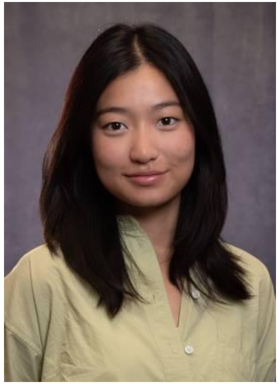
Multi-Agent Geometric Inspection and Classification (MAGIC)

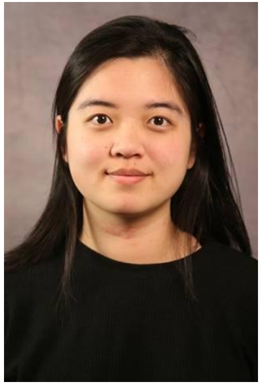
Team H

System Development Review

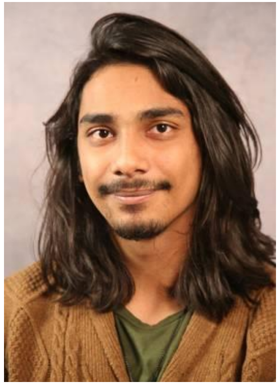
The Team



Megan Lee



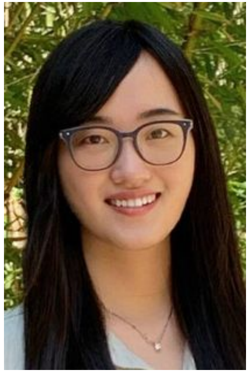
Emma Hon



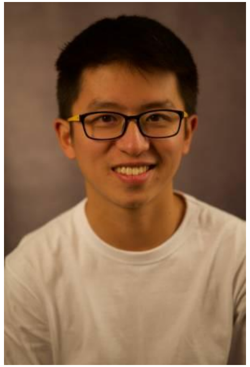
Kartik Agrawal

Kailash Jagadeesh

Shreya Ragi



Jiaoyang Li



Phillip Huang

Yorai Shaoul

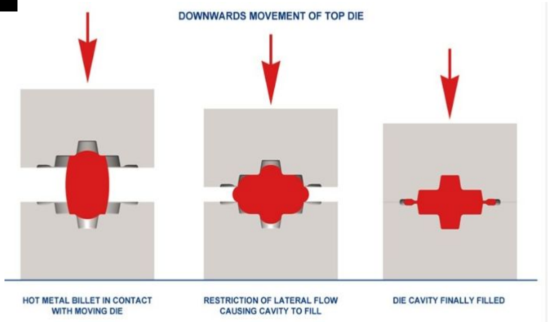
01

Project Recap

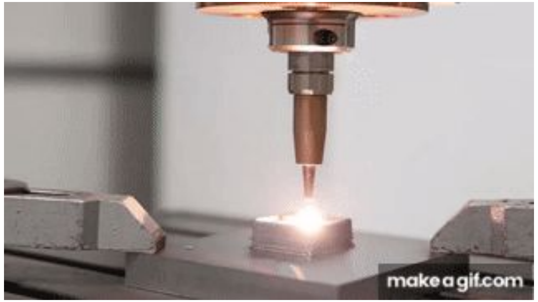
Manufacturing Process

Casting

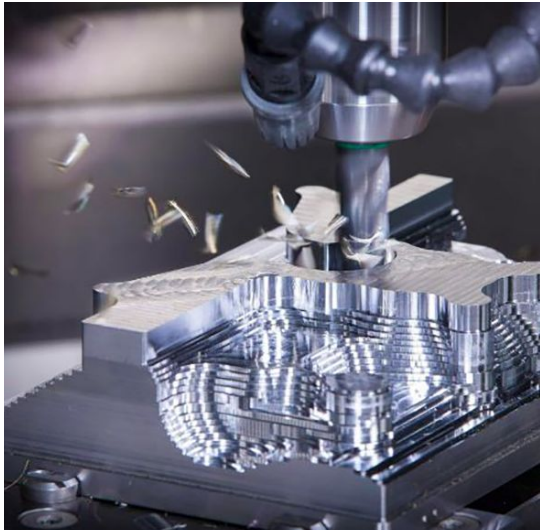
Forging



WAAM

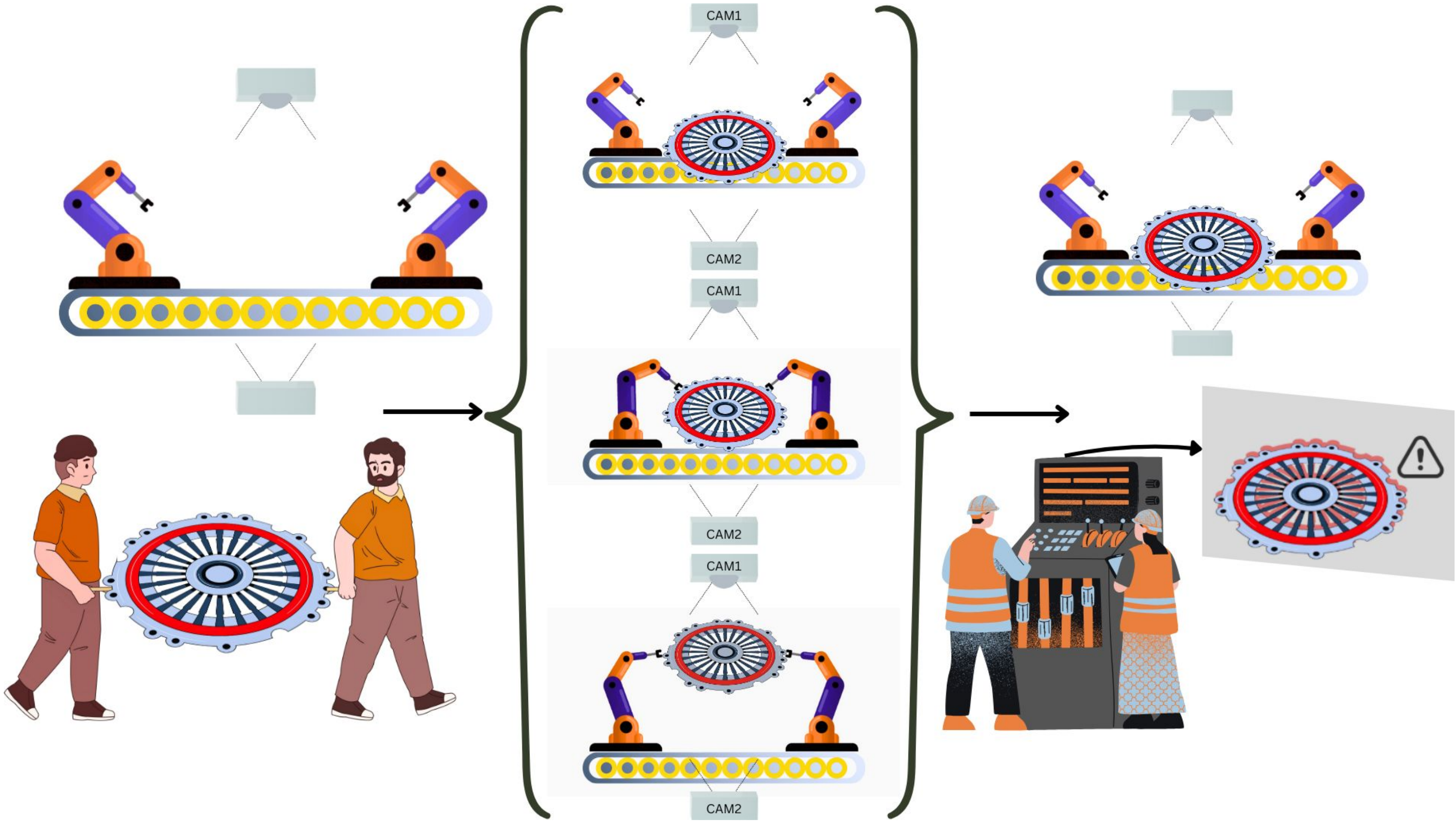


CNC Finishing

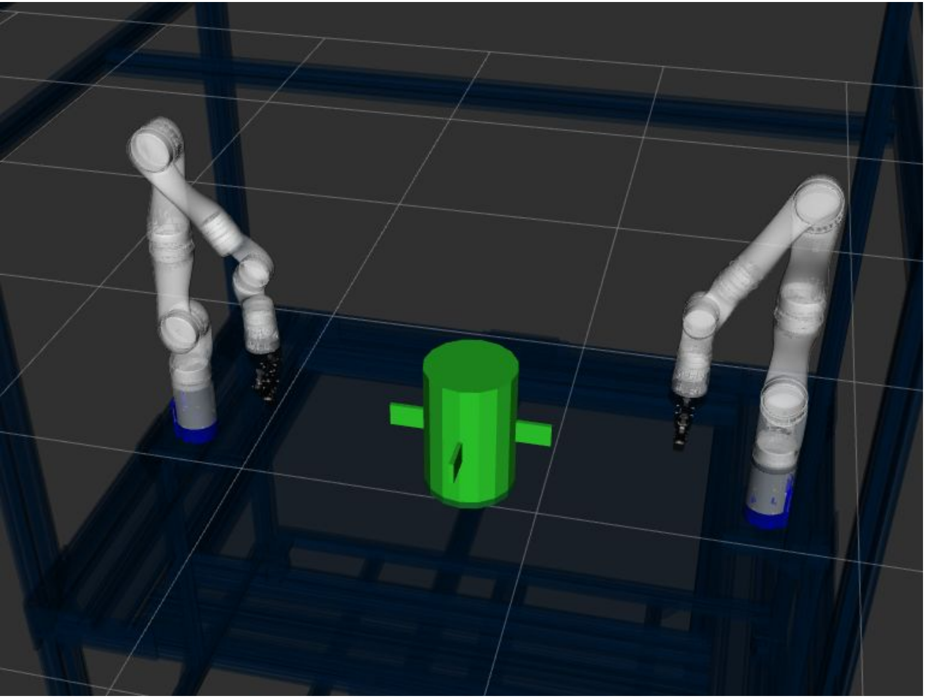


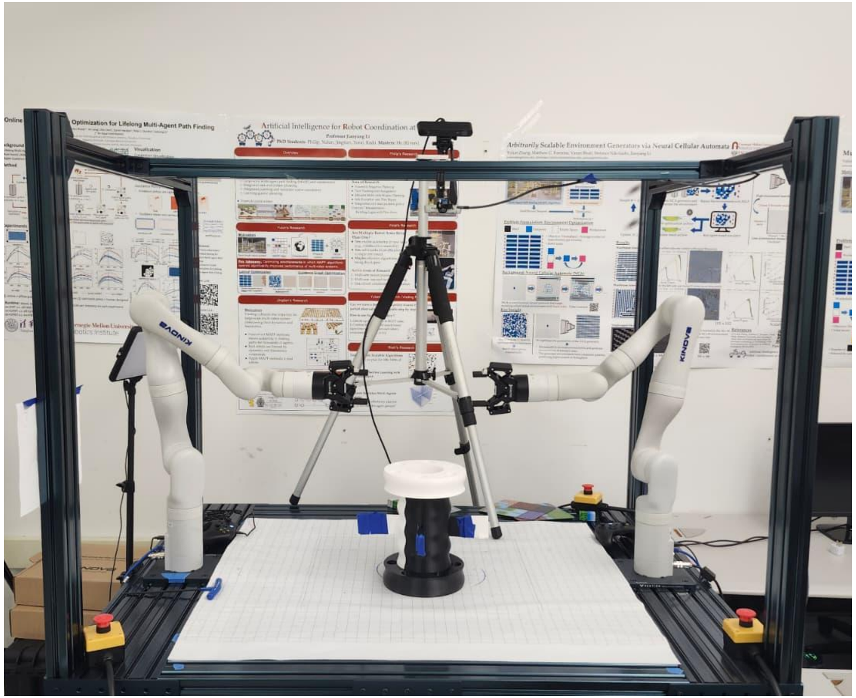
Our Use Case

Project Description



Overall System





Functional Requirements (No Changes)

Functional Requirement	Performance Requirements
M.F.1 Sense and estimate part pose	M.P.1 Detect given grasp points with 90% of the time
M.F.2 Plan arm trajectory and move to desired point	M.P.2.1 Plan movement inside valid zones 100% of the time M.P.2.2 Plan desired paths for both arms within 4.4 $\mp$ 3.4 seconds
M.F.3 Pick Up and Manipulate Part	M.P.3.1 Pick up and manipulate the part successfully 4 out of 5 times
M.F.4 Perform 3D Reconstruction	M.P.4.1 3 cm precision M.P.4.2 Construct within 10 minutes
M.F.5 Compare to ground truth and calculate differences in surface contours	M.P.5.1 Robust to outliers 95% of the time
M.F.6 Avoid causing surface damage to samples	M.P.6 No surface change to part after manipulation 80% of the time

02

Current System Status

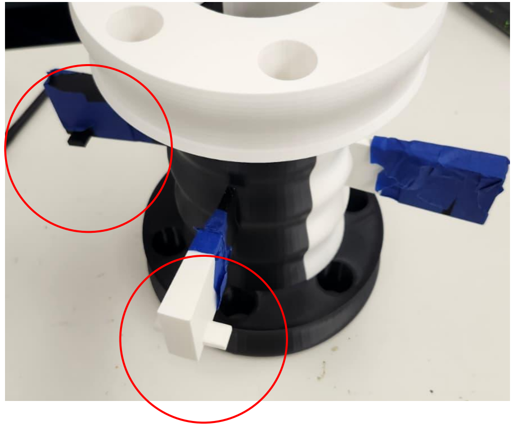
Perception Subsystem

Function Description & Current Functionality

➤ **Pose Estimation**

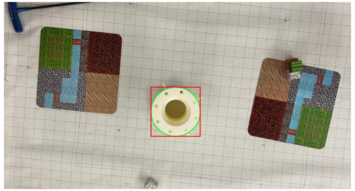
Environment Data

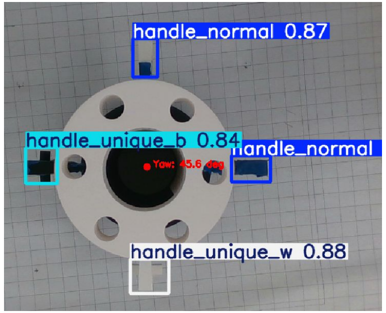
- Uses Overhead Intel Realsense camera
- Has uniquely designed handles



Pose Estimation

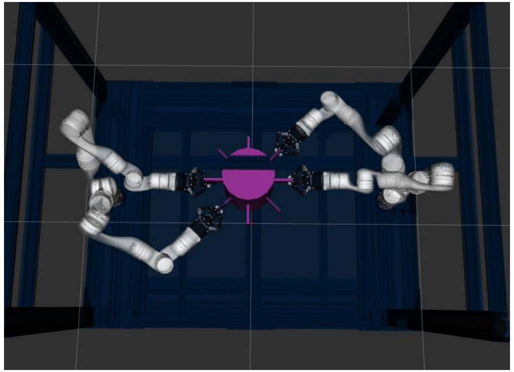
- Learning based one shot detector gives yaw based on handles
- Circle Centroid give x, y position





Go To Pose + Pick Up

- Moveit plans path to x, y, yaw goal pose



CHALLENGES

- Cannot obtain yaw for a symmetric object
- Pose can be estimated anywhere in the environment but arms cannot plan to reach

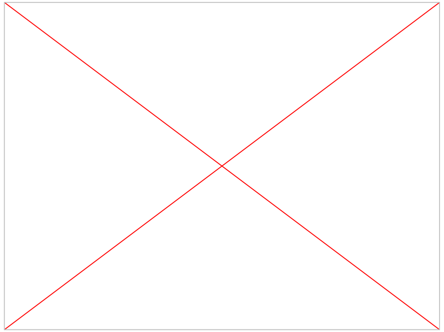
Function Description & Current Functionality

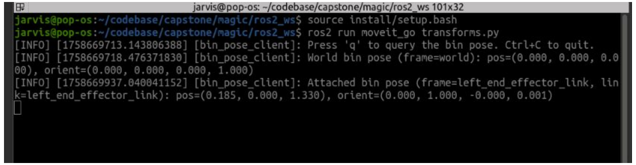
➤ **3D Reconstruction**

Manipulation Data → **Reconstruction** → **Ground Truth Comparison**

Manipulation Data

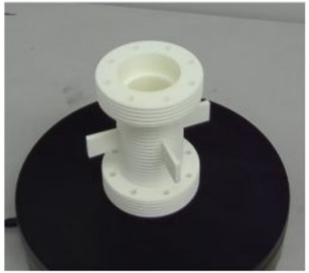
- Object motion recorded using ZED camera
- Transforms obtained for the center point between both grippers using IK

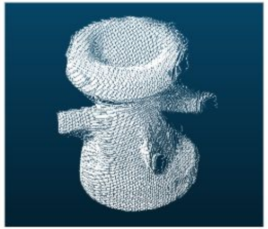




Reconstruction

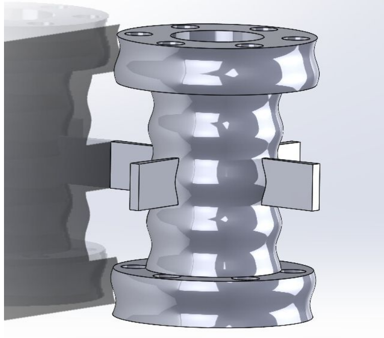
- SAM 2 segmentation
- Reconstruction using depth data and transforms





Ground Truth Comparison

- Explore CAD to Point Cloud comparison methods. Example



CHALLENGES

- Inaccurate transforms from Aruco pose estimation (OpenCV)
- Low precision depth data

Analysis and Tests

Test		Validation	Status	Notes
Test 1	Camera Calibration Verification	Low reprojection and disparity errors	Pass	Purchased new camera, factory calibration is reliable
Test 4	Object Pose Estimation	Translation error less than 5 cm and rotation error less than 5 degrees	Pass	Using classical CV for position and learning for orientation
Test 5	Extrinsic Calibration	Translation error less than 1 cm and rotation error less than 1 degrees	Pass	Between camera and world
Test 6	Transformation Verification	Position error less than 1 cm and orientation error less than 1 degrees	WIP	Relative transformation during motion
Test 8	3D reconstruction accuracy	1.Reconstruction dimensions are within 1 cm of object dimensions 2.Point cloud density is greater than 1000 points per m^2	WIP	Surface completeness still needs to be worked on
Test 9	Manipulation Camera Sync	Faster transform publish rate than camera frame rate	WIP	Transforms are published at 20 Hz and Camera fps is 15.

Manipulation Subsystem

Function Description

Last Semester

- KDL Kinematic Solver per arm → combine joint targets
- OMPL RRT* Planner
- JointTrajectoryController
- Bounding boxes constraining workspace

Now..

- Removed bounding boxes
- Cartesian Based Planning with waypoints every 1cm
- Each arm gets trajectory, interpolated with same start and end time for synchronicity with collision checking
- FCL (Flexible Collision Library)

Challenges

➔ Frequent replanning needed due to randomized search methods

➔ Failed IK due to workspace constraints and combined joint targets

Improvements

➔ Better arm synchronization and coordination

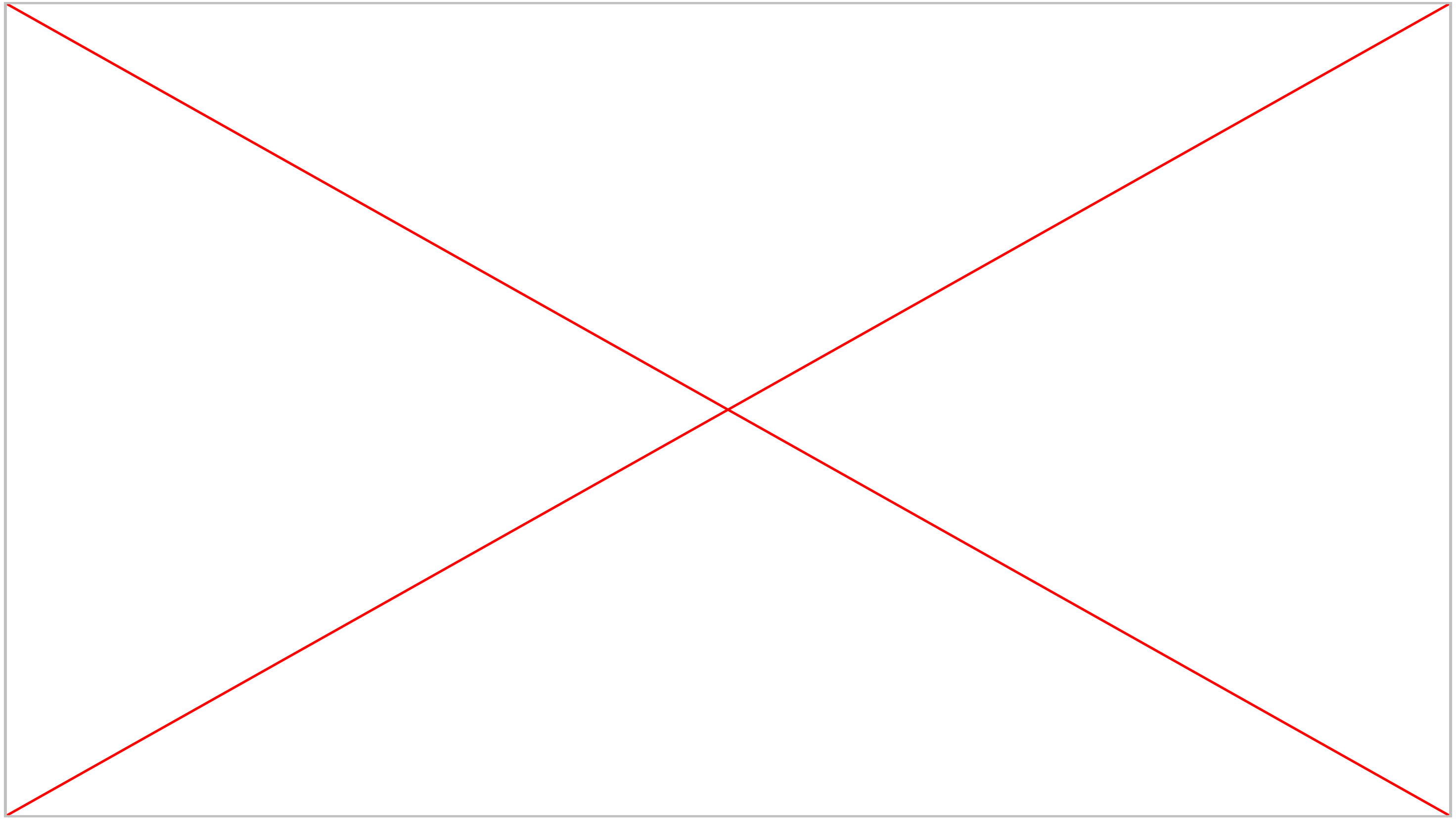
➔ Robust planning (no random based search)

➔ No more replanning

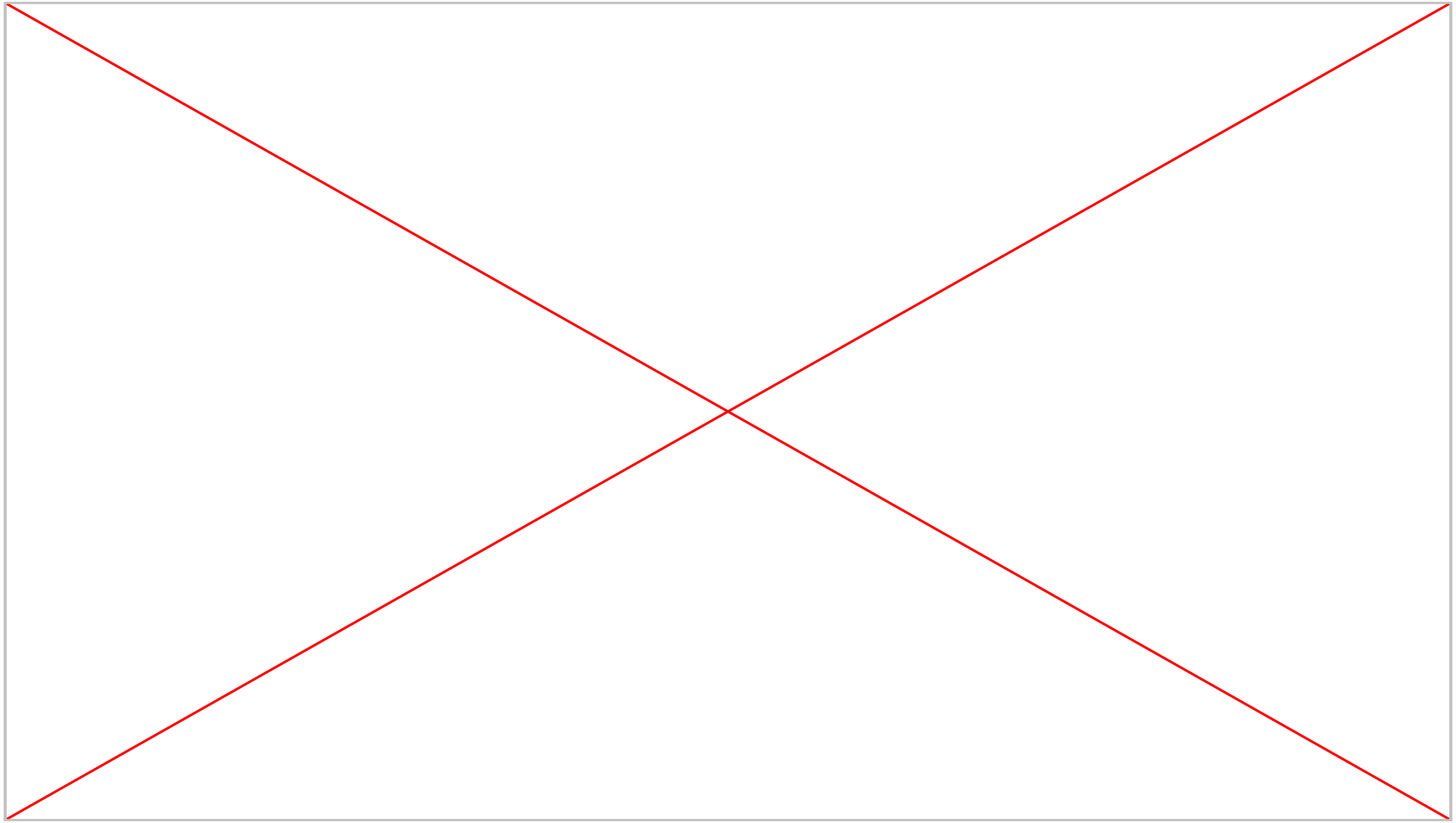
➔ Flexible to object position and angle

Current Functionality

- Completed manipulation policy



- Deployed on arms with new test object
- Integration with pose estimation in the x and y position
    - In the process of integrating angle approach



Analysis and Tests

Test		Validation	Status	Notes
Test 2	3D-Printed Object Grasp Test	plan and execute to grasp points with an 80%+ success	Pass	Able to grasp new test object
Test 3	Joint Constraint Motion for 360 Rotation	1. Orientation axis error ≤ 0.5° throughout spin 2. EE positional drift ≤ 10 mm 3. Locked joint deviation ≤ 0.2°	Pass	Able to lock joints to do 360 rotation on the end effectors
Test 7	Full Manipulation Policy Robustness	execute full FSM with an 80% or higher success rate.	Pass	90% success rate with 20 runs
Test 10	Integration of Pose Estimation with Manipulation	1. ≤10 ms latency between systems 2. grasp within 2 cm translation and 2° rotation error of the pose estimation	WIP	Latency check passed, 2cm and 2 degree error in progress

Remaining Challenges

- Integration with Manipulation - motion policy revisions
- Recording accurate transforms
- Time synchronization between camera frames and transformations - interpolations may cause inaccuracies
- Inaccurate stereo depth due to lack of features - impacts reconstruction accuracy
- Exploring the limitations of object configurations that arms can reach
- Dual arm coordination has slight timing issues

03

Project Management

Schedule Status

Are we on schedule

Short Answer: **YES**

- Subsystems modules finished.
- Initial Integration finished.

1. Actively identifying and improving gaps in sub-modules
2. Fine-tuning requirements and outputs of each subsystems.

Fall Semester Test Plan

Manipulation

- Optimize 3D printed object grasp strategies for consistency and success rate.
- Test constraint handling and robustness of the manipulation policy under varied conditions.

Perception

- Verify camera pre-calibration, extrinsic calibration, and transformation accuracy.
- Evaluate object 4D pose estimation and 3D reconstruction performance.
- Validate camera synchronization and perception data reliability

Integration

- Test integration of pose estimation with manipulation to ensure accurate spatial alignment.
- Verify transformation consistency between robot arms and 3D reconstruction outputs.
- Confirm synchronization across perception and manipulation systems during operation.
- Conduct the Fall Validation Demonstration to validate full system functionality and robustness.

Progress Reviews - capability milestones

PR 10

1. Finish Integration of 3D reconstruction with transforms from the arms.
2. Start Full Integration, to identify gaps and bugs.

PR 11

1. Complete full perception-manipulation system integration
2. Perform comprehensive testing and validation across all modules

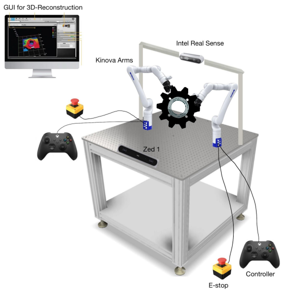
FALL Validation Demonstration and Encore

Location: *Wean Hall 1302 (ARCS lab)*

Equipment:

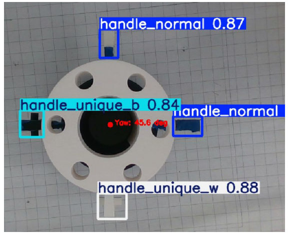
- *Two Kinova arms*
- *desktop workstation*
- *3D printed objects (regular + stretch goal)*
- *ZED 2 Stereo Camera*
- *Realsense Overhead Camera*

Sequence of Events

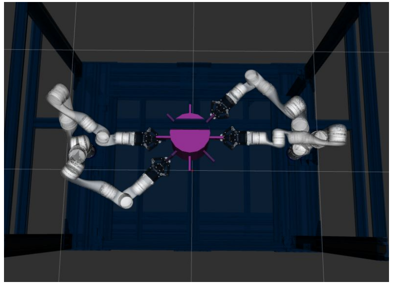


Setup

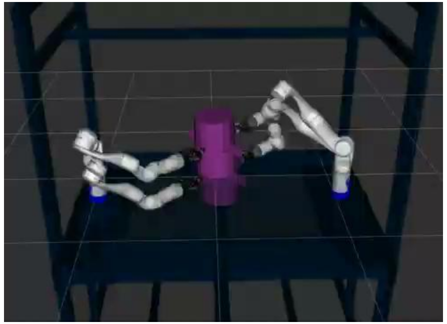
Part
Placed



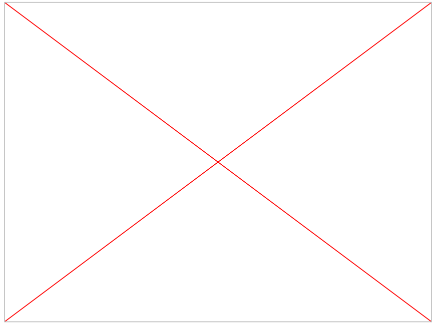
Pose estimation



Planning and
grasp

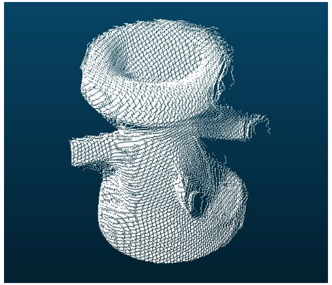


Lift up



Capturing
surfaces

Place back



Performance Metrics

Metric	Target	Pass Criteria
Grasp Accuracy	±2 cm, ±2 deg	All grasp points reached within tolerance
Planning Time	4 ± 3 sec	Stable and repeatable trajectory generation
3D Reconstruction Precision	≤ 3 cm	Reconstruction completed within 10 min
Repeatability	≥ 3 successful runs	No unexpected errors or delays
Object Integrity	No damage	Safe and stable manipulation

Budget

Out of $5000, used

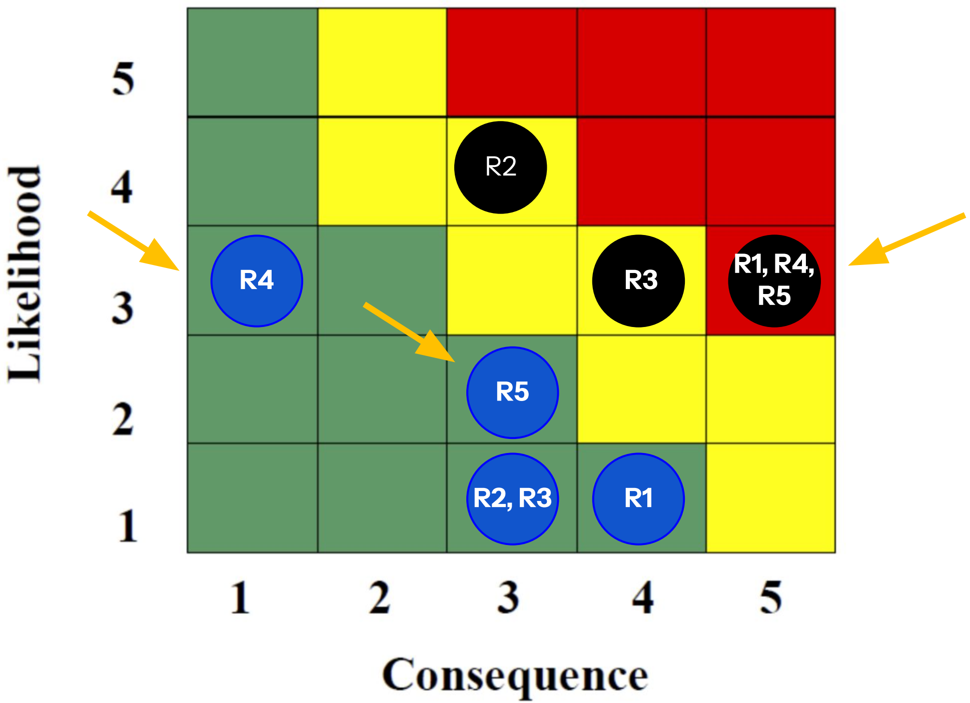
24.34%

Item	**$**
Test Object	150
Experiment (e.g. turntable)	93
Monitor	320
Lab setup (e.g. light)	85
Camera	569
Total	**1217**

Risk Management

ID	Risk	Type	Likelihood	Consequence	Mitigation
R1	Robot arms collide with undefined environment	Technical, Programmatic, Cost	2	5	During testing, someone is always on the manual e-stop.
R2	Falling behind schedule because of learning curve	Schedule	4	3	Seek mentorship early
R3	Resource availability	Schedule	2	4	Schedule lab time efficiently Set up SSH/TeamViewer Fall back on simulation if it can't be done on real hardware. Use Kinova robot in the AI maker space as a backup.
R4	End effector/Test object breaks	Technical, Cost	3	5	Keep backup items readily available and ensure quick-change mechanisms for rapid replacement.
R5	Integration issues between subsystem	Schedule	3	5	Perform unit tests and subsystem validation experiments continuously. Integrate one subsystem at a time.

Risk Likelihood-Consequence Table



Thank You!!

Questions?