HIPSTER

Autonomous Reaming for Total Hip Replacement

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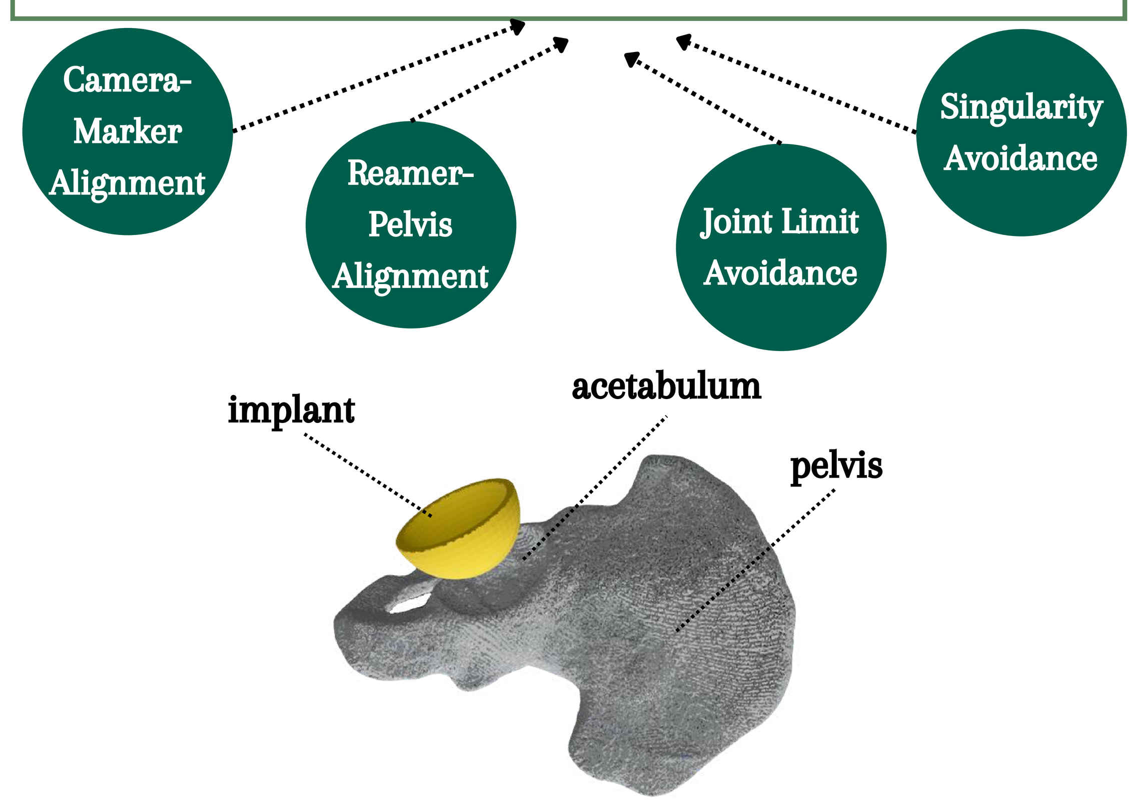
Controls Subsystem

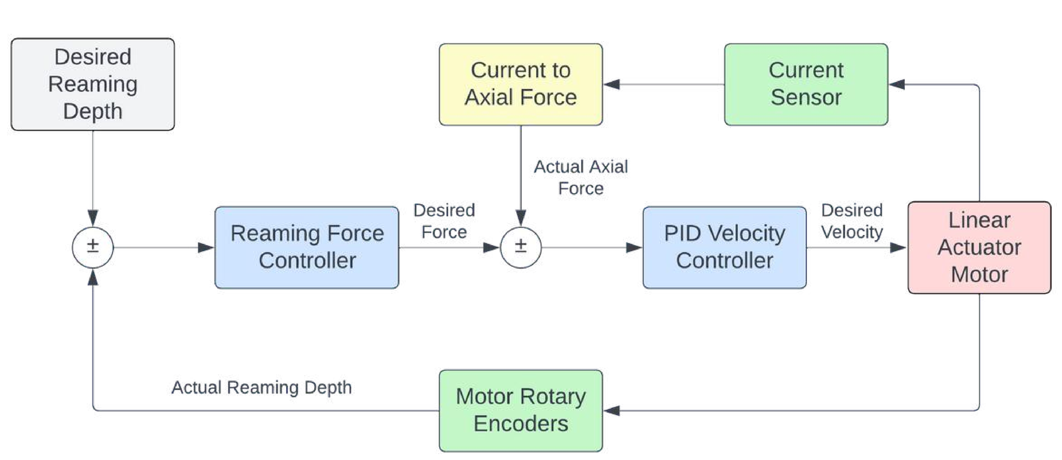
- **Free Motion Mode (FMM)** for initial alignment of the robot arm with the acetabulum.
- **Task Prioritization Controls** to autonomously ream
- **Dynamic Compensation** tracks the pelvis position and orientation to adjust itself to the given surgical plan.

Task Prioritization Framework

Allows us to take advantage of the redundancy of our arm and **perform multiple tasks simultaneously**!



End-effector controls are able to actuate the linear actuator until it reaches the reaming endpoint, while maintaining the desired amount of **axial force** and allowing the reamer to rotate at a desired **constant velocity.**



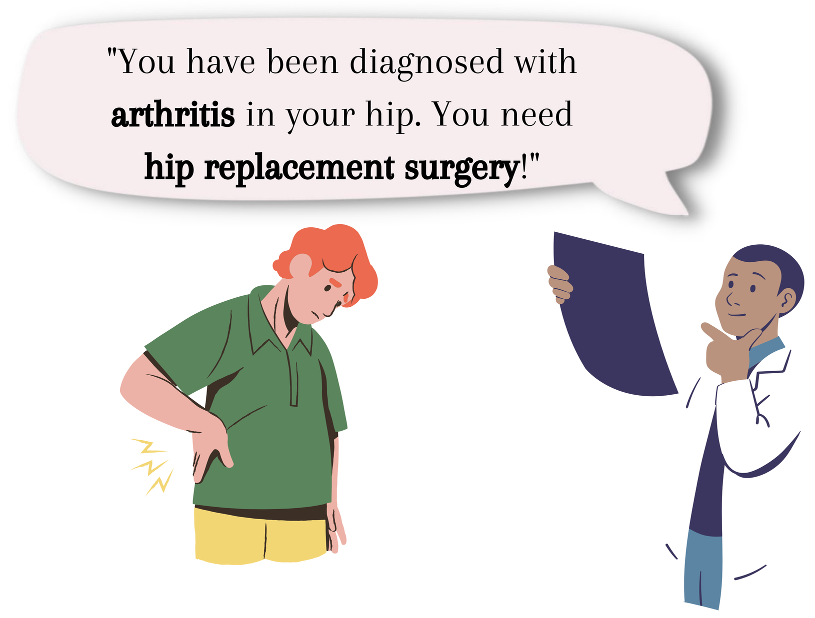
WatchDog

Monitors the health of all subsystems by mainly checking the streams via which each subsystem passes information.

- Are all **markers visible**?
- Is the arm in **singularity/joint limits**?
- Is the system within **tolerable errors**?

Watchdog is able to **e-stop** the system!

Use Case

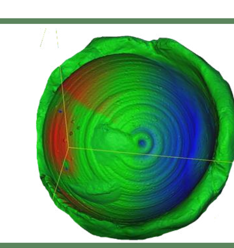
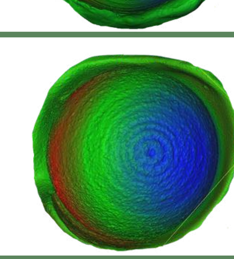
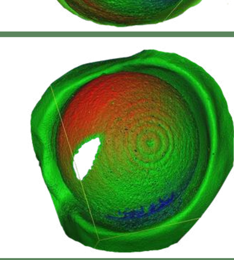
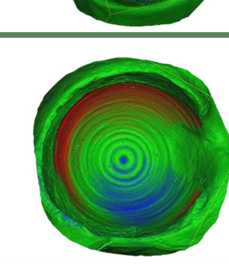
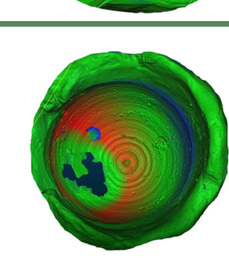


Surgeons must ream the acetabulum on the pelvis to remove the arthritic bone. However, they cannot see the acetabulum well because of tissue/blood and have to deal with patient movement as a result of the forces applied by the surgeon on the reaming tool. If they do not ream in the required position/orientation, it may lead to bad surgery outcomes!

Surgery with ARTHuR

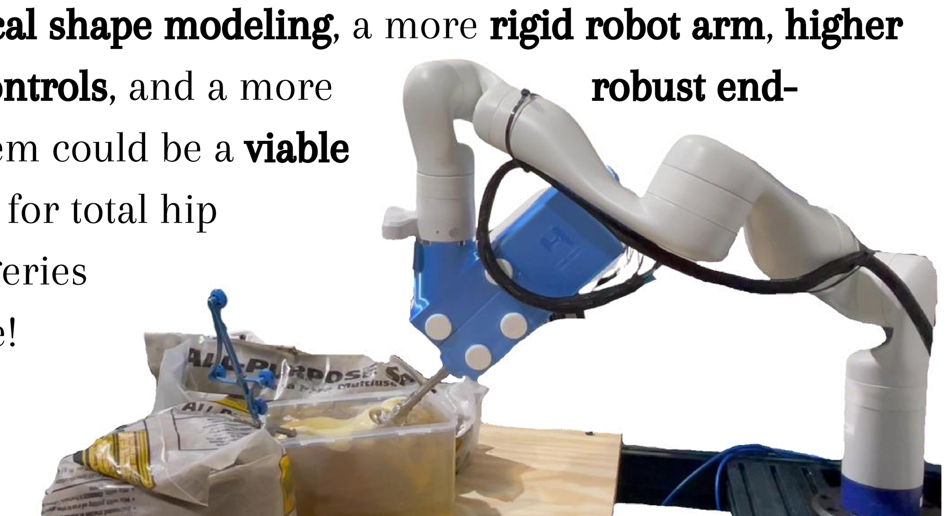
A fully autonomous robotic arm aimed at performing acetabular reaming with **high accuracy**, and **dynamically compensating** its position/orientation with the pelvis movement.

Validation Results and Conclusions

Pelvis #	Result	Distance Errors
Pelvis 1		Max: 3.0 mm Average: 0.43 mm
Pelvis 2		Max: 3.4 mm Average: 0.95 mm
Pelvis 3		Max: 2.0 mm Average: 0.29 mm
Pelvis 4		Max: 1.3 mm Average: 0.42 mm
Pelvis 5		Max: 3.3 mm Average: 0.52 mm

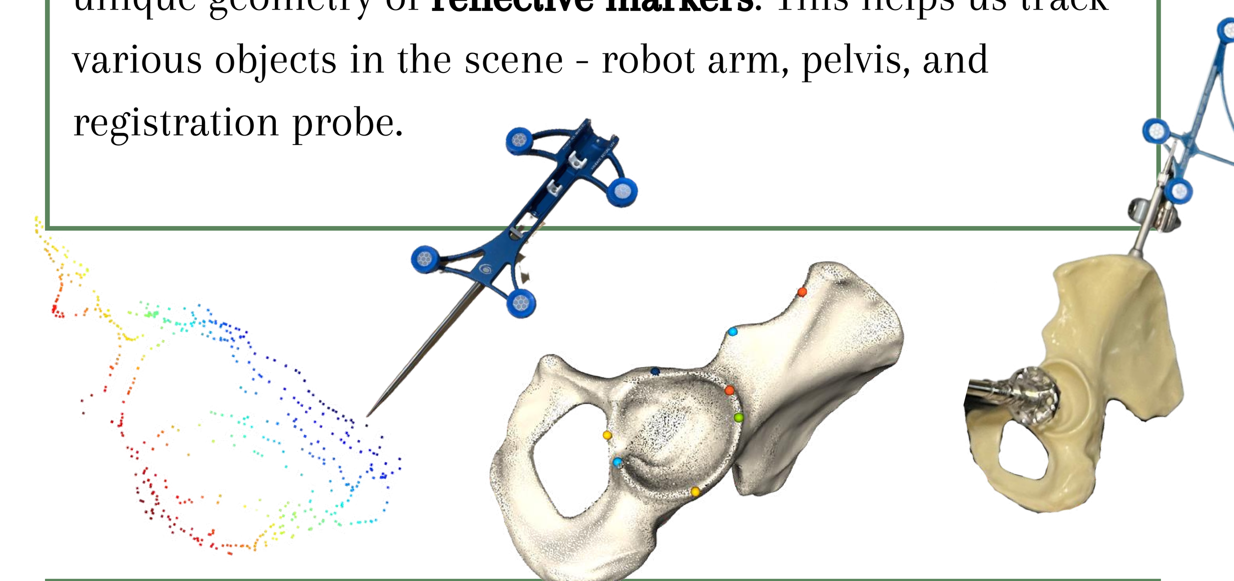
To validate our experimental results we generated a 3D mesh before and after reaming a Sawbone pelvis so that we could compare our actual reamed pelvis to our desired pelvis. Our goal was to be within 2 mm at maximum from our desired pelvis, which we achieved in 2 out of our 5 experiments, with the other 3 remaining under 3.5 mm. This inaccuracy can be attributed to a stack-up of **error in the registration**, errors in the **end-effector calibration**, and **elasticity in the collaborative robot arm**. In general, the **depth reamed to is accurate**, however due to these errors the orientation and position to which we ream can be offset.

These results prove that **our system is capable of accurately reaming a pelvis to a desired surgical plan**. With improved registration including **statistical shape modeling**, a more **rigid robot arm**, **higher frequency arm controls**, and a more **robust end-effector**, our system could be a **viable reaming solution** for total hip replacement surgeries in the near future!



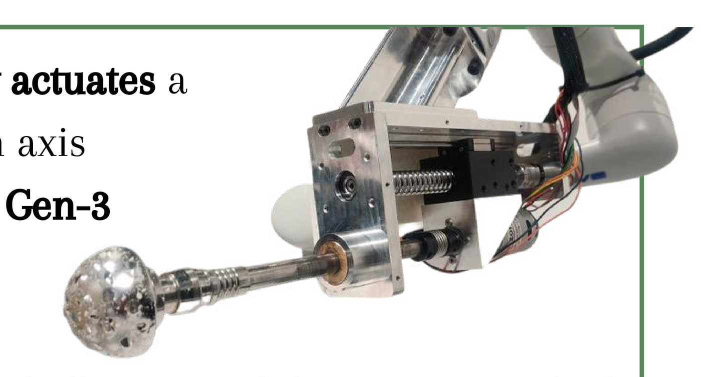
Sensing and Perception

We use the **Atracsys Sprytrack 300** camera to track a unique geometry of **reflective markers**. This helps us track various objects in the scene - robot arm, pelvis, and registration probe.

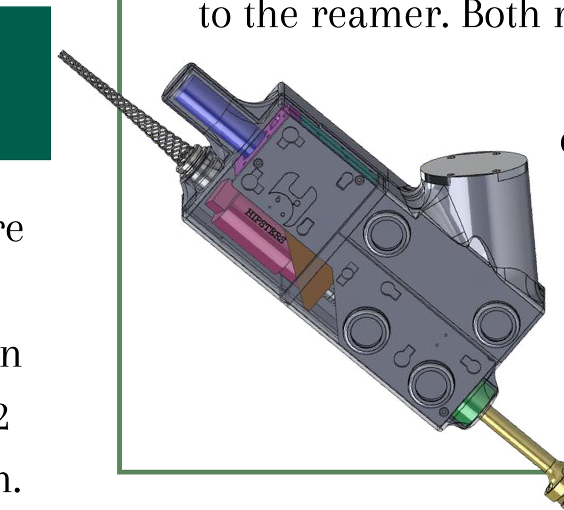


We use ICP **(Iterative Closest Point)** to perform registration between the **collected pelvis pointcloud** during surgery with the **pre-surgical pelvis CT scan**.

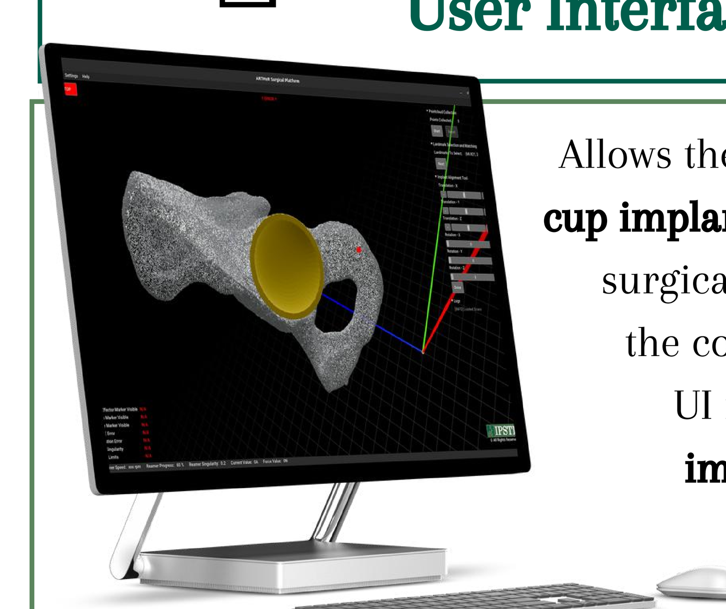
End-Effector Design and Electrical Subsystem



Our end-effector **linearly actuates** a reaming handle along an axis controlled by our **Kinova Gen-3** robot arm. It is actuated by **two planetary gear motors**, one attached to a ballscrew and the motor attached to the reamer. Both motors are controlled by an **Arduino Mega** connected to a **Cytron motor controllers**. This design allows us to **ream accurately** to a prescribed position and orientation while **maintaining the axial force** necessary to cut bone.



User Interface



Allows the surgeon to **align the cup implant with the pelvis**. This surgical plan is passed on to the controls subsystem. The UI interface also **displays important system health information**. It is built using ROS and **Open3D**.