HIPSTER

Autonomous Reaming for Total Hip Replacement (ARTHuR)

Project Management Review

Team C: Kaushik Balasundar, Parker Hill, Anthony Kyu, Sundaram Seivur, Gunjan Sethi

12 September, 2022

Hi! We’re the Hipsters :)

Parker

Sundaram

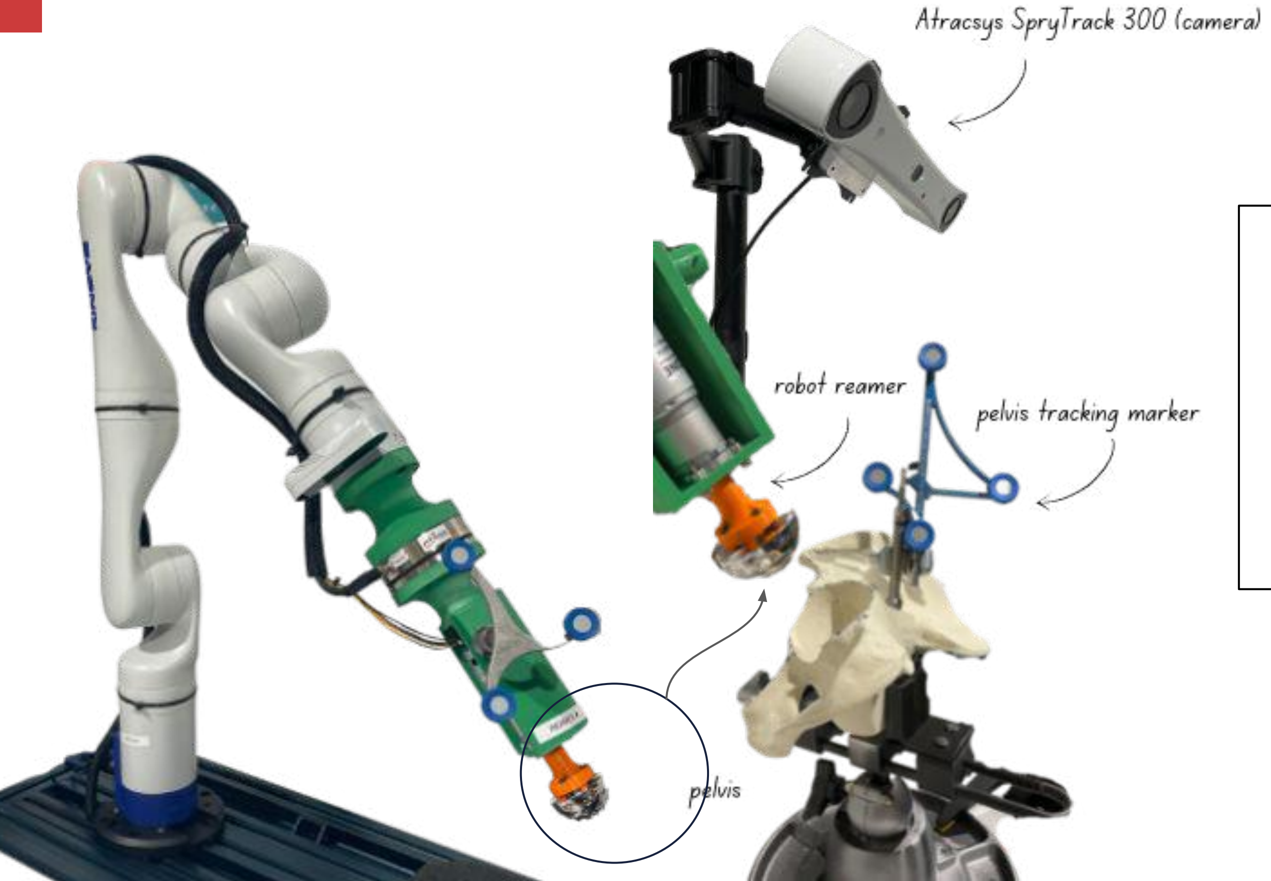
Kaushik

Anthony

Gunjan

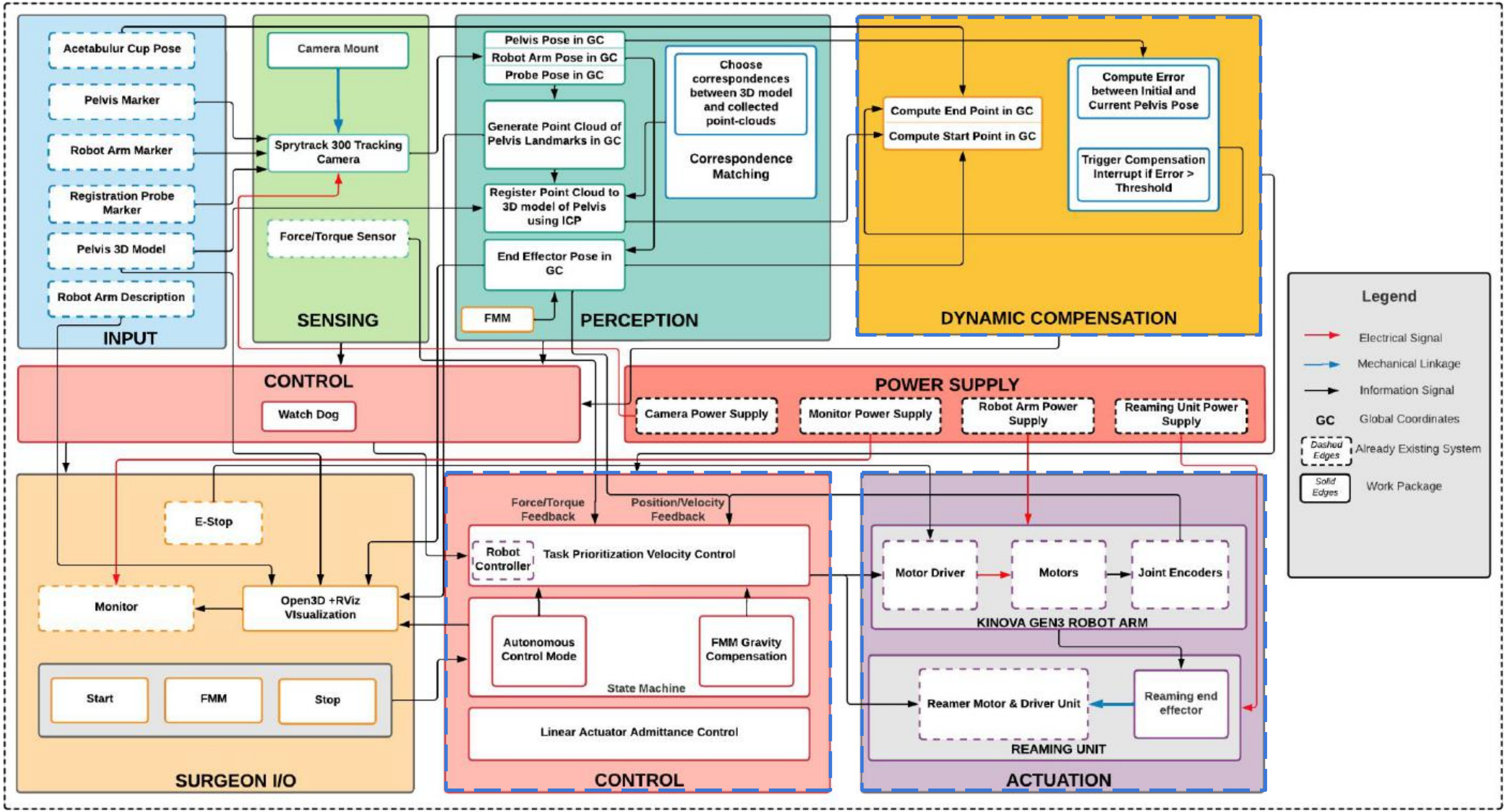
Project Description

About ARTHuR

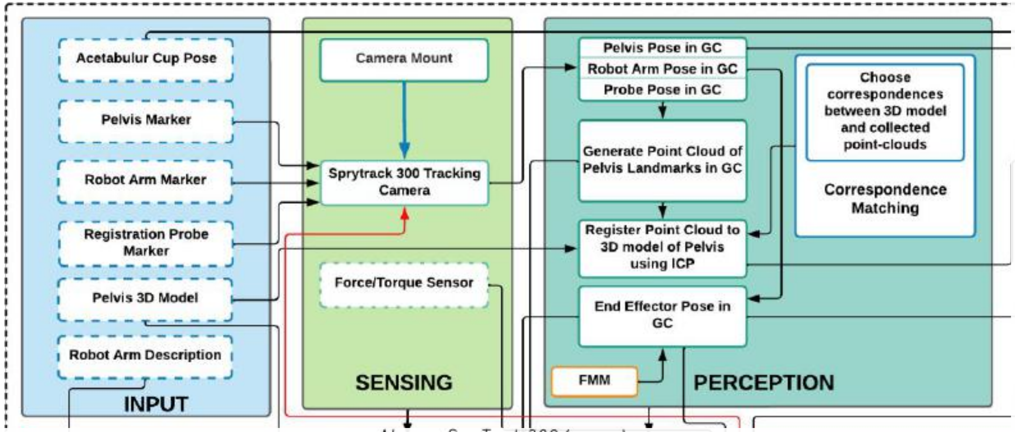


- Fully autonomous robotic arm
- Acetabular reaming
- High position+orientation accuracy, no surgeon intuition required

Subsystem Status



INPUT
Acetabulur Cup Pose
Pelvis Marker
Robot Arm Marker
Registration Probe Marker
Pelvis 3D Model
Robot Arm Description
SENSING
Camera Mount
Sprytrack 300 Tracking Camera
Force/Torque Sensor
PERCEPTION
Pelvis Pose in GC
Robot Arm Pose in GC
Probe Pose in GC
Generate Point Cloud of Pelvis Landmarks in GC
Register Point Cloud to 3D model of Pelvis using ICP
End Effector Pose in GC
FMM
Choose correspondences between 3D model and collected point-clouds
Correspondence Matching
DYNAMIC COMPENSATION
Compute End Point in GC
Compute Start Point in GC
Compute Error between Initial and Current Pelvis Pose
Trigger Compensation Interrupt if Error > Threshold
CONTROL
Watch Dog
POWER SUPPLY
Camera Power Supply
Monitor Power Supply
Robot Arm Power Supply
Reaming Unit Power Supply
SURGEON I/O
E-Stop
Monitor
Open3D +RViz Visualization
Start
FMM
Stop
CONTROL
Force/Torque Feedback
Position/Velocity Feedback
Robot Controller
Task Prioritization Velocity Control
Autonomous Control Mode
FMM Gravity Compensation
State Machine
Linear Actuator Admittance Control
ACTUATION
Motor Driver
Motors
Joint Encoders
KINOVA GEN3 ROBOT ARM
Reamer Motor & Driver Unit
Reaming end effector
REAMING UNIT
Legend
Electrical Signal
Mechanical Linkage
Information Signal
GC Global Coordinates
Dashed Edges Already Existing System
Solid Edges Work Package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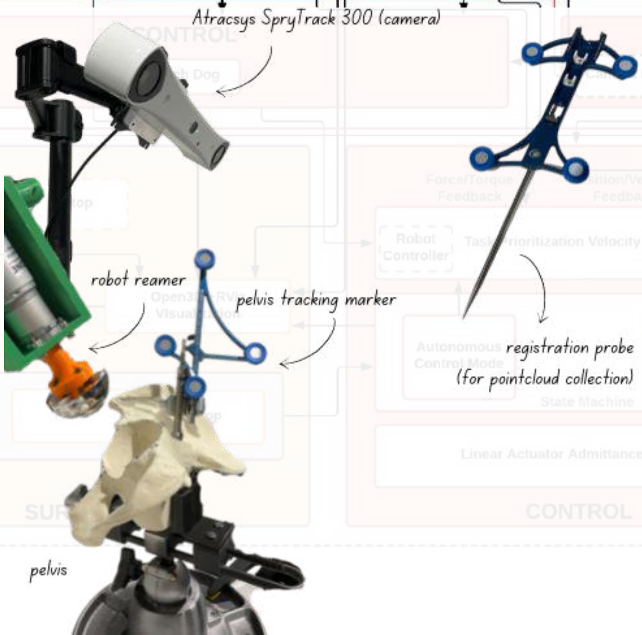
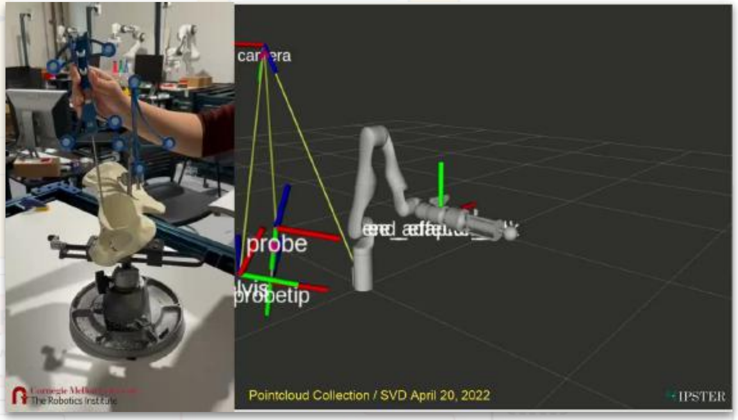
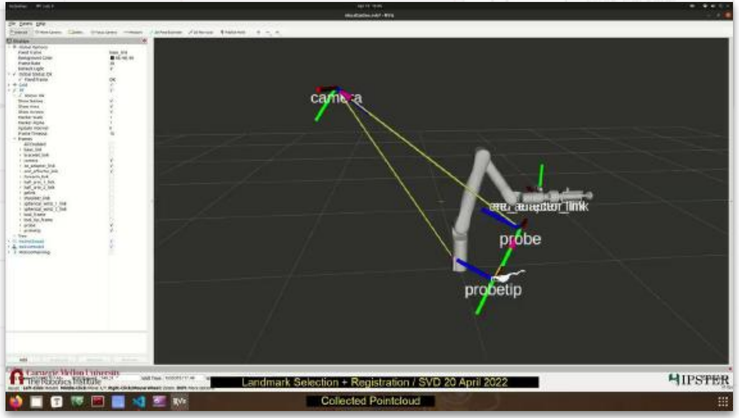
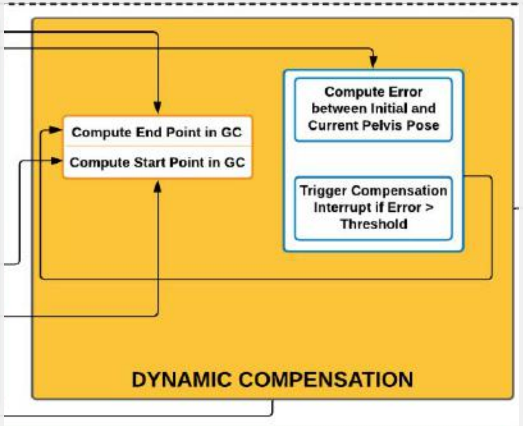
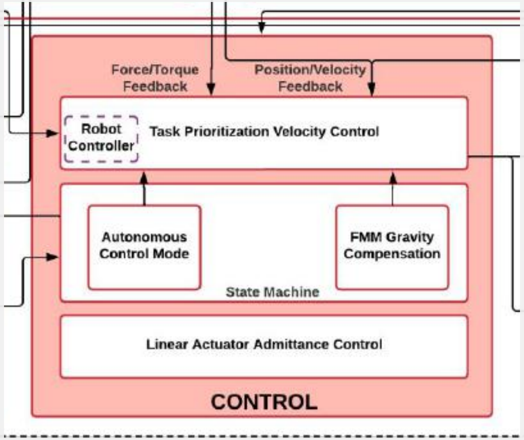
PERCEPTION


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


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


camera
probe
probetip
Landmark Selection + Registration / SVD 20 April 2022
Collected Pointcloud
IPSTER

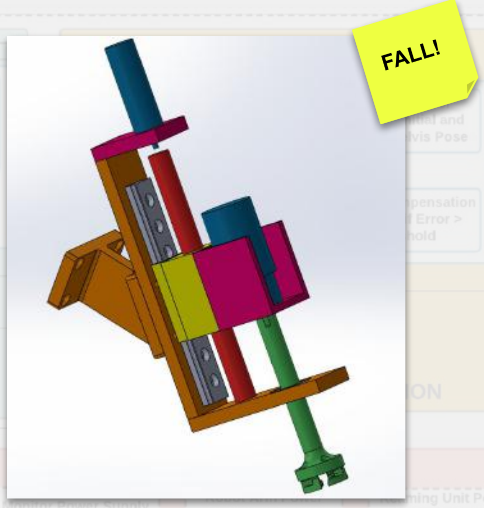


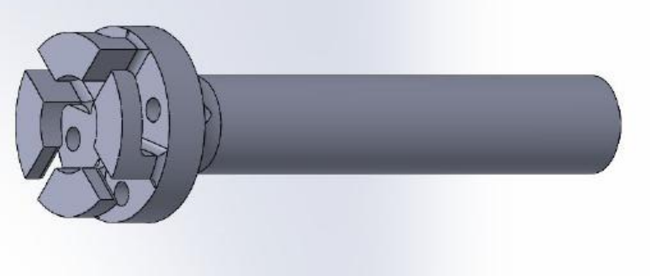


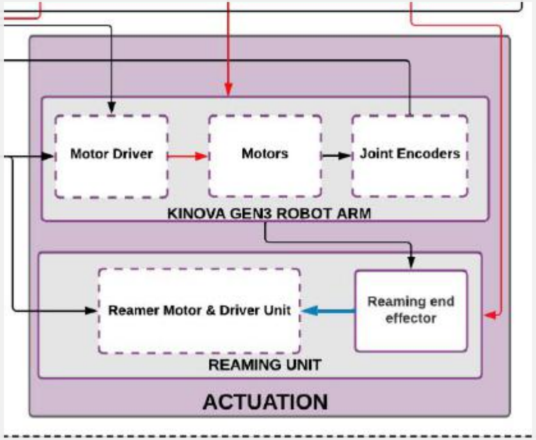
- Direct joint-level velocity control
- Executes/Performs multiple tasks simultaneously
- Dynamically aligns EE with pelvis
- Dynamically aligns EE markers with camera
- Avoids singularities

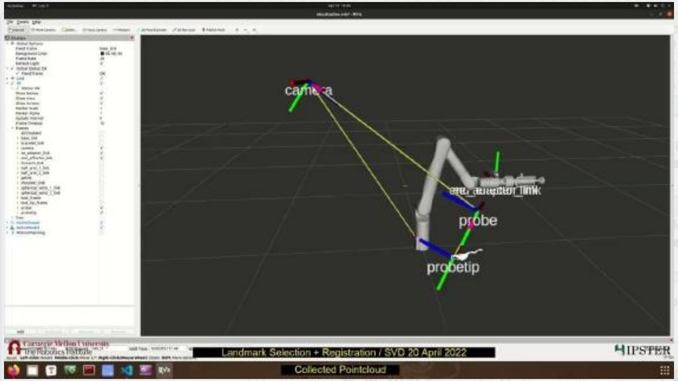
FALL!

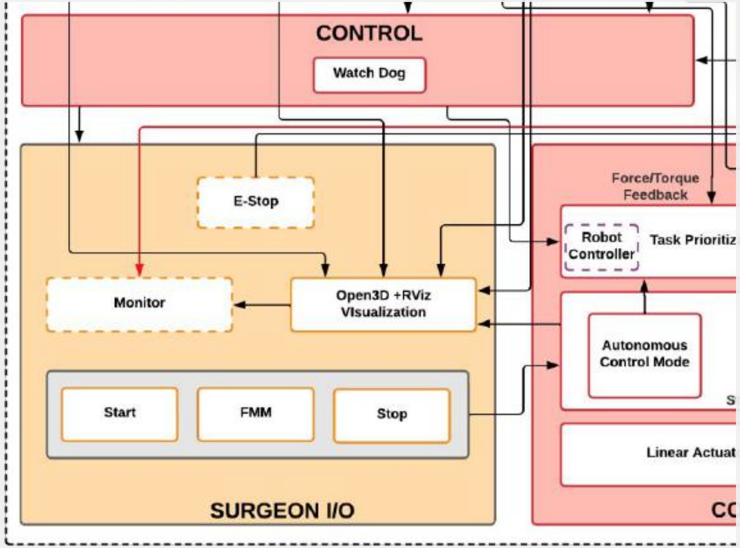

Reaming Operation
HIPSTER


FALL!




Motor Driver
Motors
Joint Encoders
KINOVA GEN3 ROBOT ARM
Reamer Motor & Driver Unit
Reaming end effector
REAMING UNIT
ACTUATION





Goals

- Provide simple visual feedback to the surgeon to estimate cup implant placement
- Log all important inputs, outputs and system metrics
- Prevent system from breaking down due to sub-system level errors

Key Challenges & Plans

End-Effector Development Delays and PCB Failure/Delays

- Start early!
- Fallback to current system
- Use 3D printed design
- Use an off-the-shelf IC
- Use a breadboard backup

System Robustness Issues

- Create internal deadlines
- Start testing early (by Oct 31st)
- Fallback on the earlier working demo
- Allocate last 2 weeks for system optimization

Dynamic Compensation and Latency Issues

- Try multiple control architectures
- Utilize SVD control routine as fallback
- Evaluate need for isolating controller from ROS
- Benchmark latencies

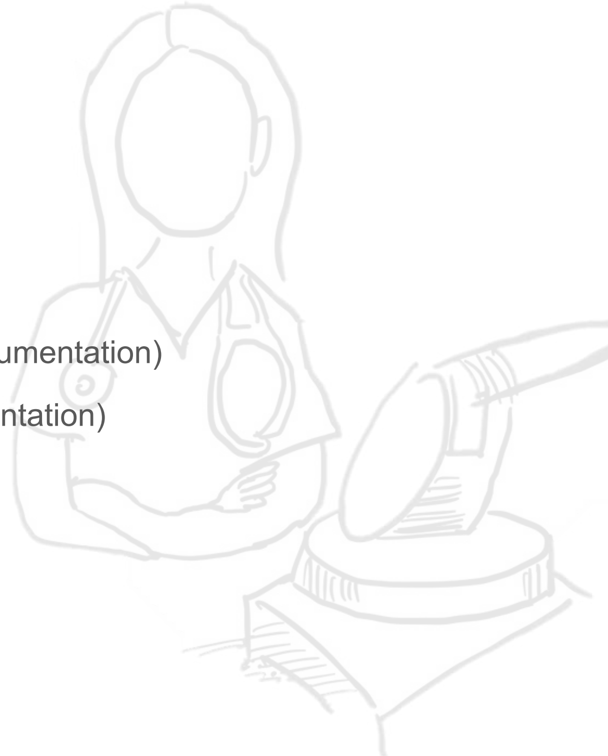
WatchDog and UI Integration Challenges

- Start working on the UI early and integrate in a step-by-step basis
- Plan architecture and consult each stakeholder before implementation

Project Management

Overview

- Agile
  - Short and long deadlines
  - Meetings two or more times a week; 15 min standups
  - 3 hours/meeting on average
- Tools
  - Slack (team communication)
  - GSuite (stakeholders communication, schedule syncing, documentation)
  - Confluence (meeting notes, brainstorming, technical documentation)
  - A whiteboard (task planning)
  - JIRA (roadmaps for milestone planning)
  - Github (version control)



Lessons and Improvements

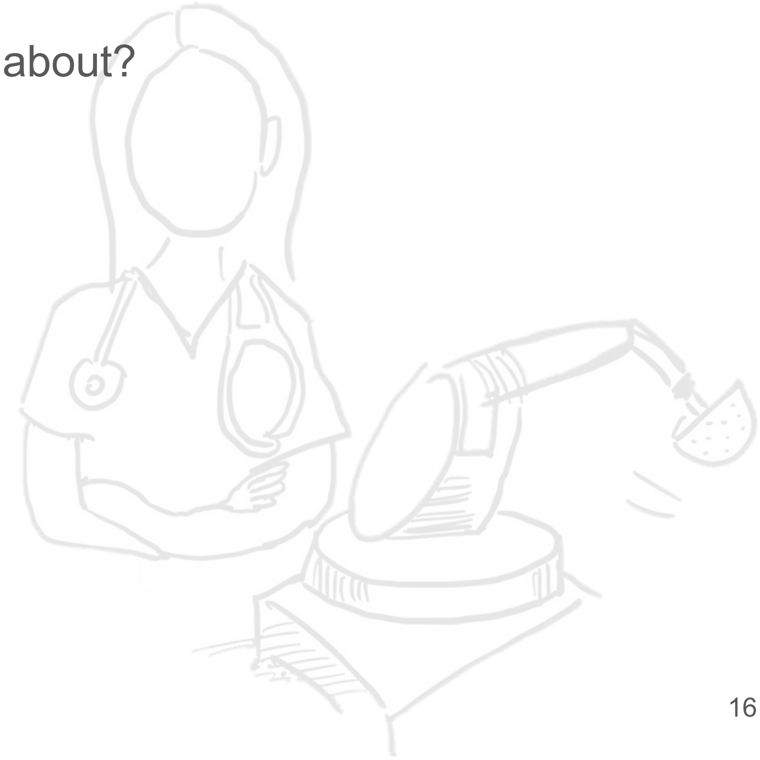
- JIRA does not work for us!
  - No one ever updates it, sprint lengths cannot be fixed
  - To-do lists are awesome; switched a sticky-note based to-do list!
- Still use JIRA Roadmaps
  - Visual representation of timelines
- Design Jams and Knowledge Transfer Sessions
  - Address key design challenges, understand other subsystems
- Increase stakeholder engagement
  - Alternate weeks to progress reviews
  - More in-person meetings
  - Refined expectations, requirements; thinking about system handover

More Lessons and Improvements

- Hard deadlines for major system design choices
    - Stay as risk-averse as possible
    - Long, iterative process need extra validation
- Sub-system level risk assessment
- Essential Stand-ups
    - Accommodate for everyone’s schedule; work independently
- SPOCs are good!
- More informal meetings and team bonding stuff!
    - Dinners and coffee together
    - Outdoor activities
    - Music while working

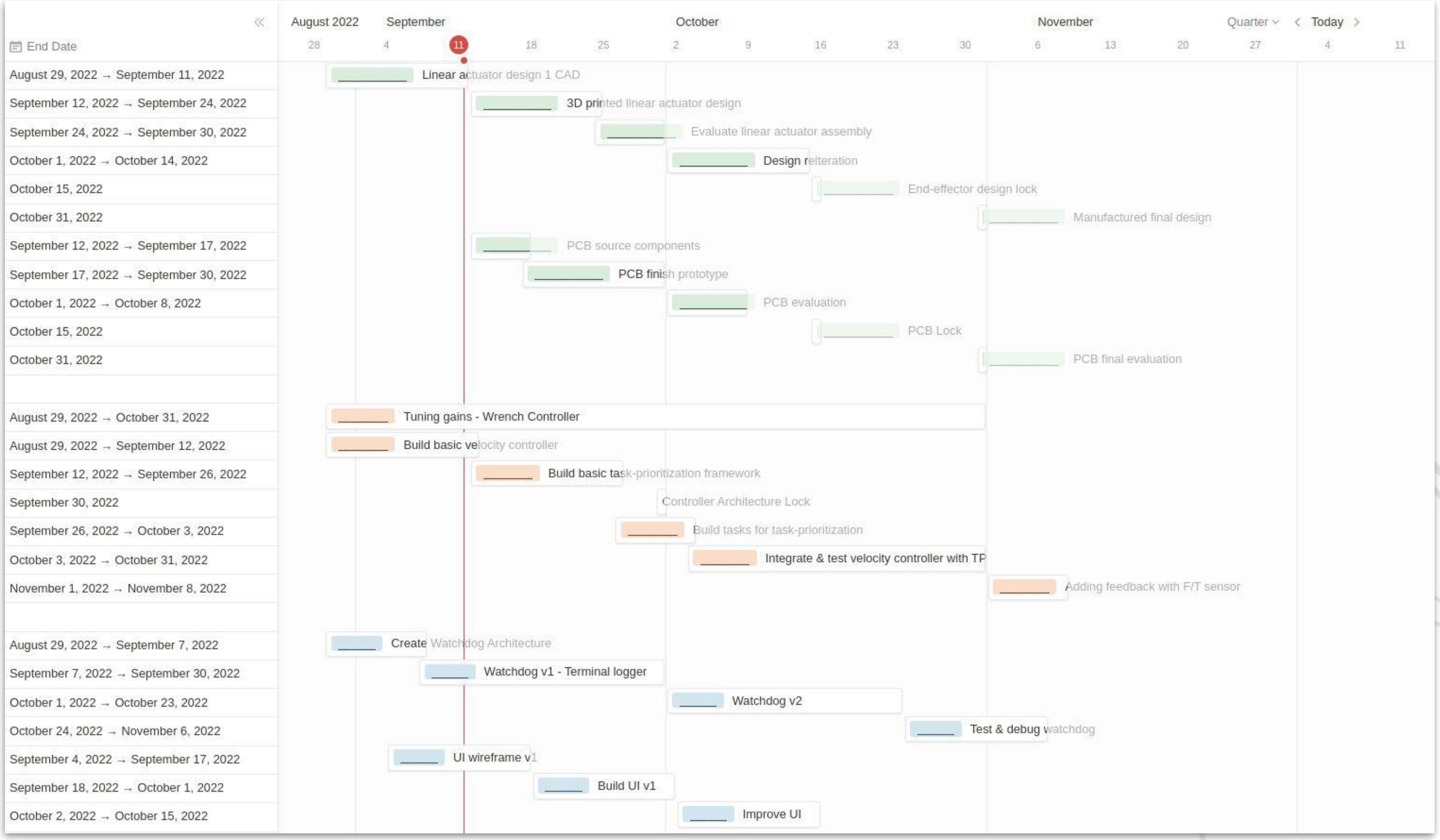
Refined Functional Requirements

- Are we meeting your expectations?
- What functional requirements do you really care about?
- Where should we drive our team’s effort?
- What is the future of this project after handover?



Functional Requirement	Performance Requirement
M.F.1. The system shall use the Atracsys camera to track the pelvis, registration probe, and robot arm markers.	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 **20 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 **0.5 mm**.
M.F.2. The system shall continuously calculate the error in pelvis movement.	M.P.2.1. The system shall continuously calculate the error in pelvis movement with a frame rate greater than or equal to **50 Hz** or latency less than or equal to **20 milliseconds**.
	M.P.2.2. The system shall use the Atracsys camera to track the pelvis, registration probe, and robot arm markers with a positional accuracy less than or equal to **2 mm**.
	M.P.2.3. The system shall use the Atracsys camera to track the pelvis, registration probe, and robot arm markers with an orientational accuracy less than or equal to **1.5 degrees**.
M.F.3. The system shall perform registration between the collected pointcloud and the given 3D pelvis scan.	M.P.3. The system shall perform registration between the collected pointcloud and the given 3D pelvis scan with a root mean square (RMS) error of **0.1 mm**.
M.F.4. The system shall dynamically compensate for the movement of the pelvis.	M.P.4.1. The system shall dynamically compensate for the movement of the pelvis by retracting or powering off the reamer with a latency of less than or equal to **25 ms**.
	M.P.4.2. The system shall dynamically compensate for the movement of the pelvis by realigning the reamer with a latency of less than or equal to **50 ms**.
M.F.5. The system shall ream the pelvis based on the provided surgical plan.	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 orientational accuracy of **1.5 degrees**.
M.F.6. The system shall allow the surgeon to place the robot arm at an initial position	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.F.7. The system shall allow the surgeon to e-stop	M.P.7 The system will allow the surgeon to e-stop the system, stopping the system within a latency of **500 ms**

Schedule & Milestones



Updated Risks

Risk #	Risk	Type	Likelihood #	Consequence #	Risk Mitigation Action
1	**End effector development delays**	Technical	4	4	• Start early and lock design by October 15th • Brainstorm multiple solutions • 3D print to test before final manufacturing • Make system simple enough to get it manufactured in-house • Use 3D printed design as a fallback
2	**PCB failure & delays**	Technical	4	4	• Test breadboard prototype • Seek feedback from Luis • Use off-the-shelf boards to reduce PCB complexity of PCB • Order spares
3	**Dynamic compensation not achievable**	Technical	3	3	• Iterate with multiple control architectures • Utilize earlier compensation solution as a fallback • Evaluate need for isolating controller from ROS • Benchmark latencies in system • Use pub/sub communication instead of server/client communication
4	**UI does not integrate with system**	Technical	4	2	• Start working on the UI early • Plan architecture and consult each stakeholder • Start testing by Oct 31st
5	Performance requirements not met	Programmatic	4	4	• Track & evaluate quantification of performance requirements • Revisit performance requirements every sprint meeting • Have a risk-manager to track key risks t
6	Integration issues between subsystems	Technical	5	4	• Define clear inputs and outputs of each subsystem • Host frequent meetings & retrospectives • Create documentation at the end of every milestone

Complete Risk Assessment

Risk #	Risk	Type	Likelihood #	Consequence #	Risk Mitigation Action
1	Robot arm does not arrive on time	Schedule	0	4	• Follow-up with sponsor to get robot arm ordered as soon as possible • Plan project to focus on simulation early • **Risk mitigated: robot arm arrived**
2	Robot arm breaks	Technical	2	5	• Implement code on robot arm only after it has proven safe in simulation • Store robot arm in safe environment • Talk with other professors to see if we could use their robot arms as a backup
3	ROS simulation does not match up to reality	Technical	0	0	• Allocate time to find and fix problems in transition from simulation • Discuss differences in simulation and reality in end of sprint meetings • **Risk mitigated: development done only in real robot**
4	Too many requirements	Schedule	3	3	• Determine requirements that are necessary and that are desirable • Individually check progress on requirements in end of sprint meetings • Have regular meetings with sponsor
5	Performance requirements not met	Programmatic	4	4	• Conduct research to re-evaluate quantification of performance requirements • Revisit performance requirements every sprint meeting • Have a project manager who checks our performance against requirements

Complete Risk Assessment

Risk #	Risk	Type	Likelihood #	Consequence #	Risk Mitigation Action
6	Integration issues between subsystems	Technical	5	4	• Define clear inputs and outputs of each subsystem in work breakdown structure • Host end-of-sprint meetings • Create documentation at the end of every sprint
7	Camera hardware fails	Technical	2	4	• Store camera in a safe location • Design pipeline for the use of the camera • Ask sponsor for a backup camera to use in an emergency • Find another camera online to order in case of emergency
8	ROS and IGSTK data conversion difficulties	Technical	0	0	• Schedule project to have enough time to determine and fix potential problems • Research data types needed for ROS and IGSTK visualization • **Risk mitigated: Not using IGSTK**
9	Team member has difficulties working on their part of the project	Programmatic	5	2	• Schedule primary and secondary roles, so all work tasks have two owners • Have time during end-of-sprint meetings to communicate issues • Twice-a-week standups
10	Development Environment Incompatibility	Technical	0	0	• Use Docker so that everyone's ROS environment is set up the same • Train on ROS and Docker during the winter break • **Risk mitigated: MRSD system used for central development and access via SSH**

Complete Risk Assessment

Risk #	Risk	Type	Likelihood #	Consequence #	Risk Mitigation Action
11	Unable to access workspace	Programmatic	1	5	• Set up simulation environment on everyone's personal computer • Discuss with sponsor potential back-up workspace
12	End effector development delays	Technical	4	4	• Start early and lock design by October 15th • Brainstorm multiple solutions and 3D print to test before final manufacturing • Make system simple enough to get it manufactured within the university; use 3D printed design as a fallback
13	PCB Failure & Delays	Technical	4	4	• Make a breadboard prototype and test updated circuit • Seek feedback from Luis • Off-the-shelf integrated circuits to mitigate complexity of PCB • Order spares
14	Dynamic compensation not achievable	Technical	3	3	• Iterate with multiple control architectures • Utilize earlier compensation solution as a fallback • Evaluate need for isolating controller from ROS • Benchmark latencies in system • Use pub/sub communication instead of server/client communication
15	System robustness issues	Technical	4	3	• Create internal deadlines • Start testing early (by Oct 31st) • Fallback on the earlier working demo by making new changes in a separate branch • Allocate last two weeks for system optimization

Complete Risk Assessment

Risk #	Risk	Type	Likelihood #	Consequence #	Risk Mitigation Action
16	Reamer does not ream rigid bone	Technical	3	2	• Fallback on foam bones • Order bones early for rigid bone testing
17	UI does not integrate with system	Technical	4	2	• Start working on the UI early and integrate in a step-by-step basis • Plan architecture and consult each stakeholder before implementation • Start testing by Oct 31st

Likelihood	5	#10	#9			
	4		#3, #17	#14	#5, #12, #13	#6
	3		#16	#4	#15	
	2				#7	#2
	1	#1, #8				#11
		1	2	3	4	5
		Consequence				

Questions?