HIPSTER

Autonomous Reaming for Total Hip Replacement

Fall Validation Demonstration

November 30, 2022

Team C

November 21, 2022

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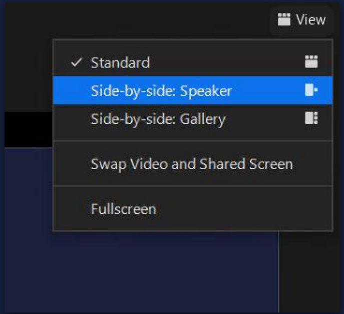
Zoom Viewers please mute your microphone and turn off your video! Thank you!

Recommended Zoom Settings:



Zoom Viewing Info:

- Presentation Cam - screenshare of slide presentation
- System Cam - video which highlights system

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Autonomous Reaming for Total Hip Replacement

Fall Validation Demonstration

November 30, 2022

Team C

The Team

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Perception and Sensing Lead

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Mechanical Systems Engineering Lead

Anthony Kyu

Controls and Actuation Lead

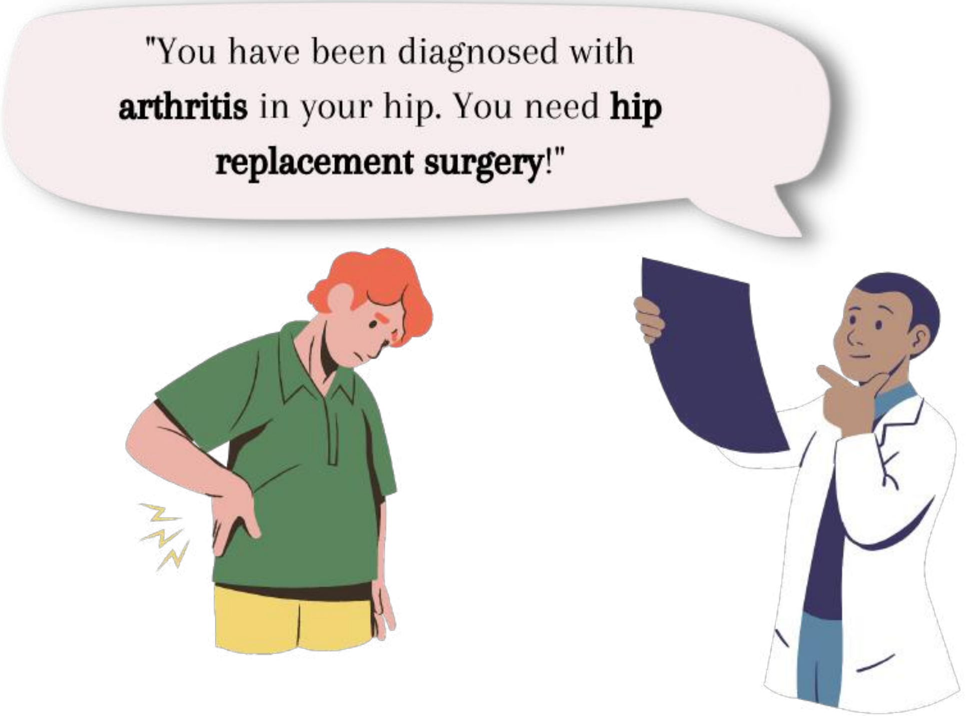
Gunjan Sethi

Software Engineering Lead

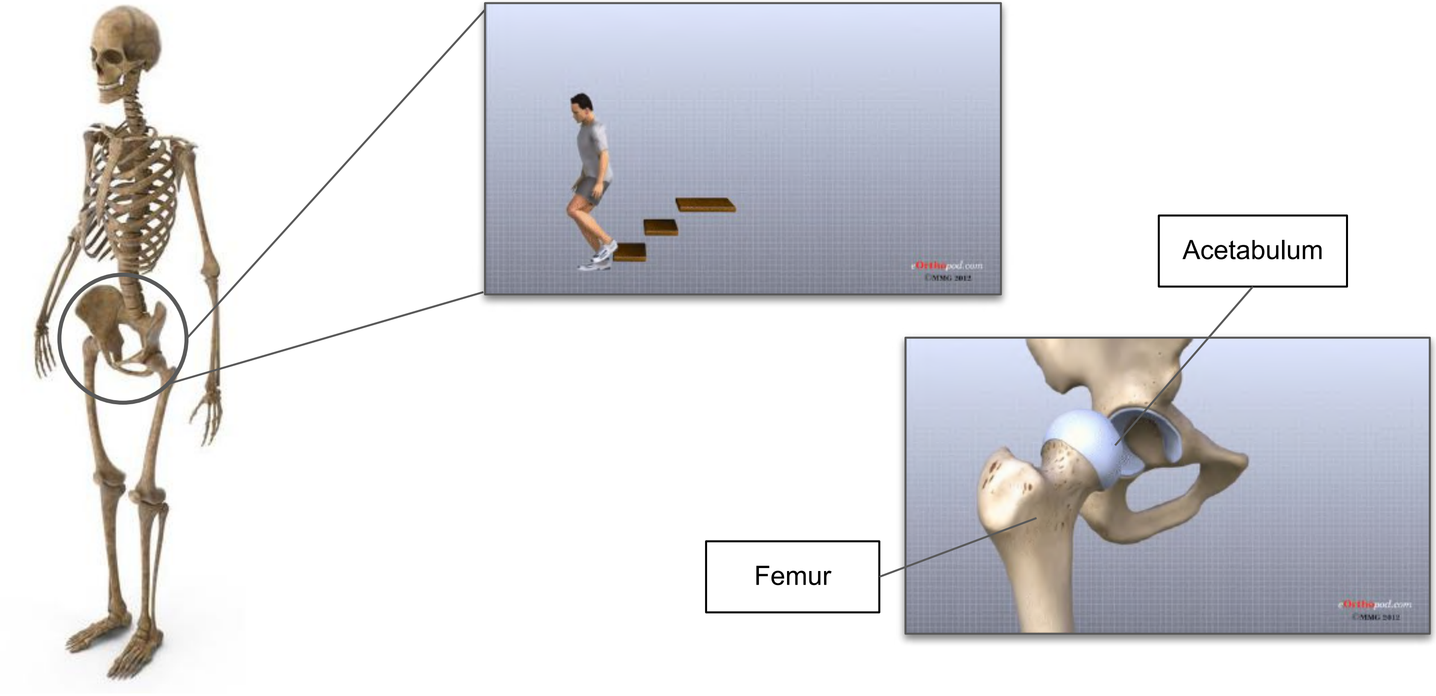
Sundaram Seivur

System Validation Lead

Total Hip Replacement

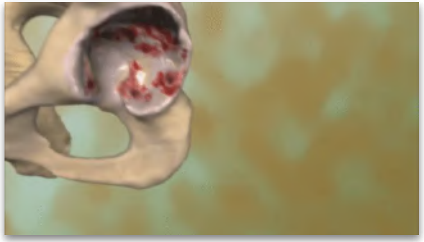


Total Hip Replacement

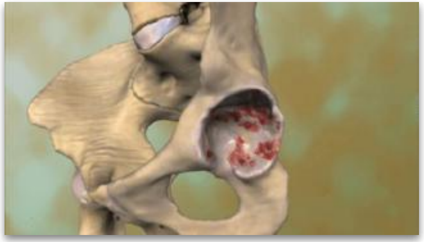


Media Credits: Hip Anatomy Animated Tutorial

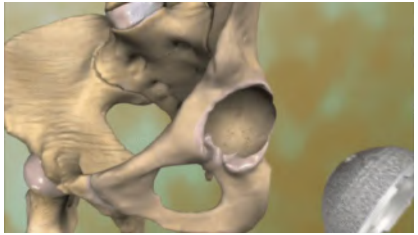
Total Hip Replacement



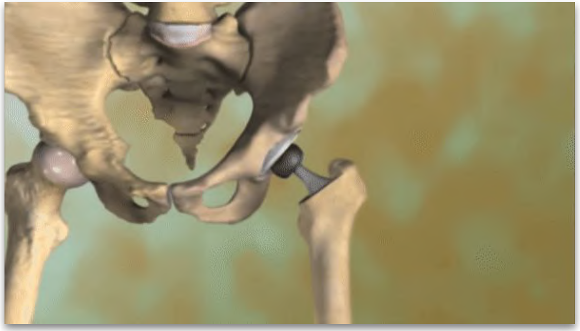
Bone within acetabulum is damaged and must be removed



A reamer is used to remove bad bone



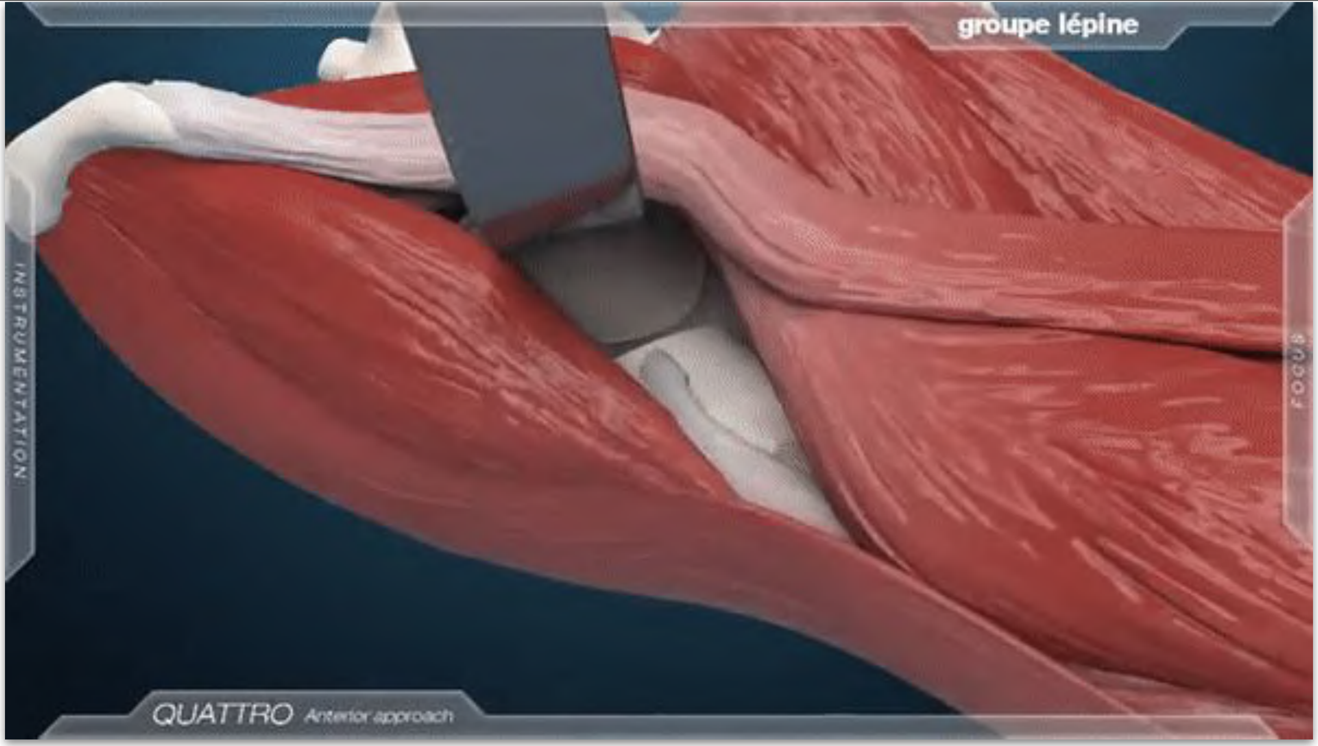
Acetabular implant is fitted



Femur implant fitted, surgery complete!

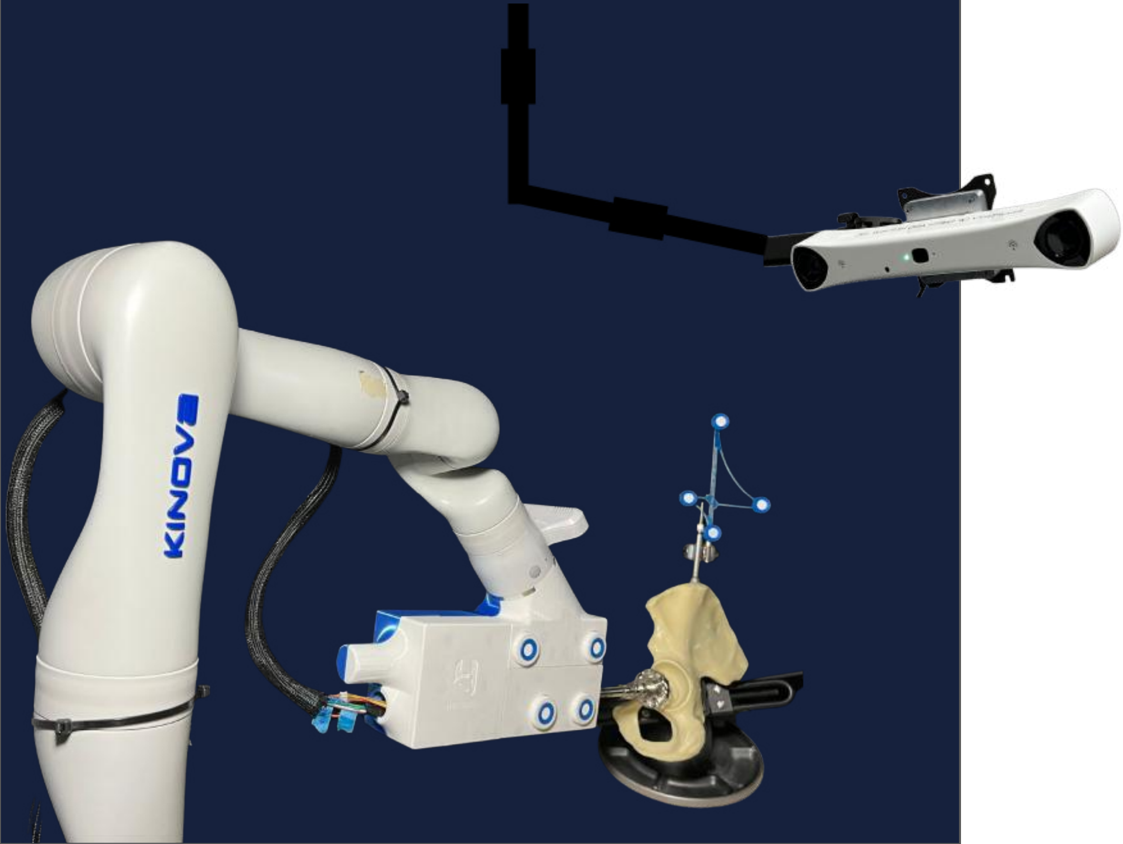
Media Credits: Total Hip Replacement

Total Hip Replacement

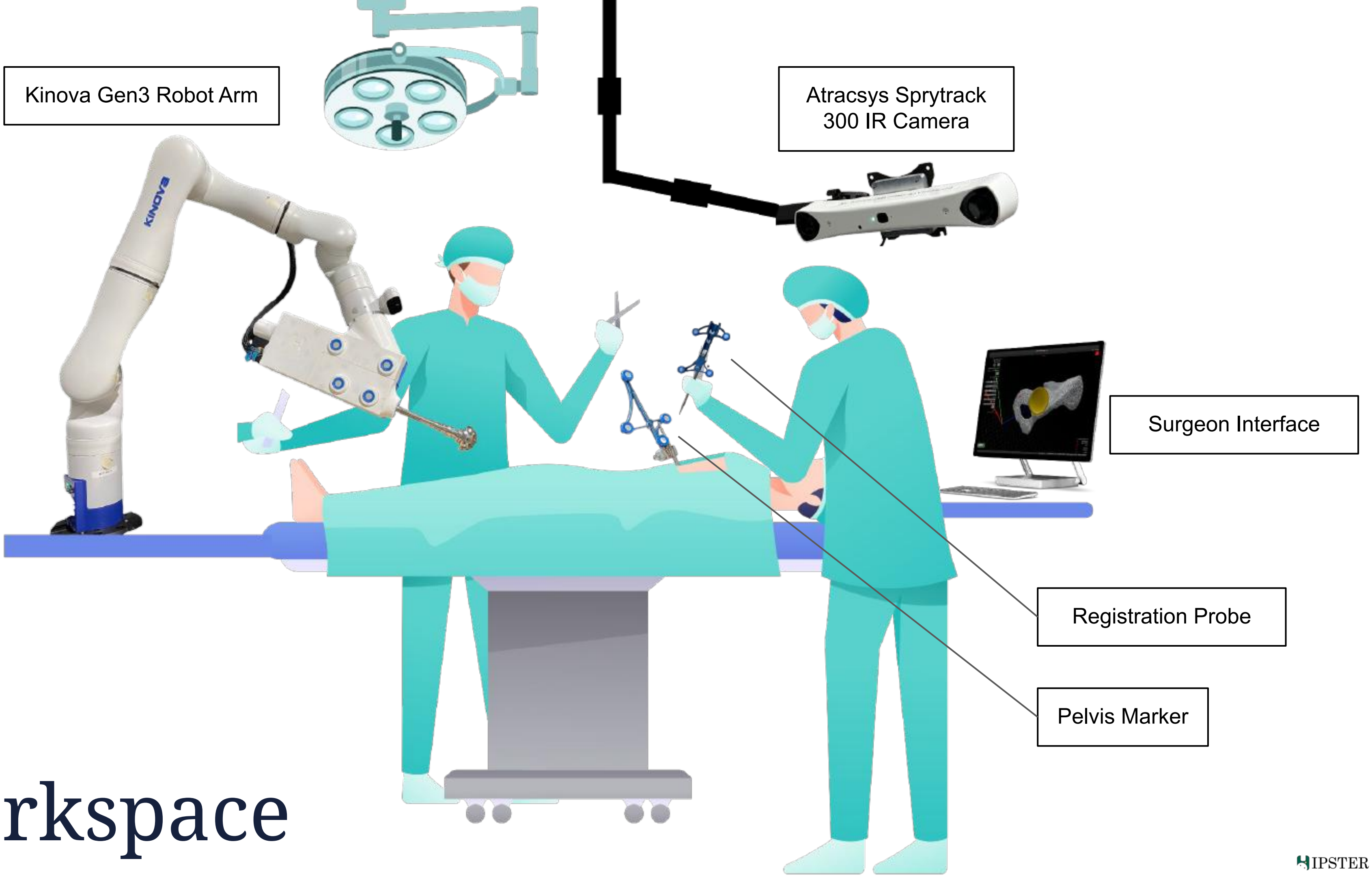


But surgeons can hardly see the acetabulum and a lot of forces are involved in reaming!

Our Solution



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.


Kinova Gen3 Robot Arm
Atracsys Sprytrack
300 IR Camera
Surgeon Interface
Registration Probe
Pelvis Marker

Workspace

Why is the pelvis in that? Why are there sandbags?

Ballistics gel simulates how bone moves within soft tissue

We want to replicate pelvis motion within a human body as accurately as possible!

Sandbags simulate how the patient body moves during surgery

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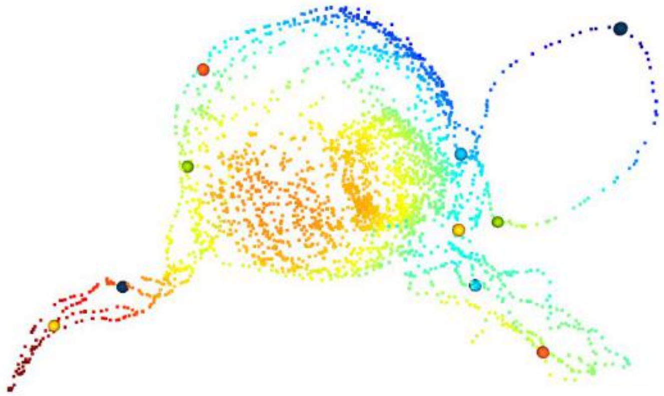
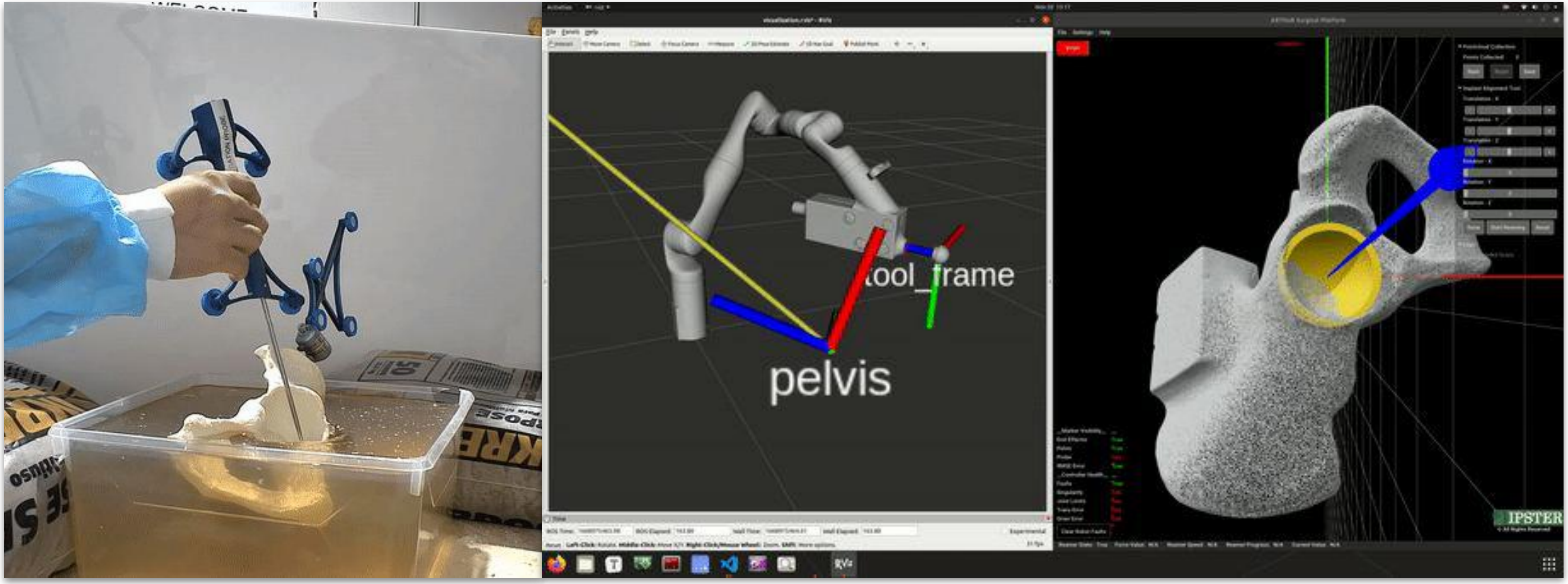
Pointcloud Collection





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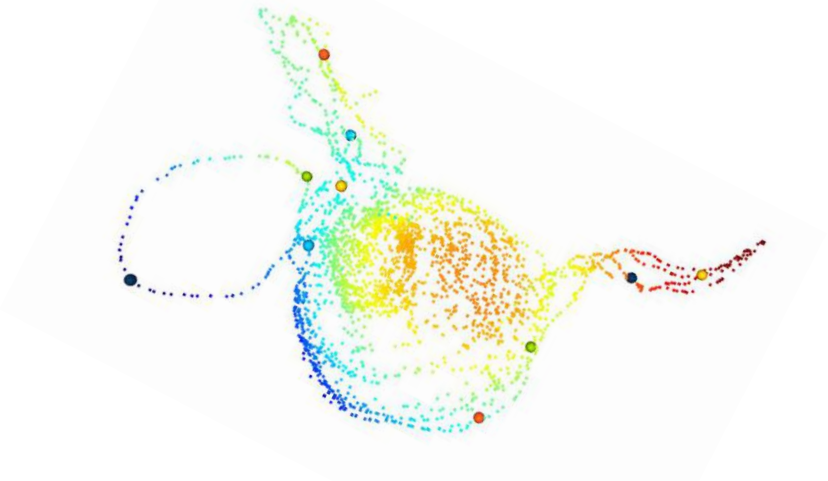
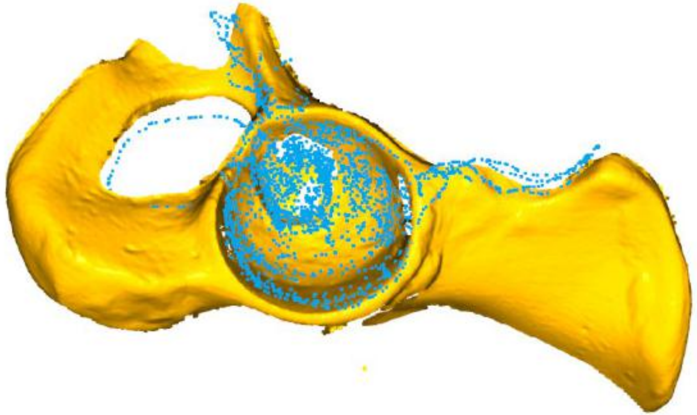
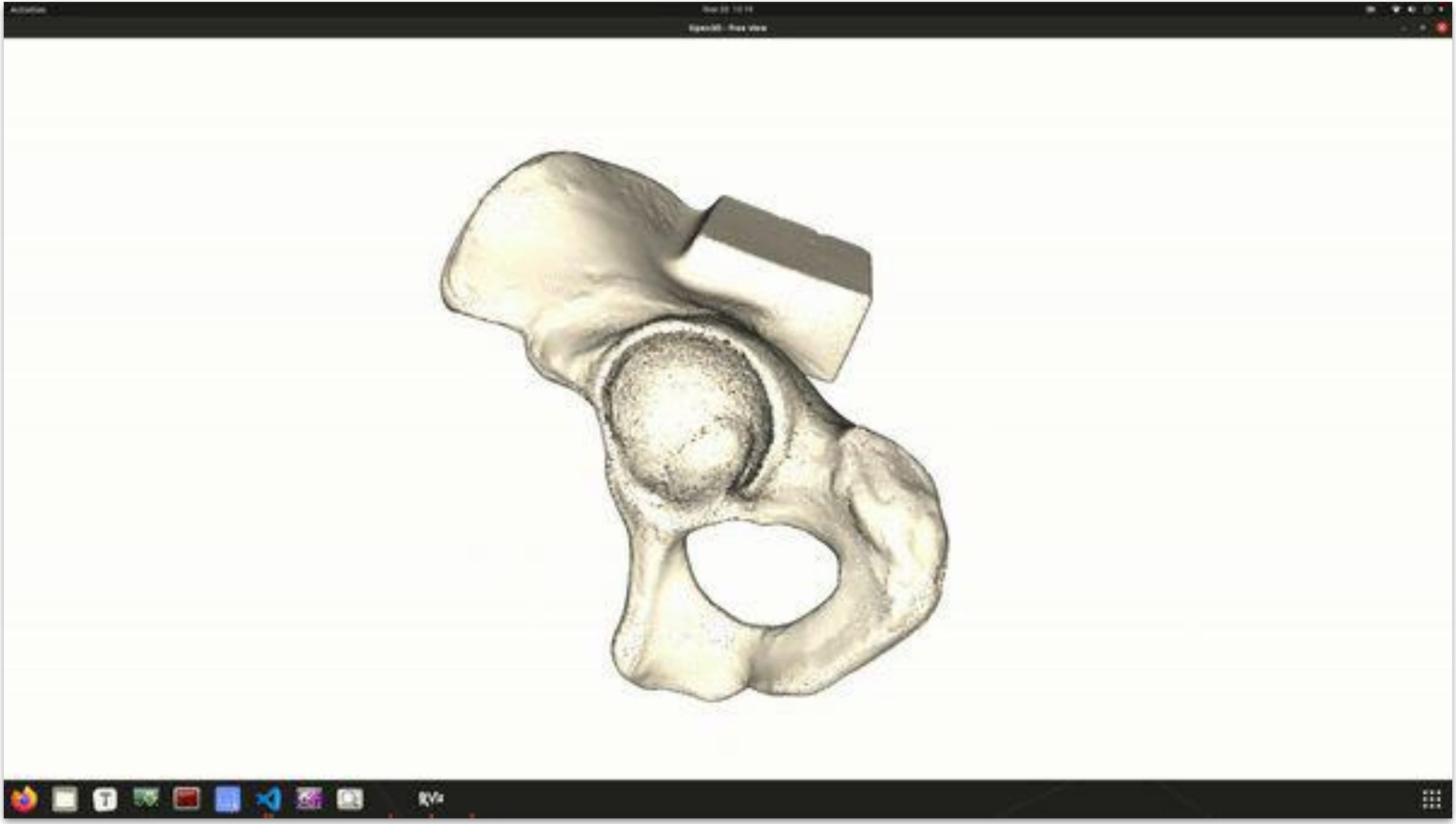
Landmark Selection + Registration







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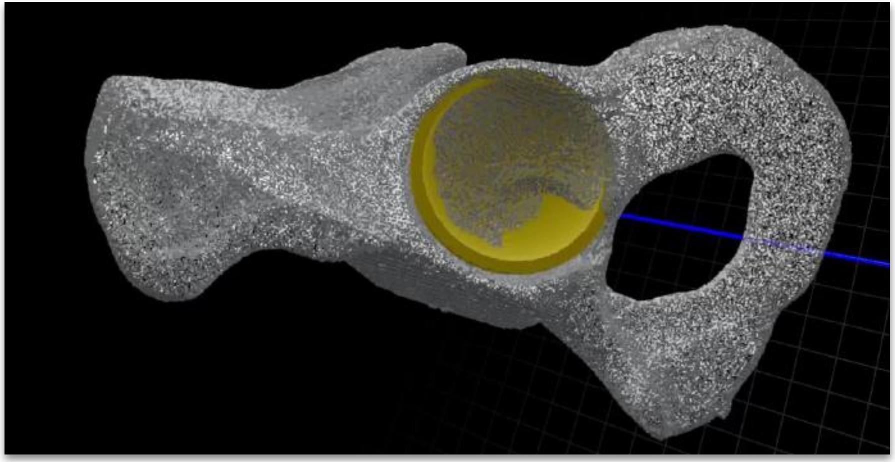
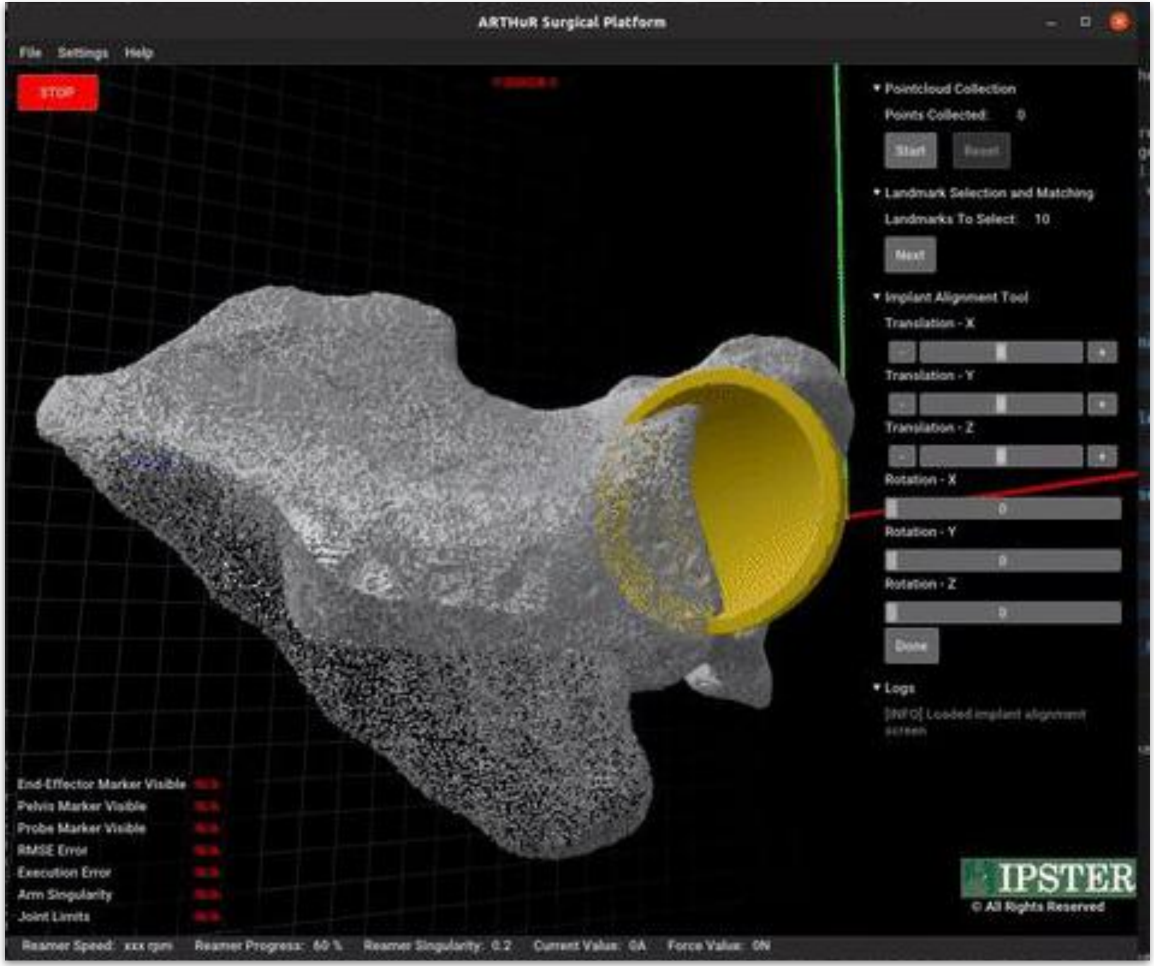
Implant Alignment Tool (Surgeon UI)





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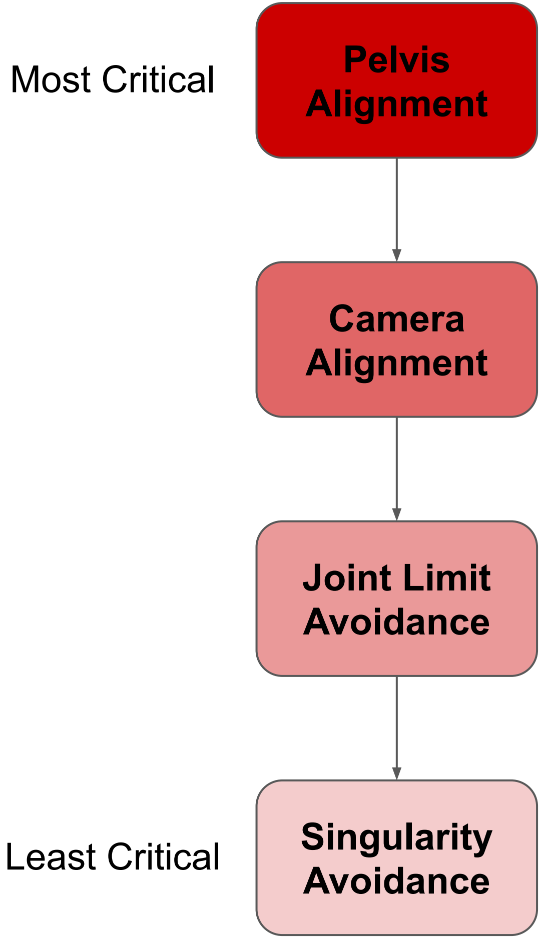
Task Prioritization Controls



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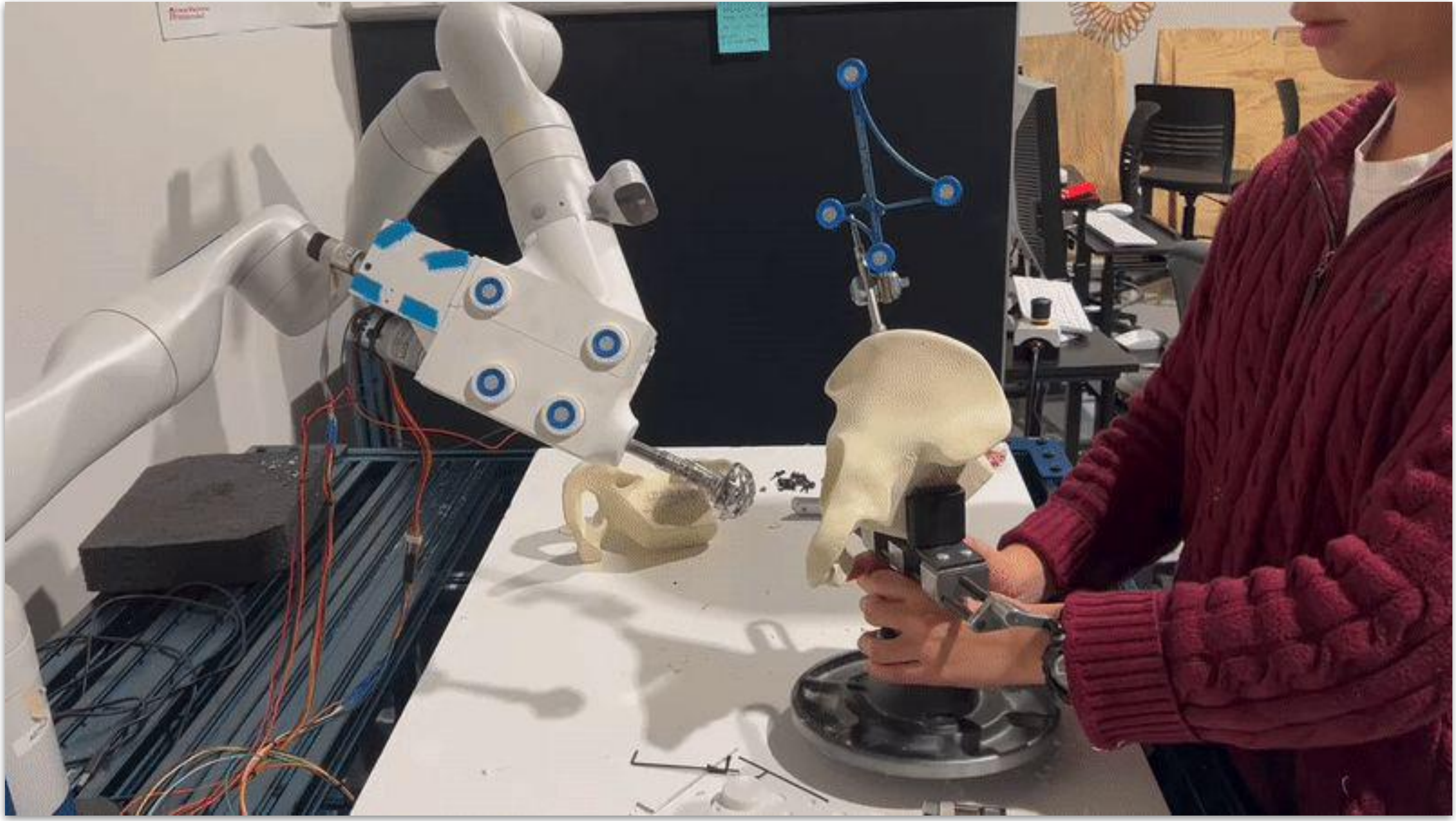
Dynamic Compensation

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 adjusts for that movement**, allowing for a consistent axis to be maintained with the acetabulum.



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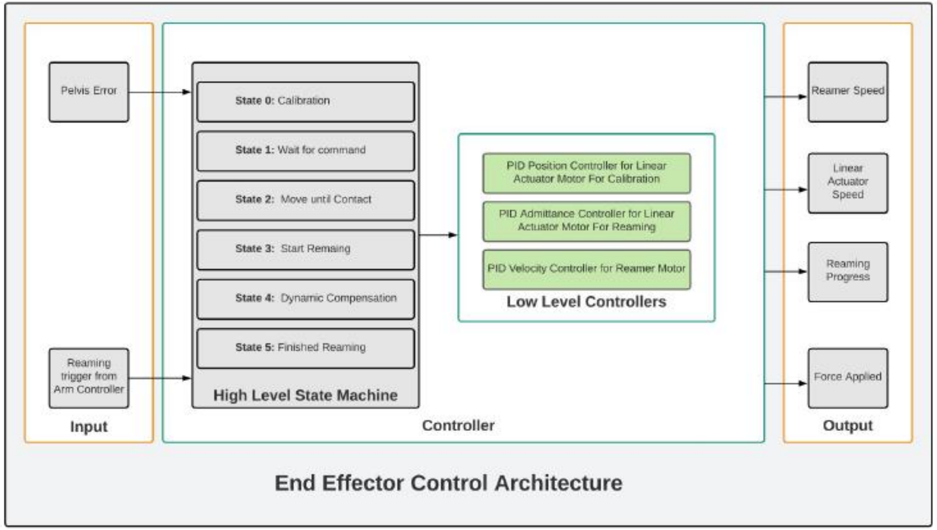
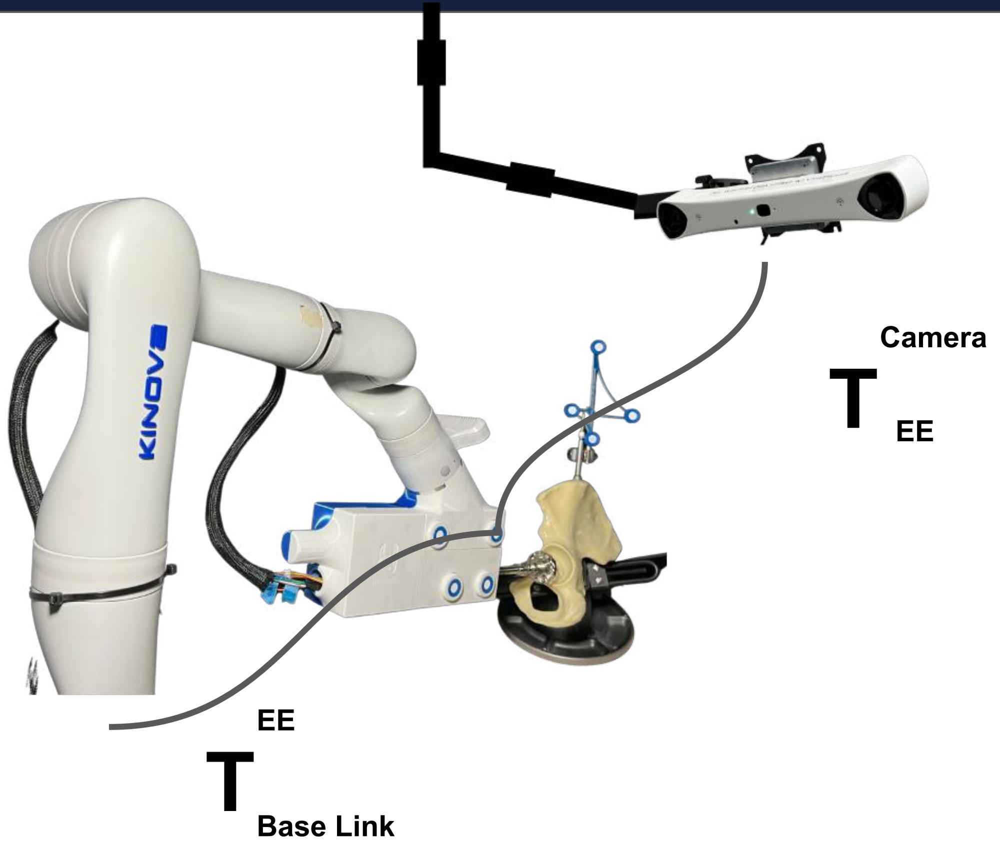
Reaming Controls



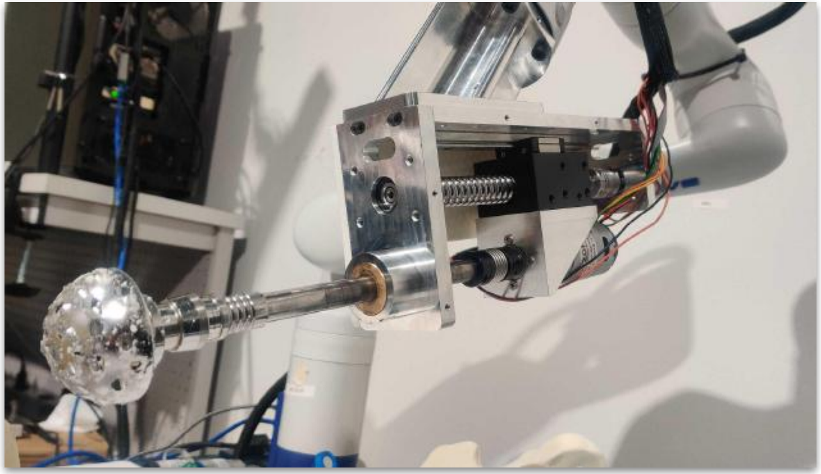
Zoom viewers watch System Cam

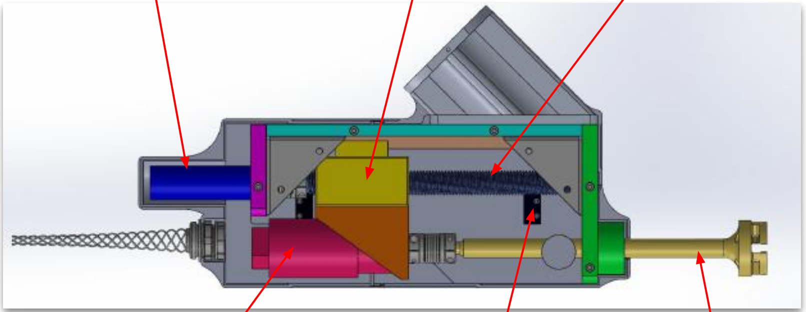
Online Calibration

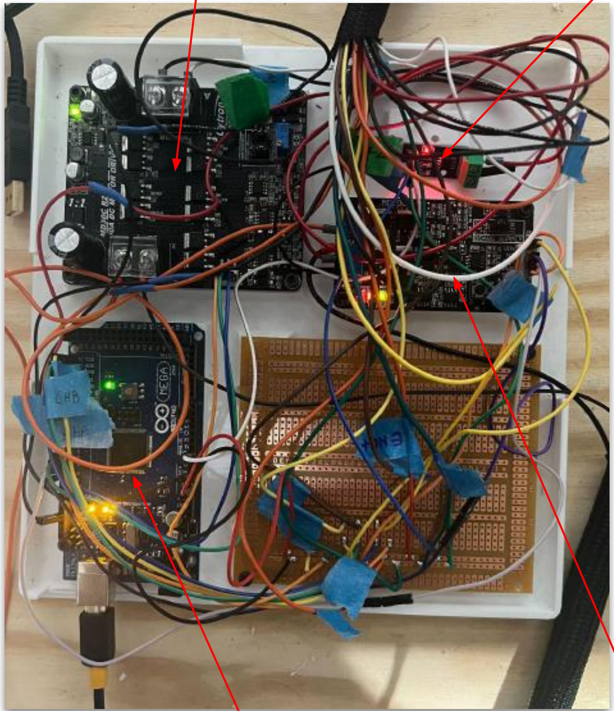


- **SVD: Offline Calibration**
  - Tsai-Lenz algorithm
  - Needs to be repeated if camera position changes
  - Time consuming
- Robust to changes in camera position
- Arm controls ensures markers are continuously visible to the camera

Hardware and Electrical

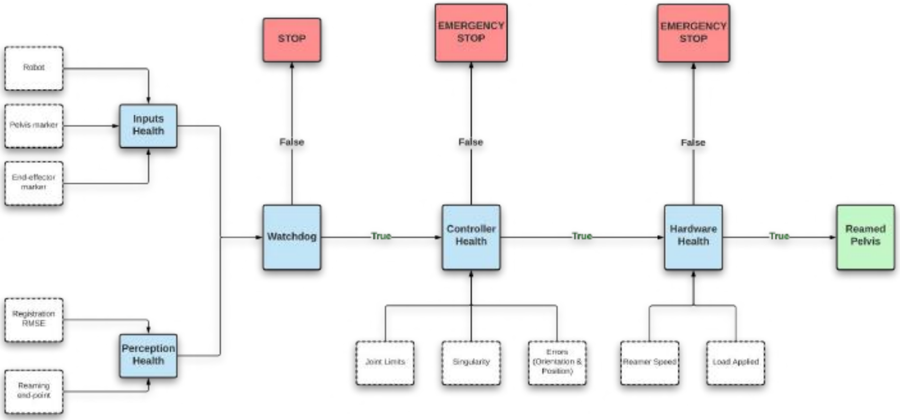


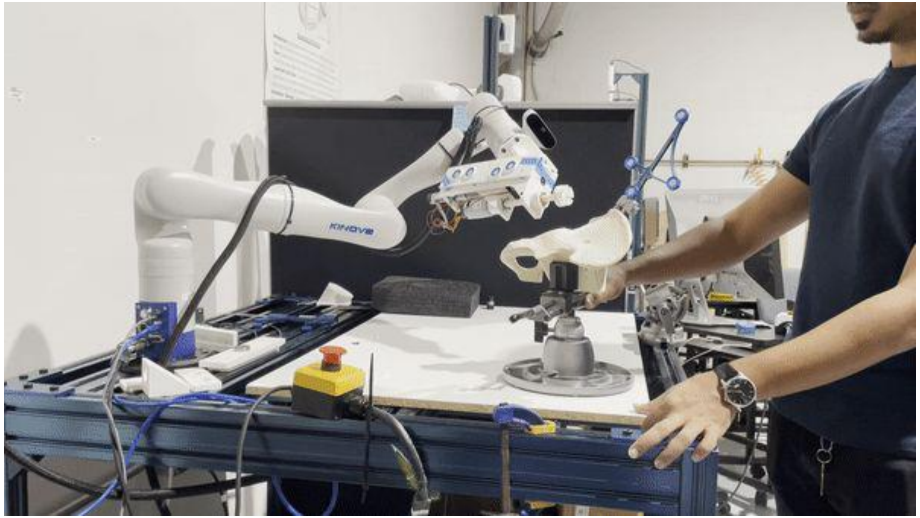




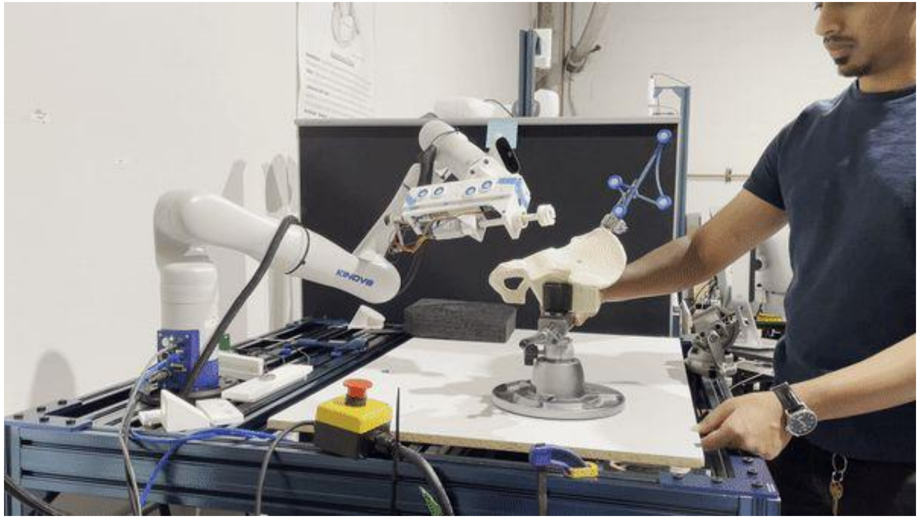
Zoom viewers watch here

WatchDog


Robot
Pelvis marker
End-effector marker
Inputs Health
Registration RMSE
Reaming end-point
Perception Health
STOP
False
Watchdog
True
EMERGENCY STOP
False
Controller Health
Joint Limits
Singularity
Errors (Orientation & Position)
True
EMERGENCY STOP
False
Hardware Health
Reamer Speed
Load Applied
True
Reamed Pelvis



Pelvis not visible
(patient decides to run away)



Stops controller at any fault

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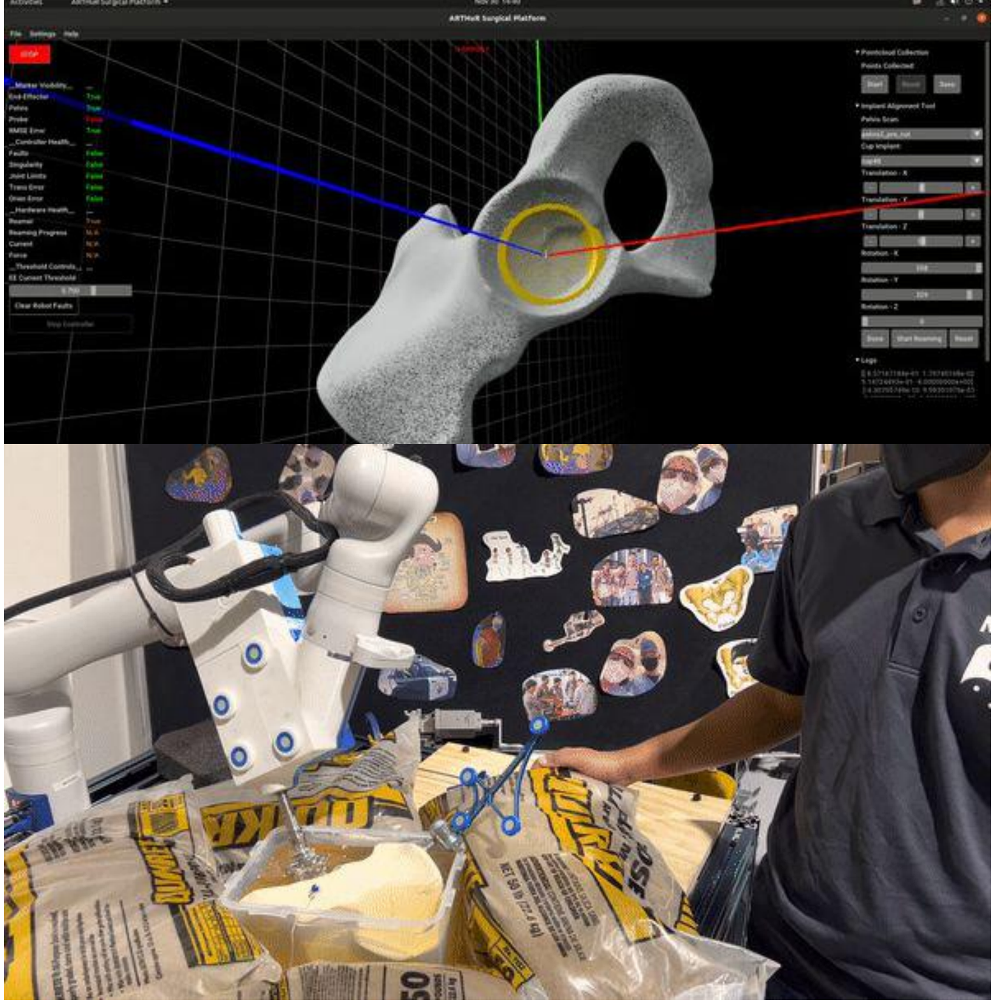

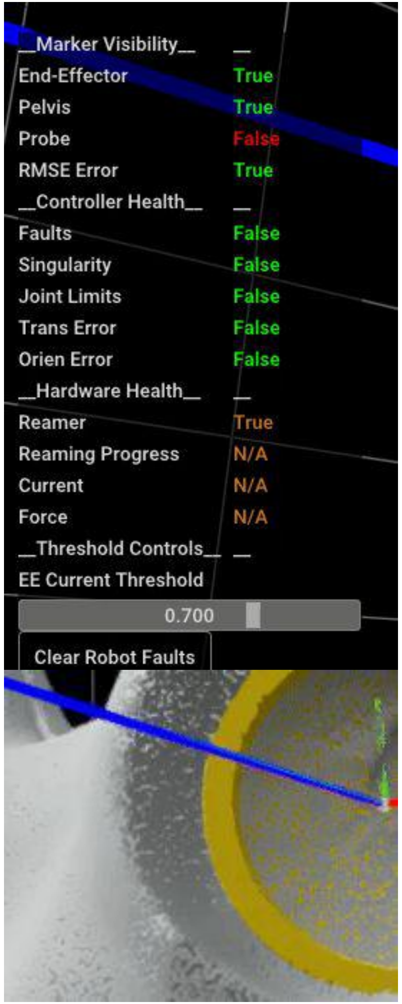

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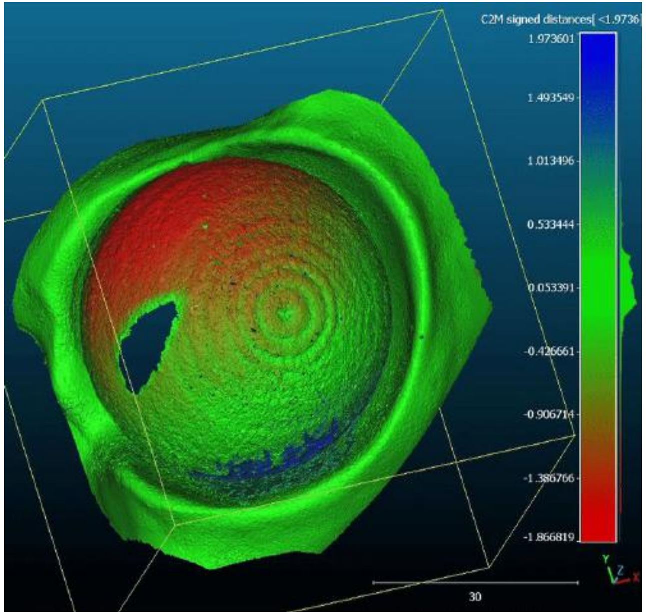
System Validation

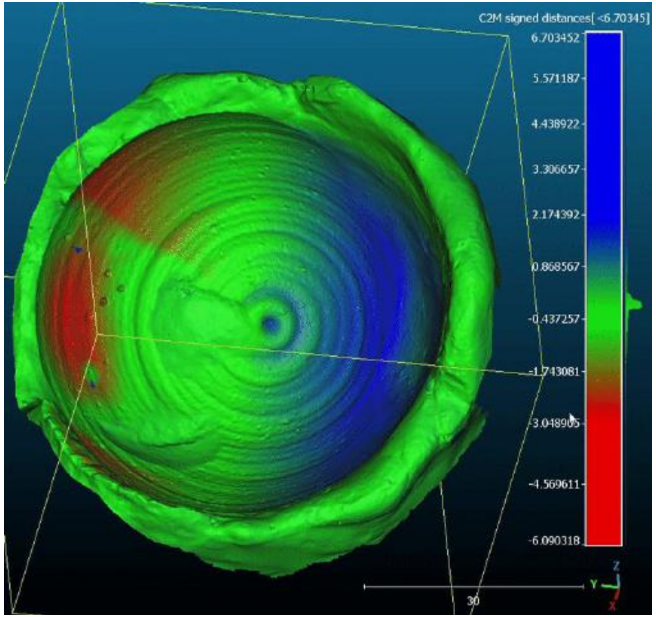
Test 1



Maximum Error: +2.0 mm

Average Error: 0.29 mm

Test 2

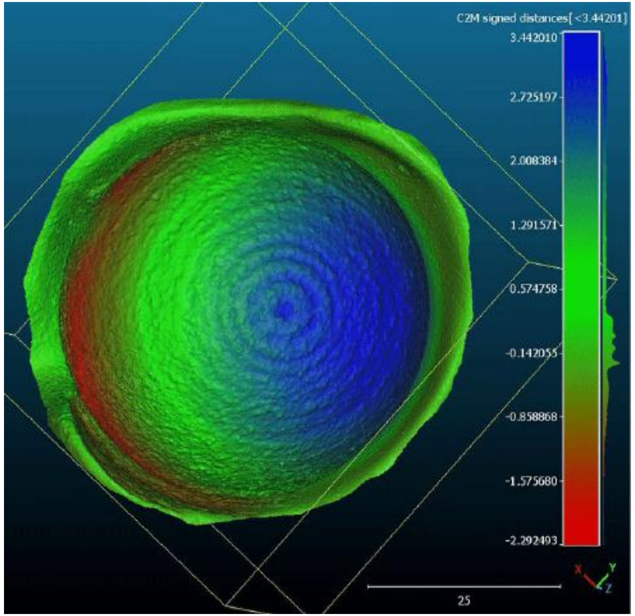


Maximum Error: -3.0 mm

Average Error: 0.43 mm

Zoom viewers watch here

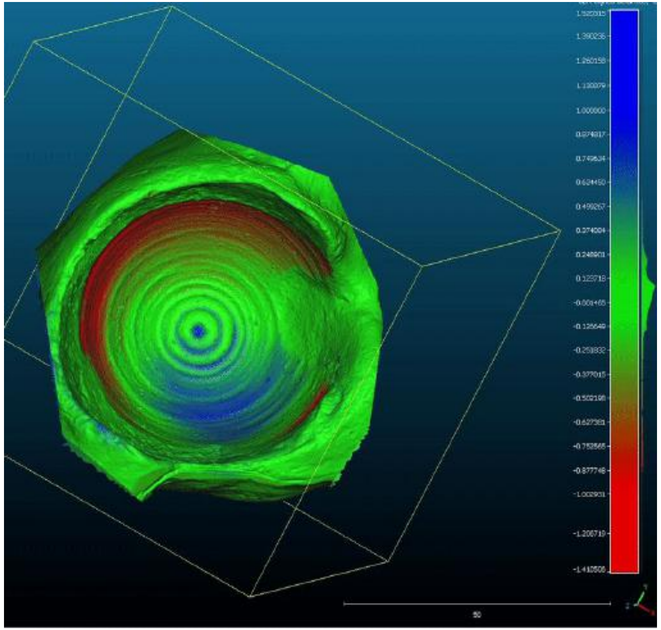
Test 3



Maximum Error: +3.4 mm

Average Error: 0.95 mm

Test 4



Maximum Error: -1.3 mm

Average Error: 0.42 mm

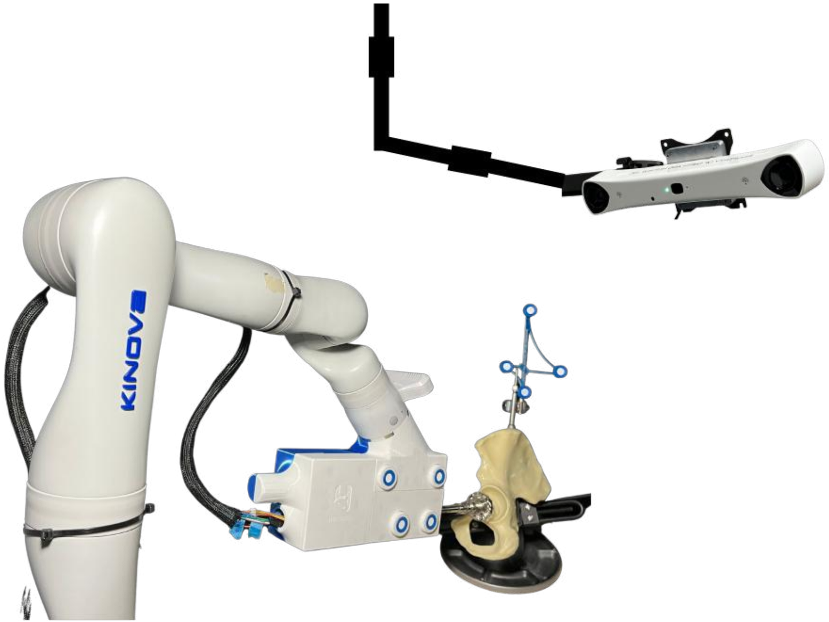
Zoom viewers watch here

All Test Results

Test No.	Max. Error
Test 1	**2.0 mm**
Test 2	**3.0 mm**
Test 3	**3.4 mm**
Test 4	**1.3 mm**

Zoom viewers watch here

Performance Criteria



Performance Requirements	Status
M.P.1.1 The system shall use the Atracsys camera to track the pelvis, registration probe, and robot arm markers with a *frame rate* greater than or equal to **50 Hz** or *latency* less than or equal to **25 milliseconds.**	✓
M.P.1.2 The system shall use the Atracsys camera to track the pelvis, registration probe, and robot arm markers with an *accuracy* of less than or equal to **0.55 mm**.	✓
M.P.2.1 The system shall continuously calculate the error in pelvis movement with a *frame rate* greater than or equal to **40 Hz** or *latency* less than or equal to **25 milliseconds**.	✓
M.P.2.2 Use the Atracsys camera to track the pelvis and robot arm error with a *position accuracy* less than or equal to **2 mm**.	✓
M.P.2.3 Use the Atracsys camera to track the pelvis and robot arm error with an *orientation accuracy* less than or equal to **1.5 degrees**.	✓
M.P.3 The system shall perform registration between the collected point cloud and the given 3D pelvis scan with a *root mean square (RMS) error* of **1 mm**.	✓

Performance Requirements	Status
M.P.4.1 The system shall start dynamically compensating for the movement of the pelvis by commanding the end-effector to retract and/or power off the reamer with a *latency* of less than or equal to **25 milliseconds** when the *error thresholds* exceed **2 mm** and **1.5 degrees**.	✓
M.P.4.2 The system shall dynamically compensate for the movement of the pelvis by beginning to realign the reamer with a *latency* of less than or equal to **50 milliseconds**.	✓
M.P.5.1 The system shall ream the pelvis based on the provided surgical plan with a *positional accuracy* of **2 mm**.	✓
M.P.5.2 The system shall ream the pelvis based on the provided surgical plan with an *orientation accuracy* of **1.5 degrees**.	✓
M.P.6 The system will allow the surgeon to place the robot arm in an initial position by back-driving the robotic arm.	✓
M.P.7 The system will provide the surgeon with visual feedback with a latency less than or equal to **150 milliseconds**.	✓
M.P.8 The system will allow the surgeon to e-stop the system, stopping the system within a *latency* of **500 milliseconds**.	✓

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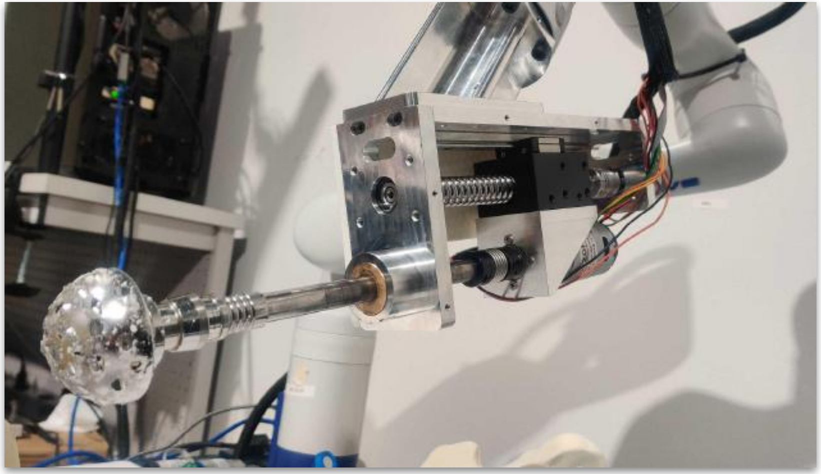
End-Effector Validation



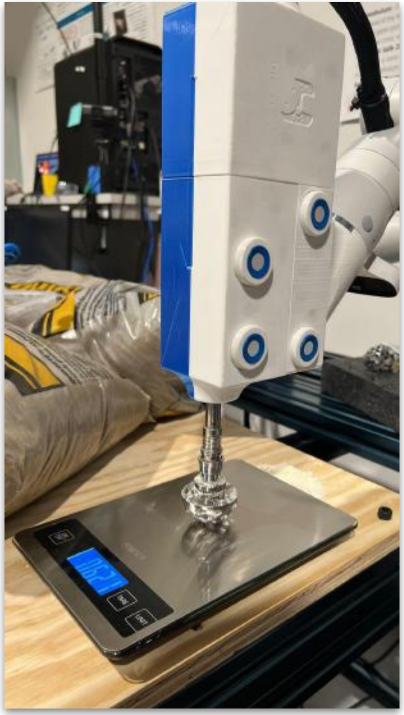
End-Effector Validation

Validation Criteria

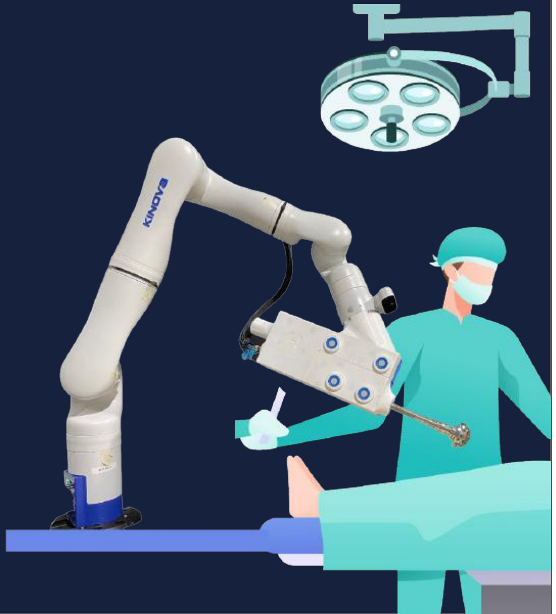
1. Force should not exceed **100 N**
    a. Max force is **62.3 N**
2. Linear position should be accurate to **0.5 mm**
    a. 5 mm traveled per revolution / 230.7 encoder ticks per revolution = **0.02 mm**
    b. +/- 5 ticks accuracy = +/- **0.10 mm**
3. Vibration in the end-effector shouldn't contribute to dynamic compensation
    a. **Vibrations occur in the arm** and not in the end-effector
4. Weight should be less than 4 kg
    a. Total weight is **2.15 kg**

End-Effector Forces

Max Force	62.3 N
Mean Force	37.6 N
StDev Force	9.7 N
Min Force	14.3 N
Median Force	36.4 N



What you saw today



A **robot arm** for **total hip replacement** surgery that **dynamically compensates** for patient movement and **improves patient outcomes**!

Thank you for your support!

MRSD Advisors:

- John Dolan
- Dimi Apostolopoulos

CMU Professors:

- Professor Kroemer
- Professor Riviere

[redacted]

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November 21, 2022

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Questions and Discussion

Autonomous Reaming for Total Hip Replacement (ARTHuR)