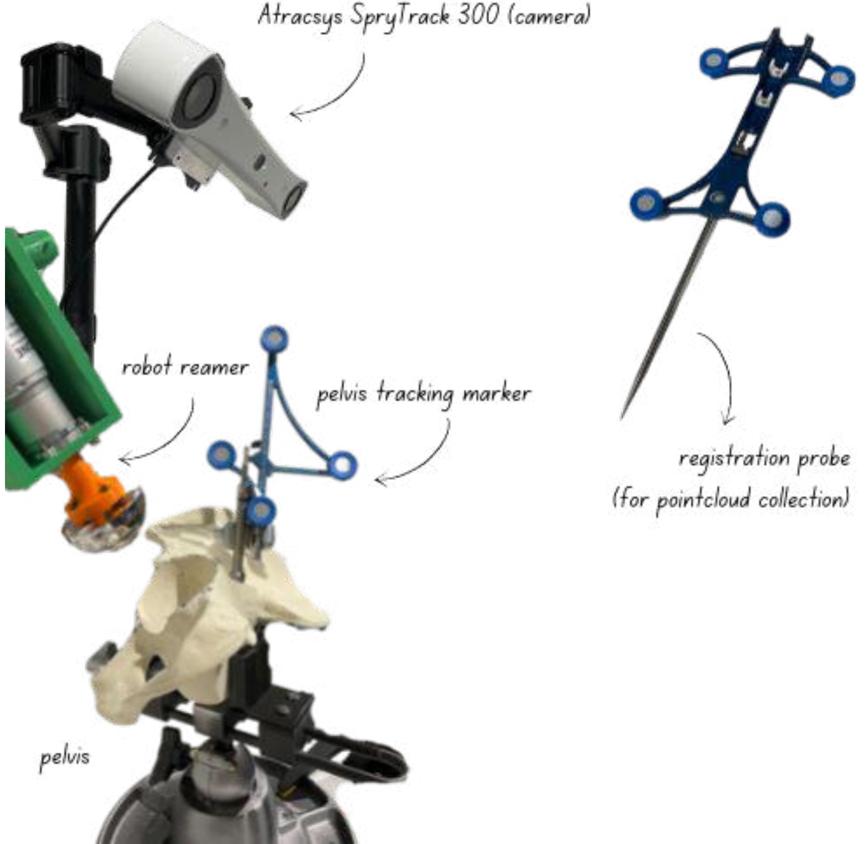


Overview

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



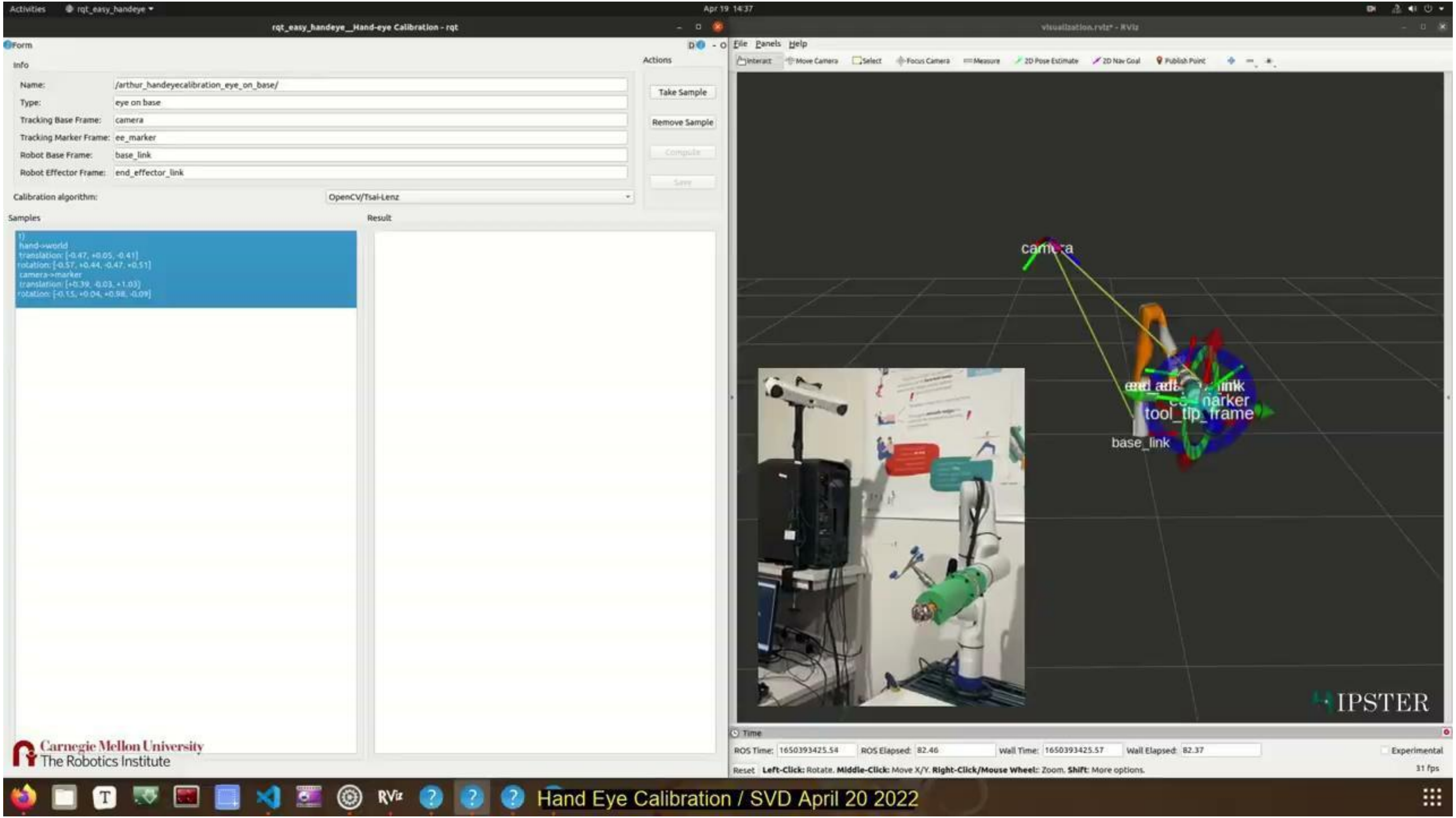

Atracsys SpryTrack 300 (camera)
robot reamer
pelvis tracking marker
registration probe
(for pointcloud collection)
pelvis

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


Activities
rqt_easy_handeye
Apr 19 14:37
rqt_easy_handeye__Hand-eye Calibration - rqt
Form
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
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]
Result
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
IPSTER
Time
ROS Time: 1650393425.54 ROS Elapsed: 82.46 Wall Time: 1650393425.57 Wall Elapsed: 82.37
Experimental
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
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Free Motion Mode / SVD 20 April 2022
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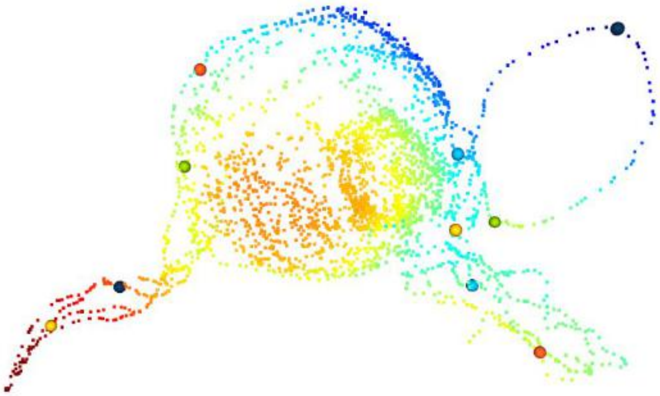
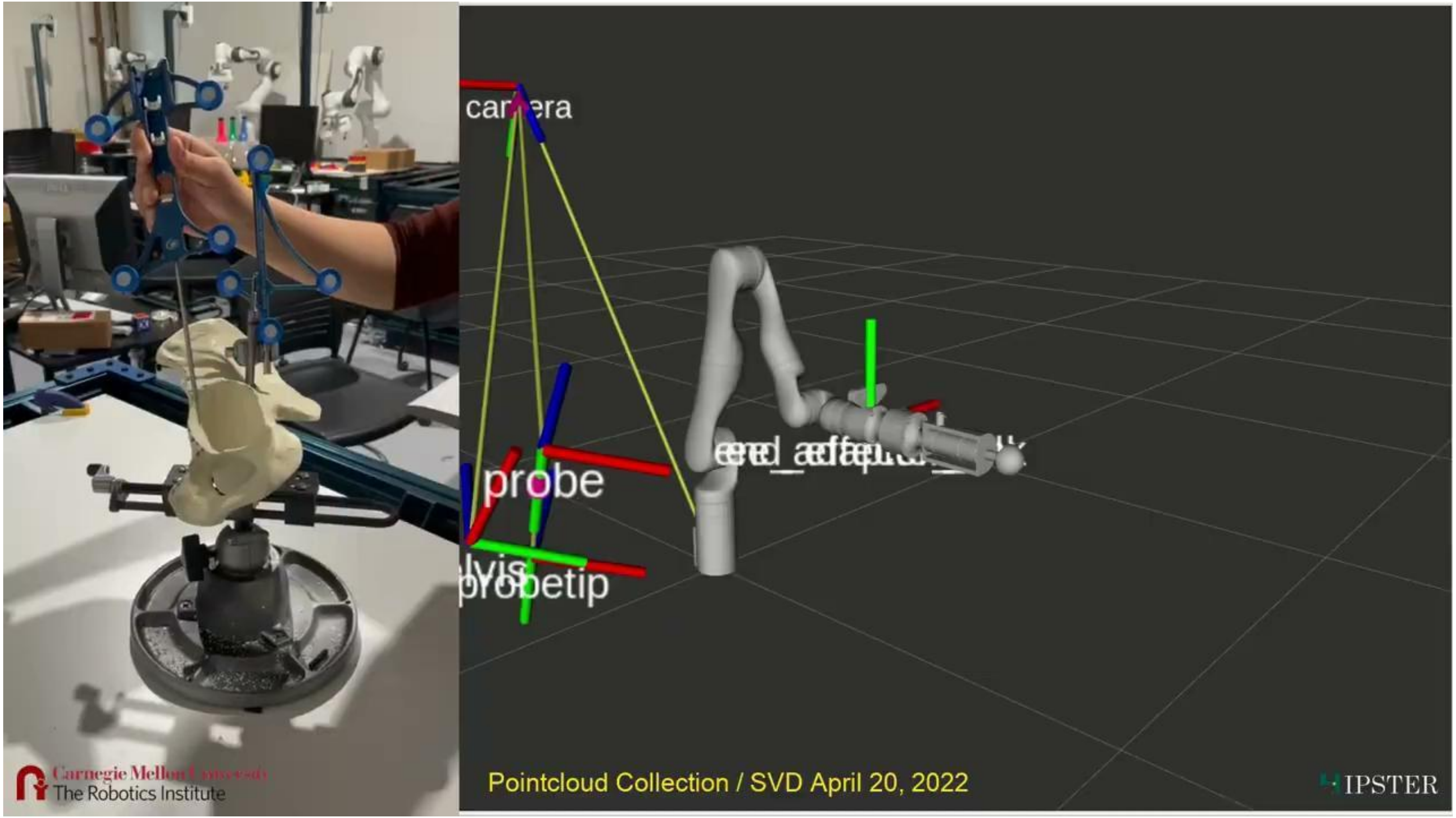
Pointcloud Collection




camera
probe
probetip
Pointcloud Collection / SVD April 20, 2022
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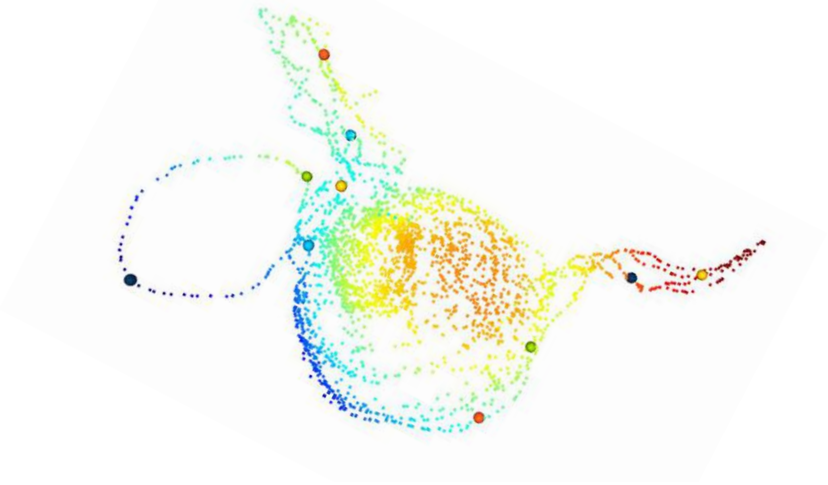
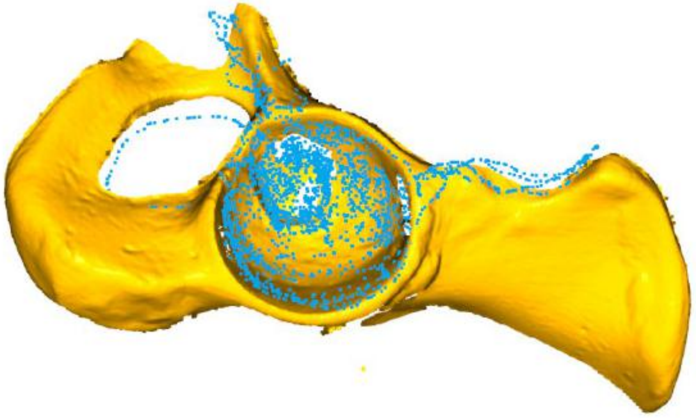
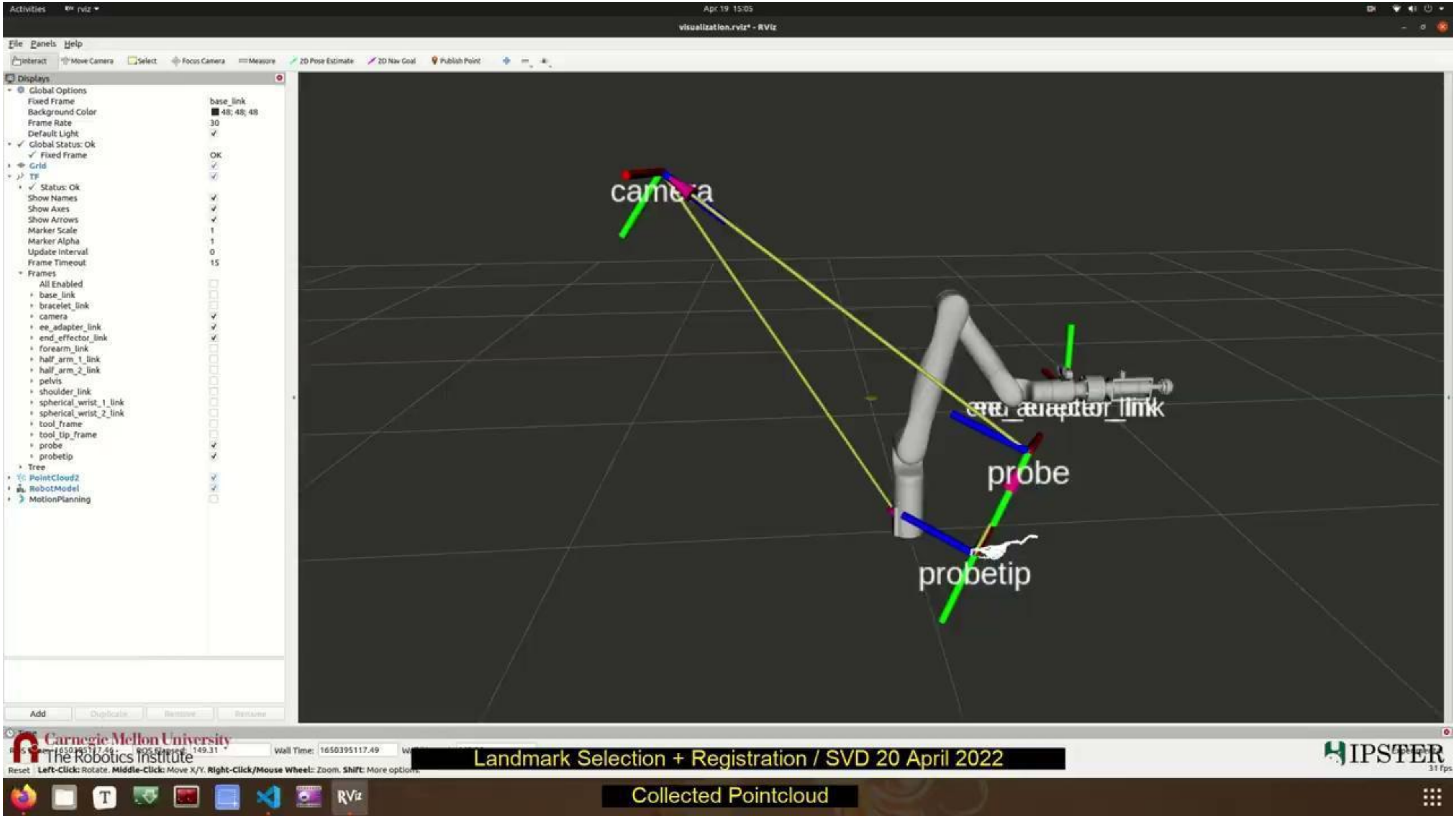
Landmark Selection + Registration






visualization.rviz* - RViz
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
Marker Alpha
Update Interval
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
camera
probe
probetip
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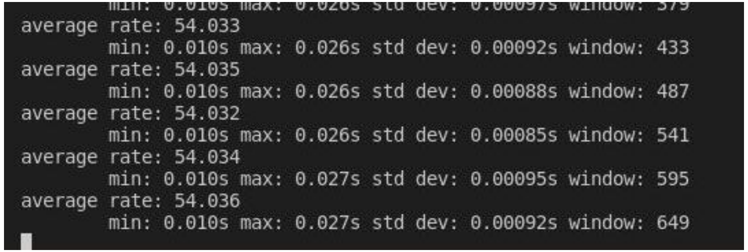
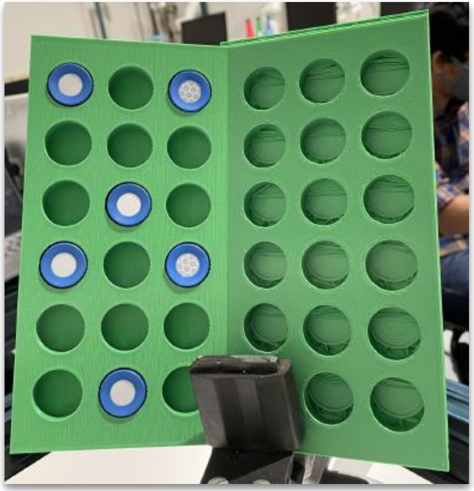
Wall Time: 1650395117.49
Reset Left-Click: Rotate. Middle-Click: Move X/Y. Right-Click/Mouse Wheel:: Zoom. Shift: More options.
Landmark Selection + Registration / SVD 20 April 2022
Collected Pointcloud

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.

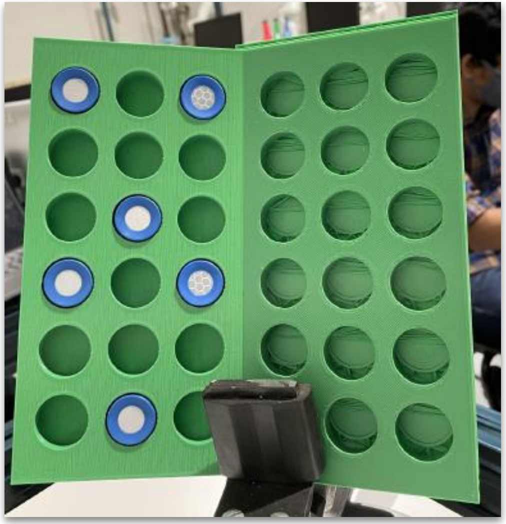




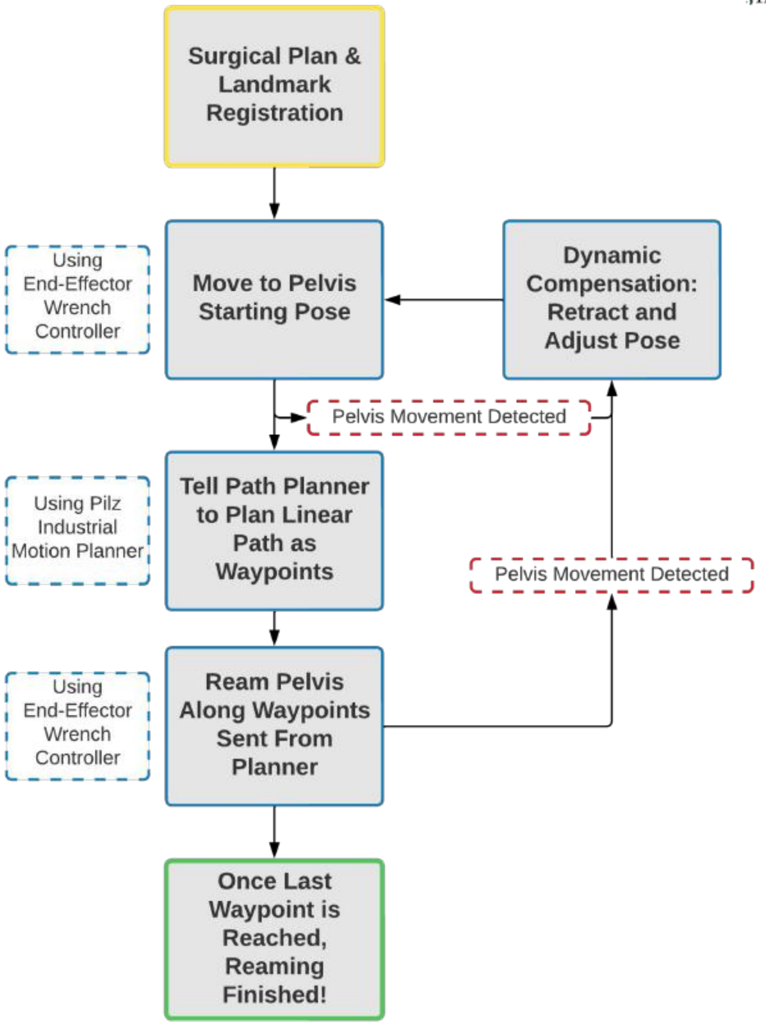
Latency & Error Detection

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




Reaming Operation
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Dynamic Compensation

During total hip replacement surgery, the forces acting on the patient while reaming are high due to which the patient moves. 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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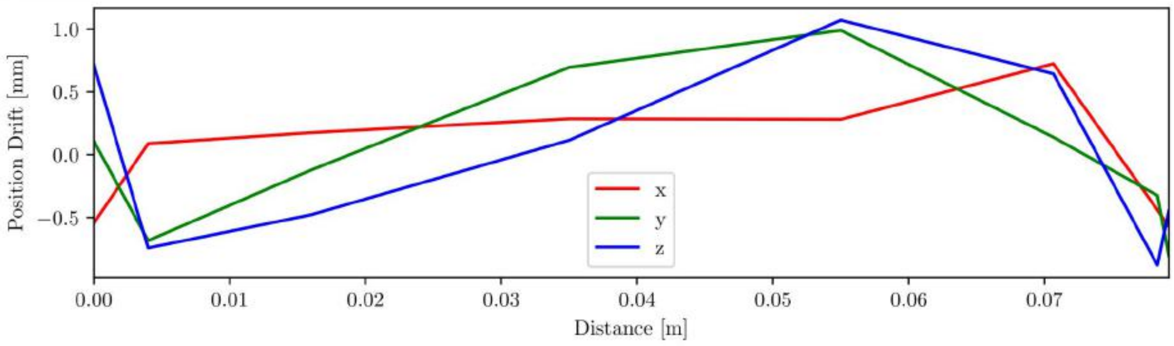
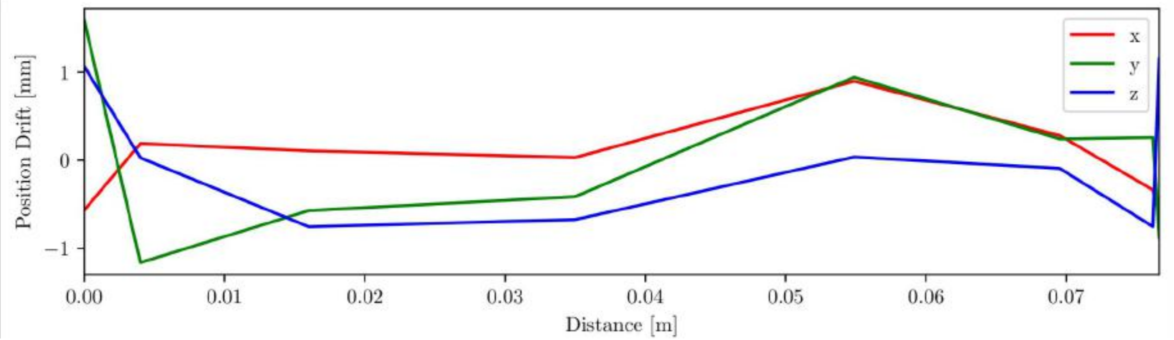
Trajectory Evaluation



Test 1



Test 2

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

Orientations threshold: **5 degrees (rpy)**

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Questions and Discussion

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