# Collaborative Cyborg Backpack Platform (CoBorg)

## Preliminary Design Review

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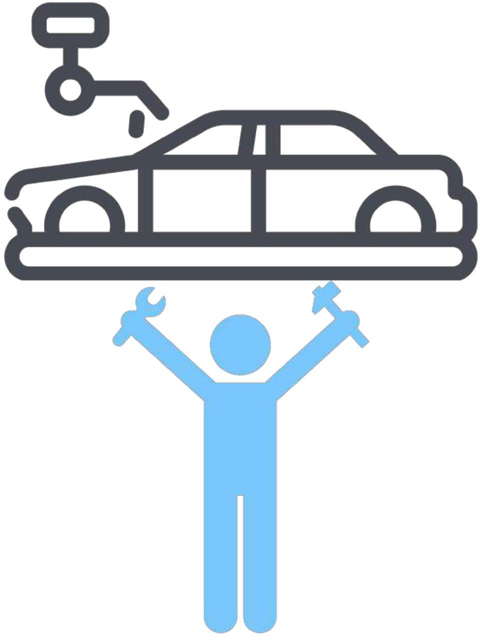
THE ROBOTICS INSTITUTE

Carnegie Mellon University

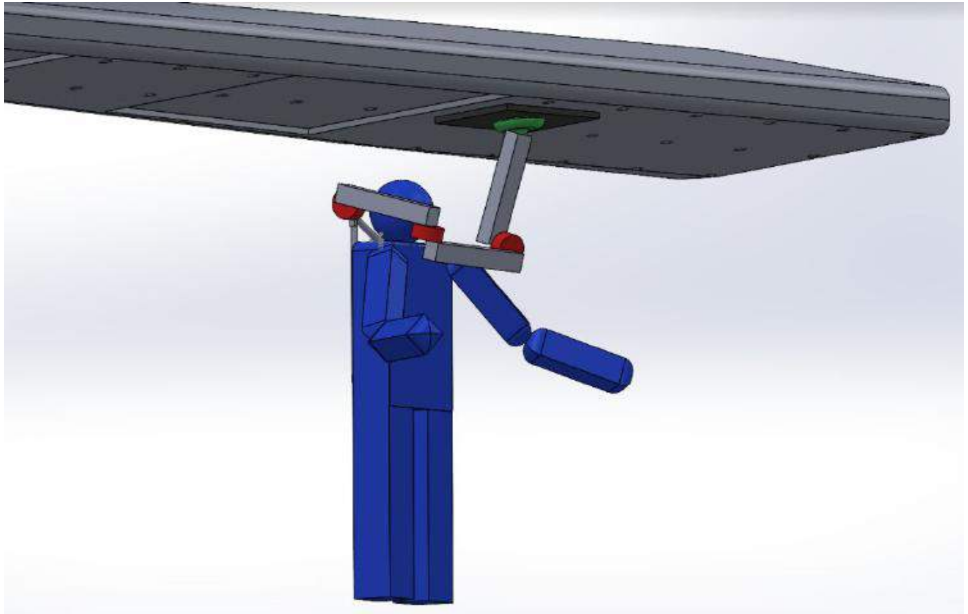
# Project Description Overview

Productivity
Safety

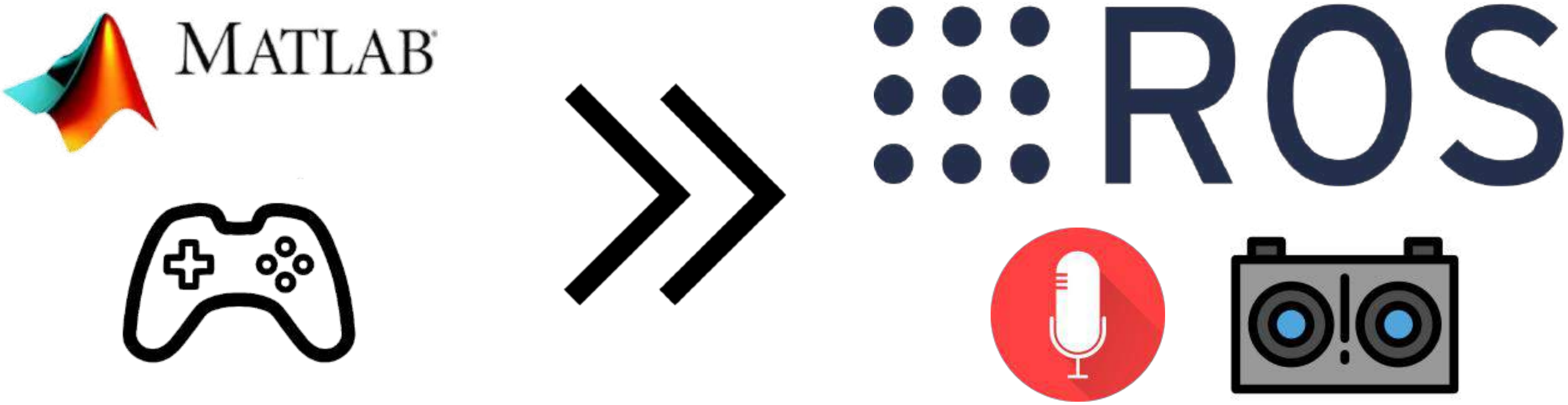
Injuries
Low Impact Roles



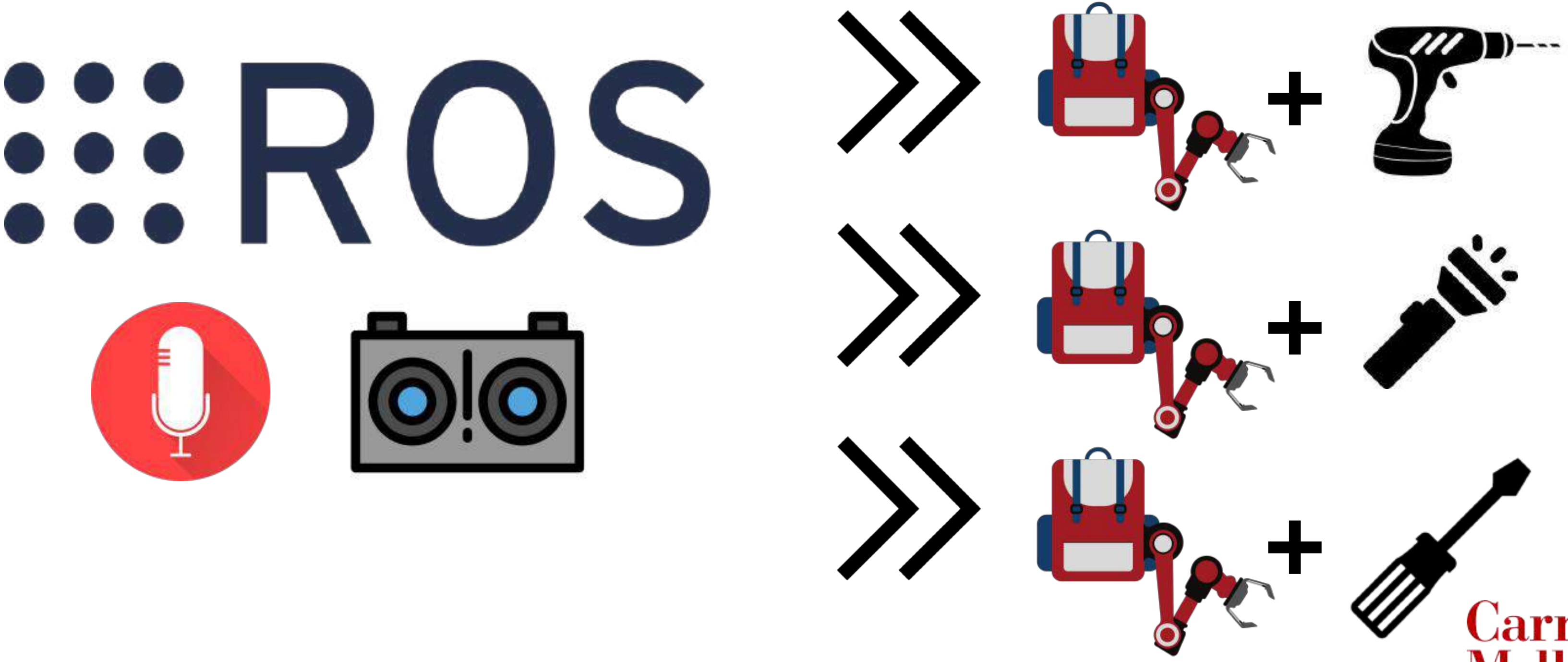
# Industrial Manufacturing Use Case



# Project Description: Spring 2021



# Project Description: Fall 2021

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# Mandatory Functional Requirements

FM-1: Shall detect intended object in 3D space.

FM-2: Shall move end effector to intended object in 3D space.

FM-3: Shall maintain object position in 3D space.

FM-4: Shall respond to preconfigured voice commands.

FM-5: Shall release control of object at current position.

FM-6: Shall navigate to designated home position.

# Mandatory Performance Requirements

PM-1.1: Will have 60% accuracy of detecting indicated part position in 3D space.

PM-1.2: Will detect intended object within 5 seconds of when the move command is issued.

PM-2: Will reach ~~the target~~ planned target position 60% of the time.

PM-3.1: Will maintain ~~target in place~~ target's spatial position with less than ~~12~~ 6 in of error margin.

PM-3.2: Will ~~provide~~ lift at least 2 lbs at full horizontal extension ~~to hold part~~.

PM-4.1: Will be able to understand the voice command 60% of the time.

PM-4.2: Will be able to understand 2+ unique voice commands.

PM-4.3: Will be able to understand commands of 2+ words in length.

PM-5: Will release object within 5 seconds of when the release command is issued.

PM-6: Will bring full robot arm to within 20 inch of the point of attachment to the backpack.

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# Mandatory Non-functional Requirements

| | |
|---|---|
| NM-1: | Will be ergonomic for spinal comfort. |
| NM-2: | Will weigh less than 40 lbs. |
| NM-3: | Will be aesthetically pleasing. |
| NM-4: | Will operate safely. |
| NM-5: | Will be simple to operate. |
| NM-6: | Will be operable untethered for 20 minutes. |
| NM-7: | Will require minimal part modification. |
| NM-8: | Will be operable on a portable computer. |

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# Desired Requirements

**Functional:**

FD-1: Shall re-orient the object based on the voice command by user.

**Performance:**

PD-1.1: Must be able to detect part while 20% of the part is occluded.

PD-1.2: Must be able to be invariant to part texture, specifically matte finish and gloss finish.

PD-1.3: Shall detect the orientation of the part (x,y,z,w,p,r) with error no greater than 45°.

**Non-Functional:**

ND-1: Will be able to operate standalone (no WiFi).

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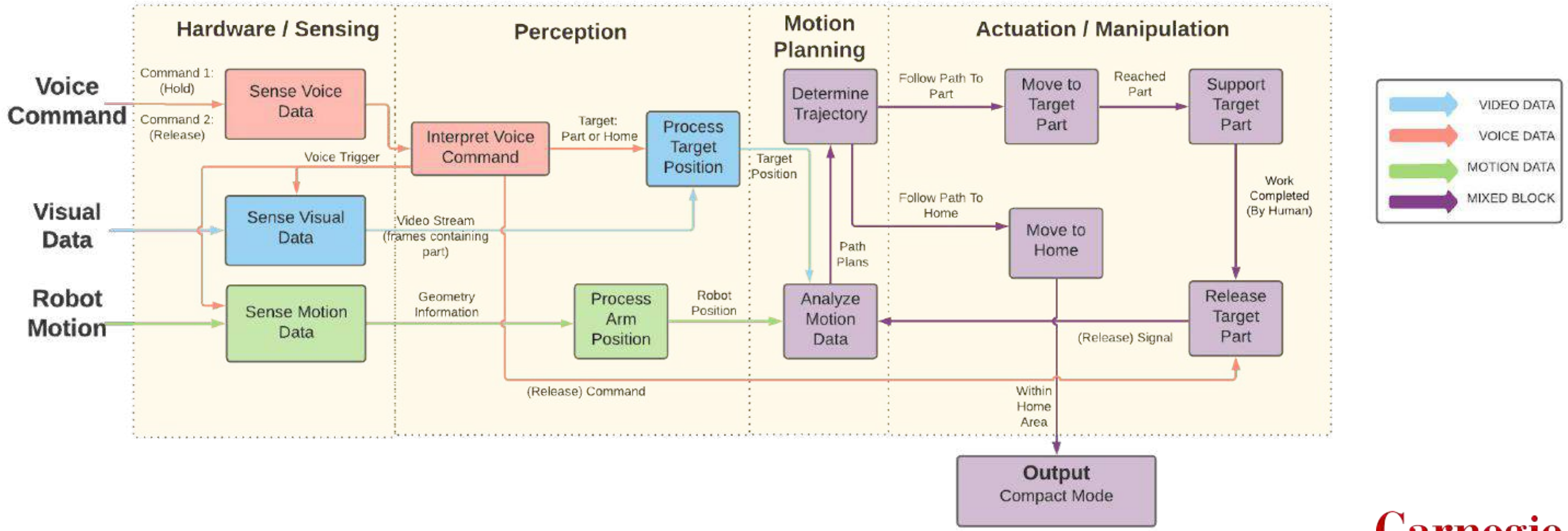
# Functional Architecture

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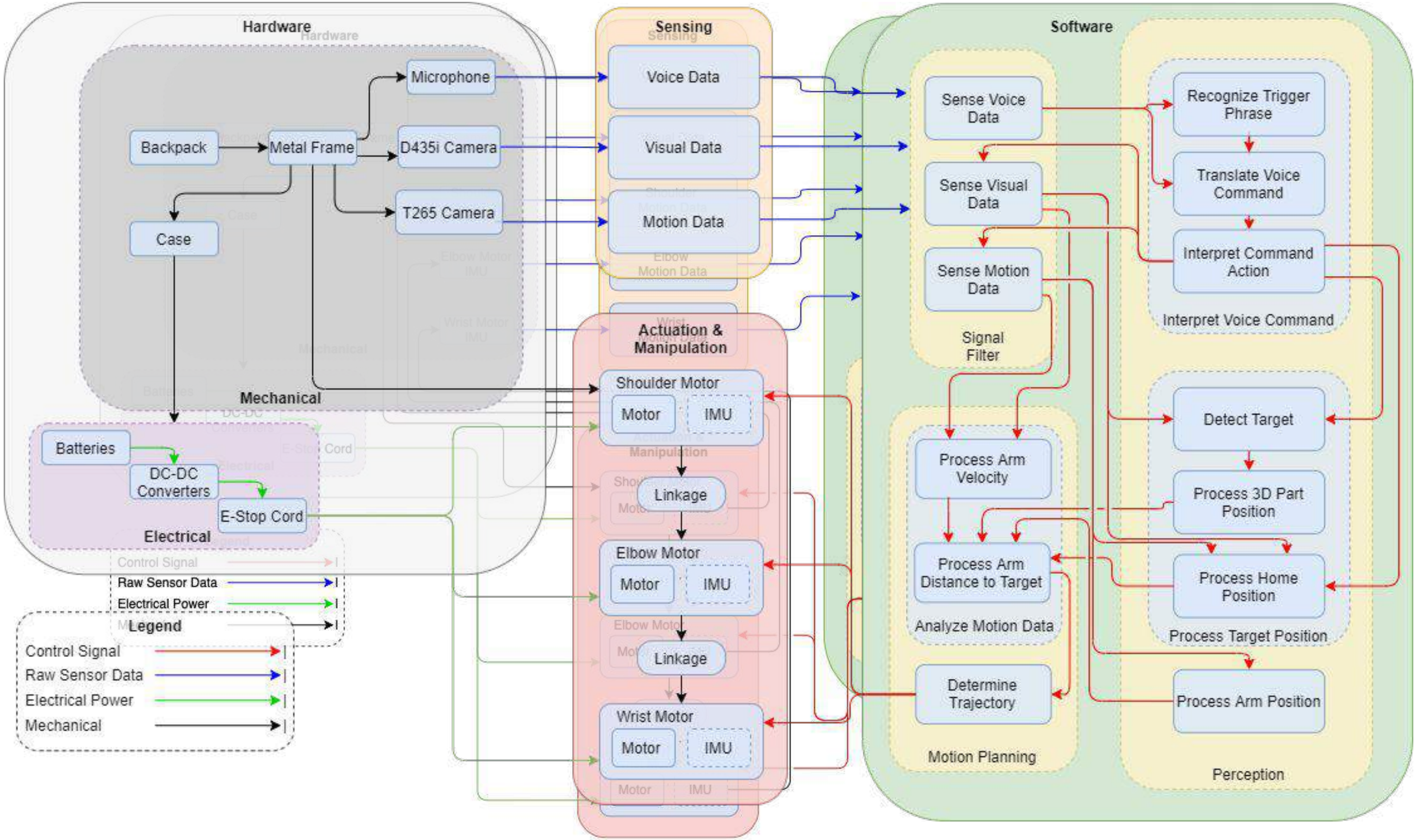
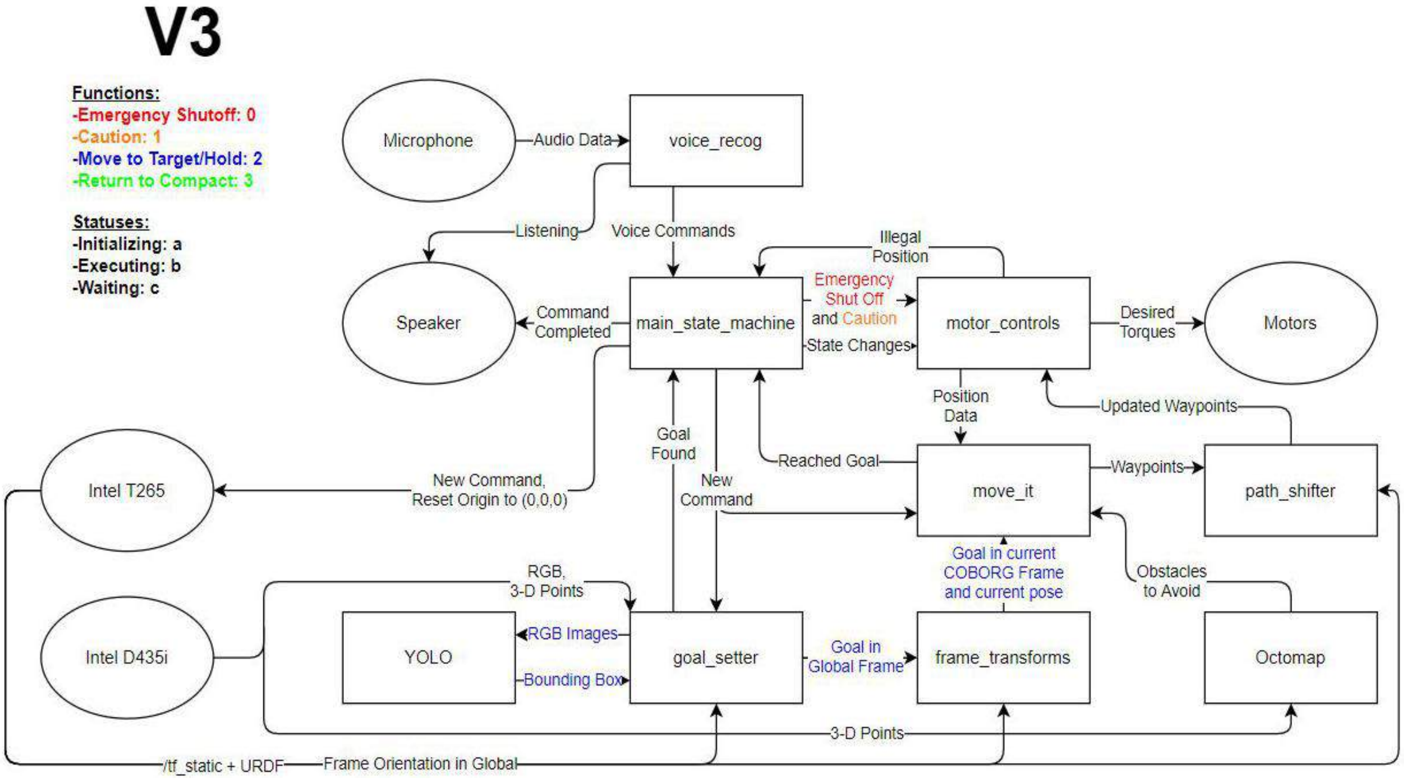
# Cyber-Physical Architecture





# Subsystem: Software Framework



# Subsystem: Hardware Framework

**Depth Camera -** Intel D435i

**Pose Camera -** Intel T265


**Microphone -** AU-UL10 USB Lavalier

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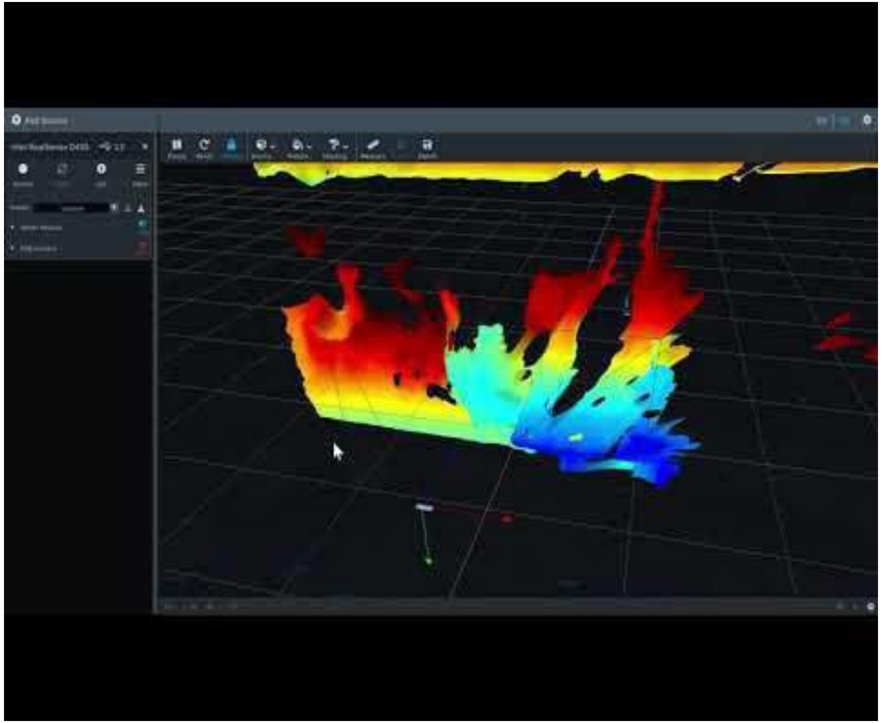
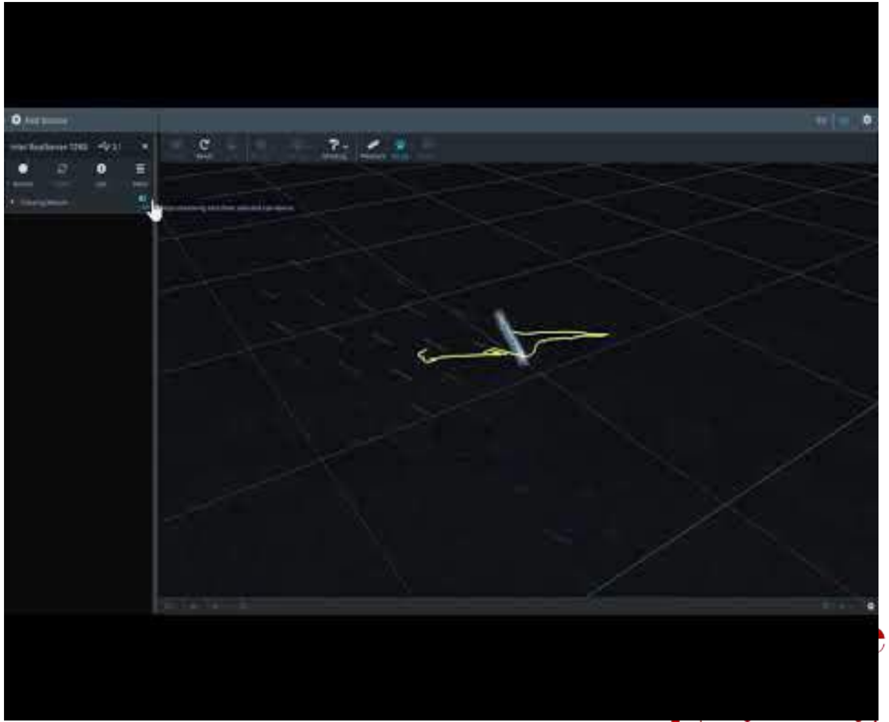
# Current Status: Hardware Framework

**Intel D435i** - Depth Camera



**Intel T265 -** Tracking (V-SLAM) Pose Camera



# Subsystem: Voice Recognition

Powered By CMUSphinx

**Input:** **Audio stream from Microphone**

**Output:** **Commands to the ROS framework main_state_machine**

**Process:**

- Recognize “COBORG” with PocketSphinx using a limited library
- Process following phrase with PocketSphinx using the full library
- Publish valid recognized commands to /voice_commands topic

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# Current Status: Voice Recognition

- Functional prototype model completed!
- Integrated into ROS framework
- Current Accuracy:

| Keywords | | Commands | |
|---|---|---|---|
| COBORG | 100.00% | Goal | 80.00% |
| Repeat: STOP | 80.00% | Home | 70.00% |
| | | Stop | 70.00% |
| | | Commands Overall | 73.33% |

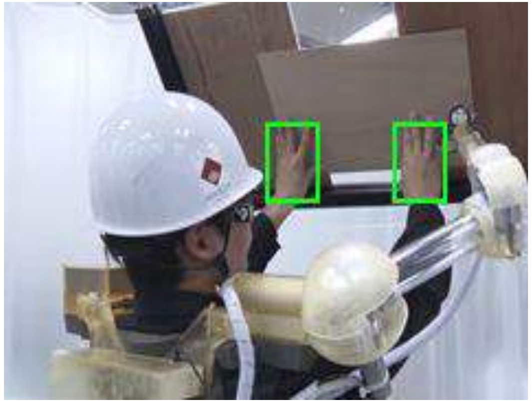
```
('Decoder Mode:', 'coborg')
('Decoder Mode:', 'lm')
('Result:', ['so'])
('Decoder Mode:', 'coborg')
('Decoder Mode:', 'coborg')
('Decoder Mode:', 'lm')
('Result:', ['wow'])
('Decoder Mode:', 'coborg')
('Decoder Mode:', 'coborg')
('Decoder Mode:', 'coborg')
('Decoder Mode:', 'coborg')
('Decoder Mode:', 'lm')
('Result:', ['yellow', 'working', 'away', 'nine', 'laps', 'of', 'infuriating', "
that's", 'us'])
('Decoder Mode:', 'coborg')
('Decoder Mode:', 'coborg')
('Decoder Mode:', 'coborg')
('Decoder Mode:', 'coborg')
```

# Subsystem: Perception

**Input:** **Raw RGB image + point cloud**

- D435i will outputs RGB raw image and also point cloud

Hand Detection



**Output:** **3D target part position relative to camera_link**

**Process:**

- 2D YOLO v3 hand detection to extract pixel level bounding box => ROS
- 3D Hand bounding boxes using point cloud data => ROS
- Post-process to get averaged 3D position of hands relative to camera_link => ROS

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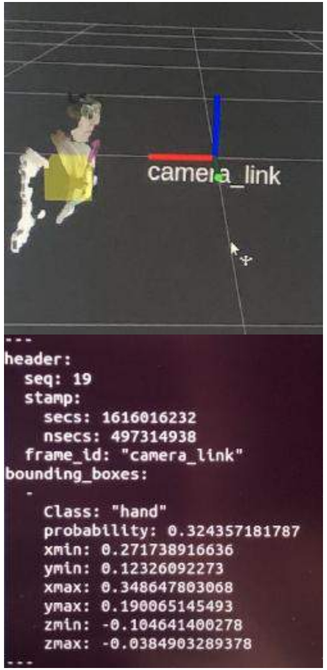
# Current Status: Perception

**2D YOLO hand detection**


**3D Hand bounding boxes**




**Averaged 3D position**

```
---
Class: "Avg on 2 hands"
x: 0.944481814901
y: 0.0347031770895
z: 0.0733169429004
---
```

**Accuracy Validation**

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# Subsystem: Actuated Manipulation

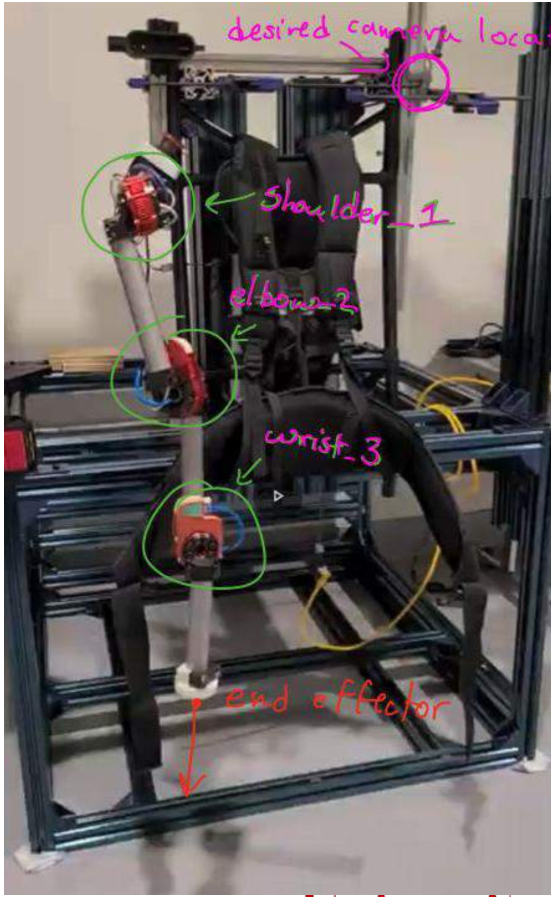
**Input: 3D position relative to camera_link + TF frame transforms + point cloud**

- Perception subsystem output 3D position of hands relative to camera_link
- TF frame transforms between global odom frame, camera_link and URDF frame
- D435i will outputs RGB raw image and also pointcloud

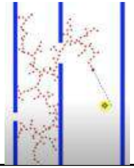
**Output: Robot actuation to goal states**

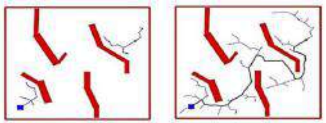
**Process:**

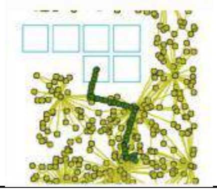
- Process 3D goal position relative to the camera_link
- Plan path from current state to goal state in free space
- Execute path
- Execute force/torque control
- Calculate temporal transform in t265_odom_frame
- Execute compensation actuation
- (Release) Upon release signal, execute release and “go home”



# Subsystem: Actuated Manipulation







| | RRT* | RRT-Connect | PRM* |
|---|---|---|---|
| Methodology | Optimal node graphing from start to goal | Two instances of node graphing at start **AND** goal | Builds node graph among 3D environment in multiple instances |
| Runtime Complexity [sec] | 1 - 6 | 0.05 - 1 | 2 - 6 |
| Non-static Environment Performance | Works well | Works well | Not optimized |
| Implementation to ROS? | MoveIt OMPL Motion Planning Library | | |
| Motivations | Trajectory path optimization over time | Efficient path planning framework | Multi-query option |

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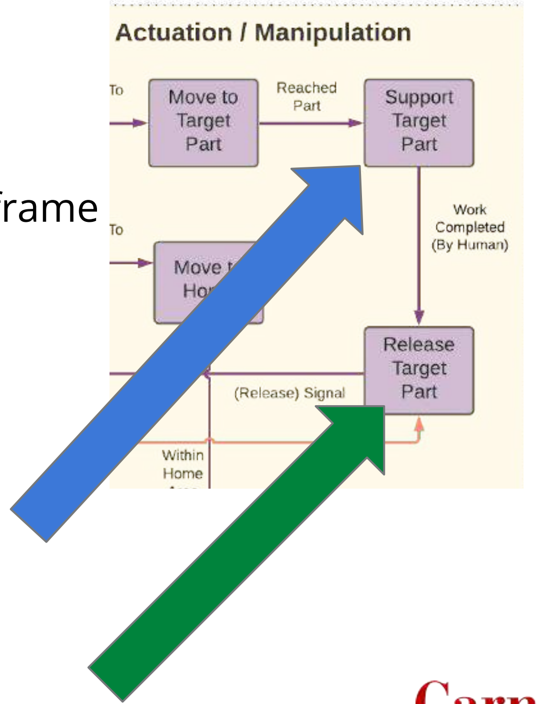
# Subsystem: Actuated Manipulation




**Stabilization**

**<u>Input:</u> Global frame transform**

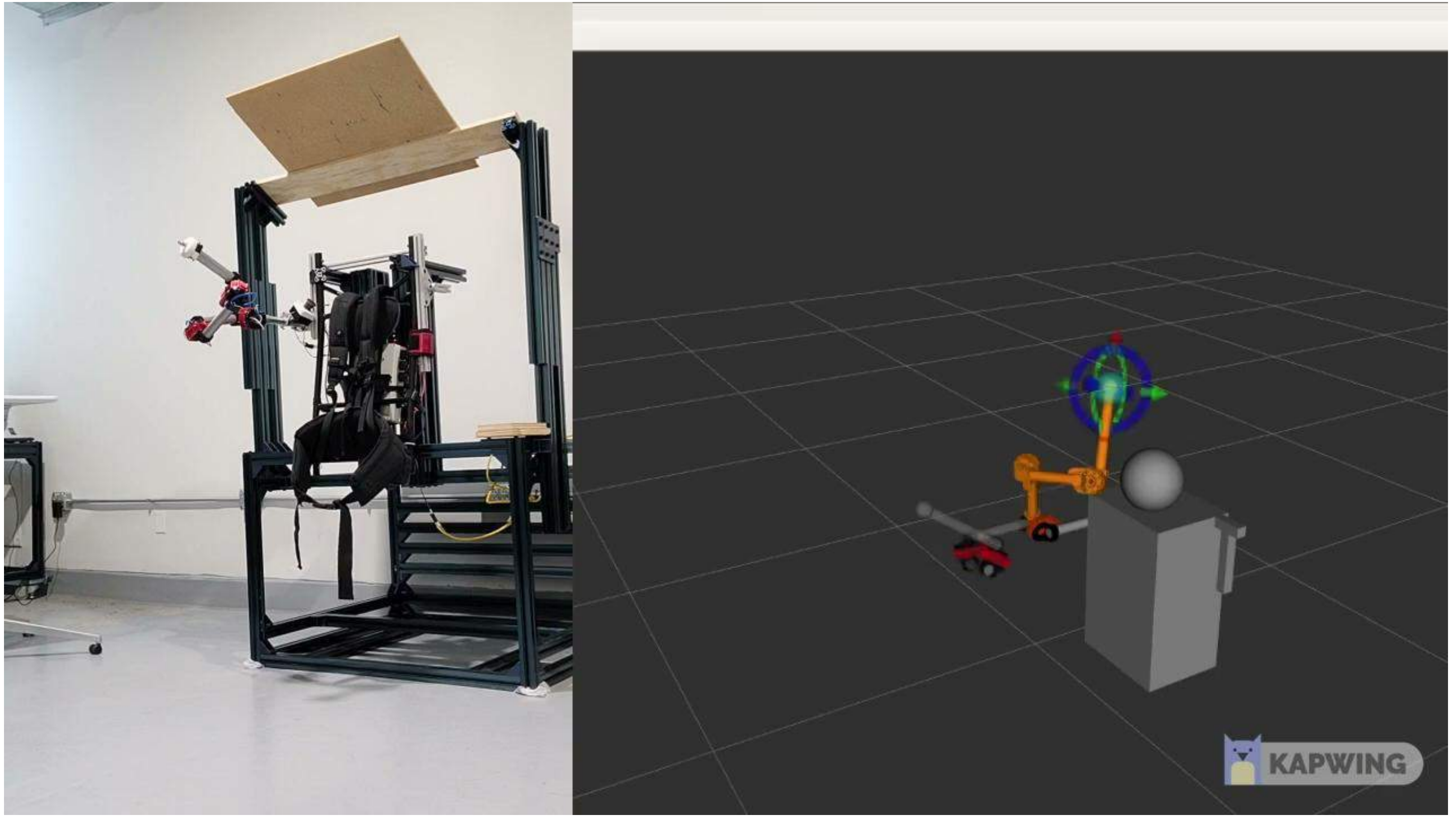
TF frame transforms between camera and t265_odom_frame

**<u>Output:</u> Robot force actuation to updated goal state**

**<u>Process:</u>**

- Execute force/torque control
- Calculate temporal transform in t265_odom_frame
- Update 3D goal position
- Execute compensation actuation
- (Release) Upon release signal, execute release and “go home” trajectory

# Current Status: Actuated Manipulation - PR 1

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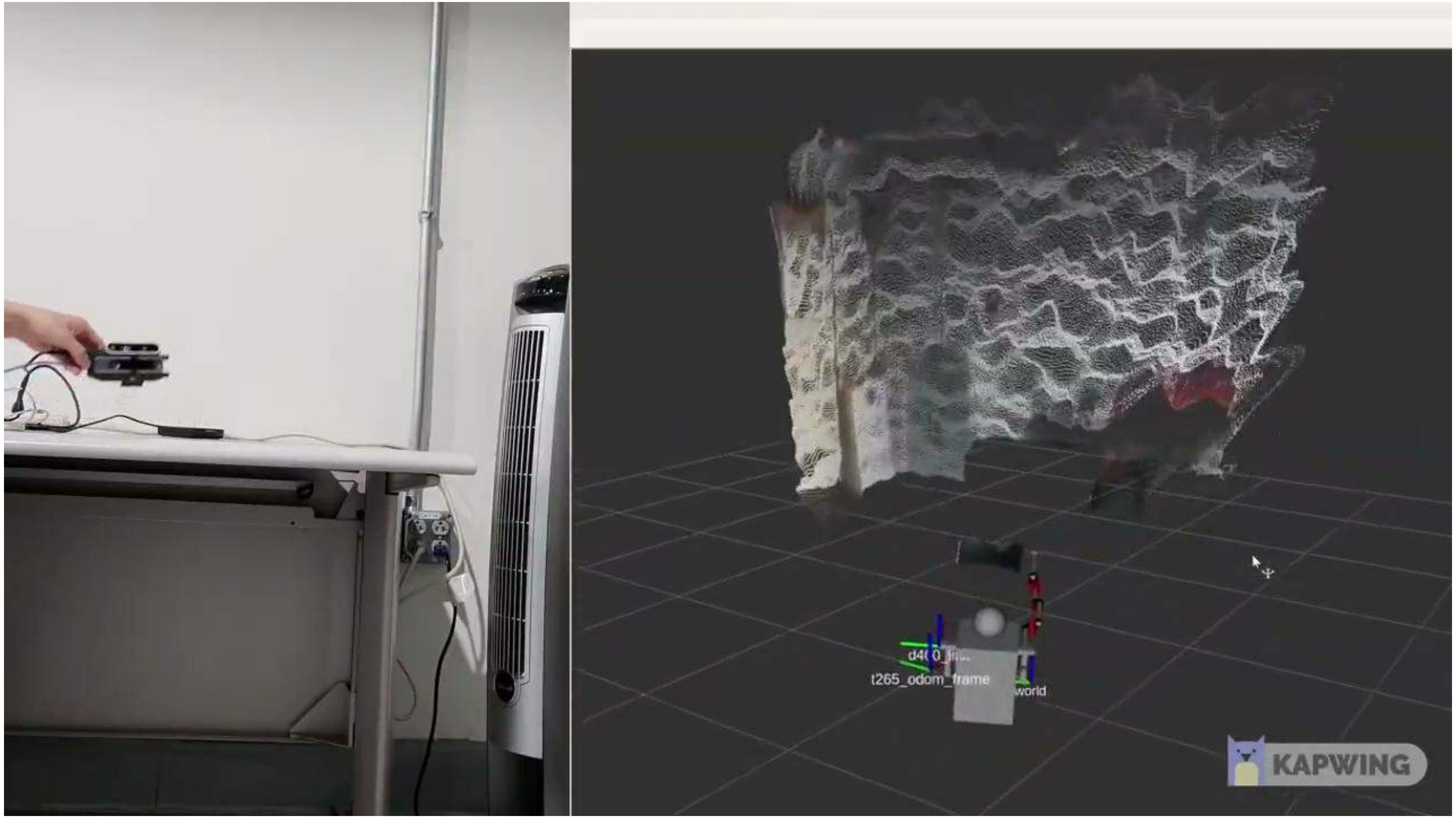
# Current Status: Actuated Manipulation - PR 2

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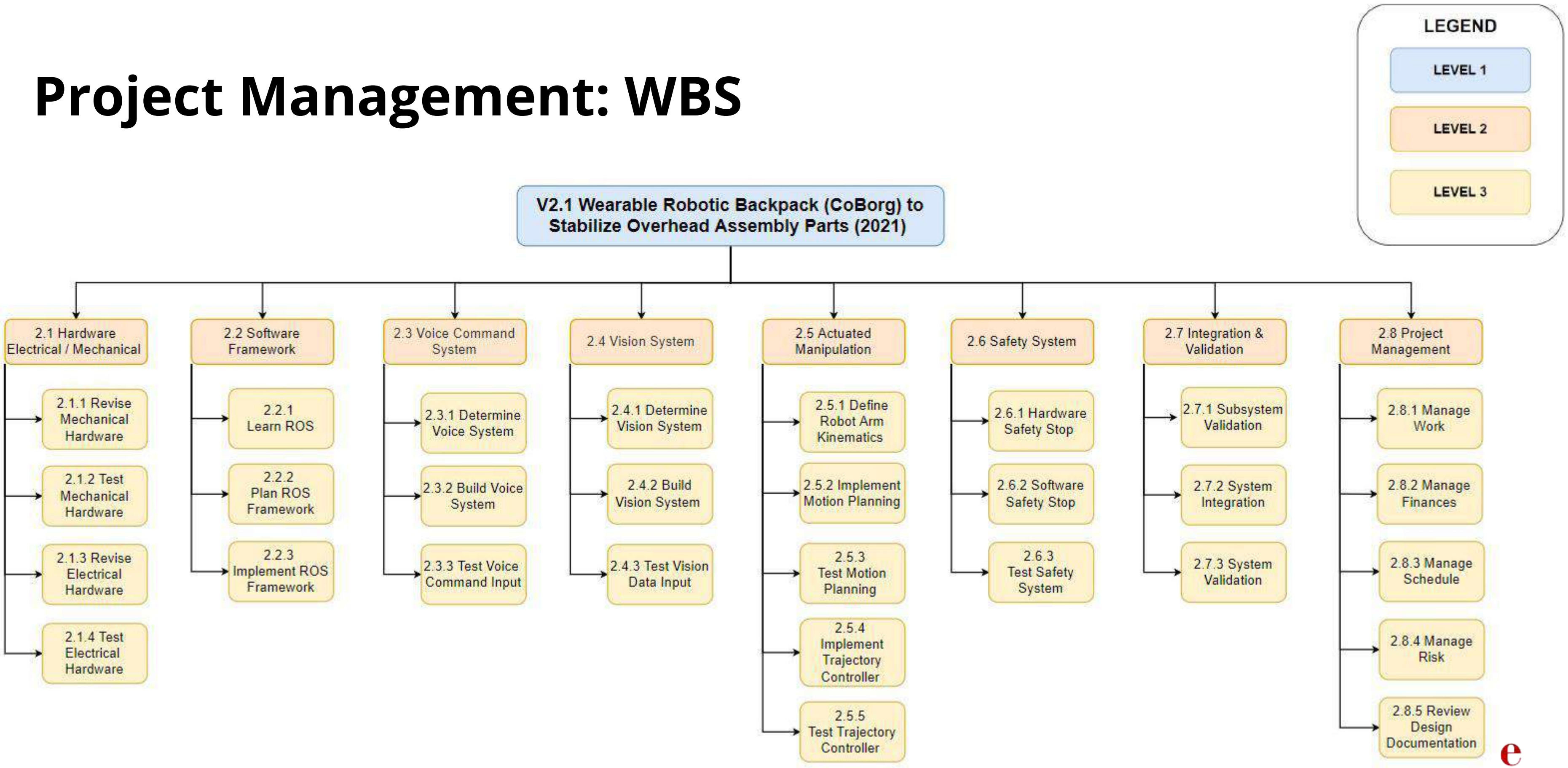
# Project Management: WBS

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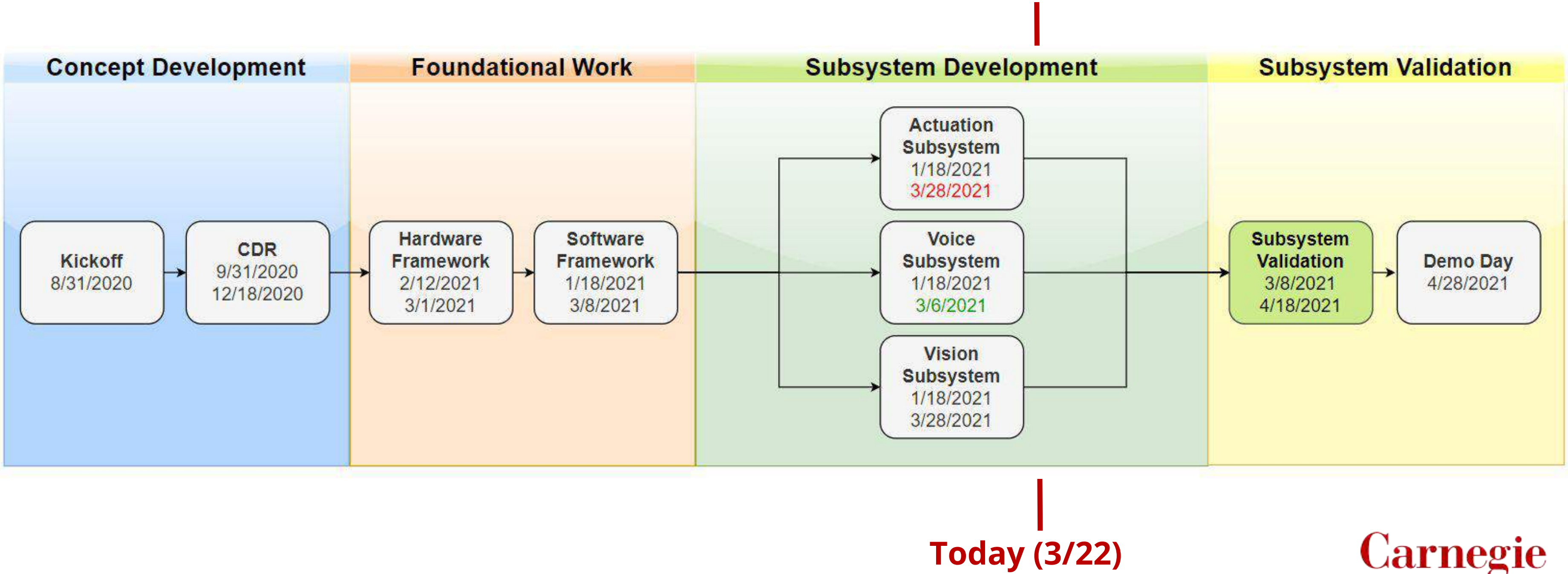
# Project Management: Spring Schedule (Updated)



# Project Management: PR3

| Functionality | Test Plan |
|---|---|
| Actuated Manipulation: | Create a ROS node that publishes a point every second to Move-It<br><br>Use this point to update the robot arm as it moves towards the goal |
| Vision System: | Have two 3D bounding boxes output to a single median point in ROS |
| Voice System: | Confirm accuracy requirements during integration |

# Project Management: PR4

| **Functionality** | **Test Plan** |
| --- | --- |
| Actuated Manipulation: | Perform torque/force control on robot arm<br><br>Validate Robot Arm Precision<br><br>Validate Motion Planning Time |
| Vision System: | Publish D435i point to robot arm through Move-It<br><br>Validate D435i Vision System Precision |

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# Project Management: SVD Overview

- **Testing subsystems independently**

- **Four different tests:**
  - Vision Subsystem
  - Actuated Manipulation Subsystem
  - Voice Subsystem
  - Nonfunctional

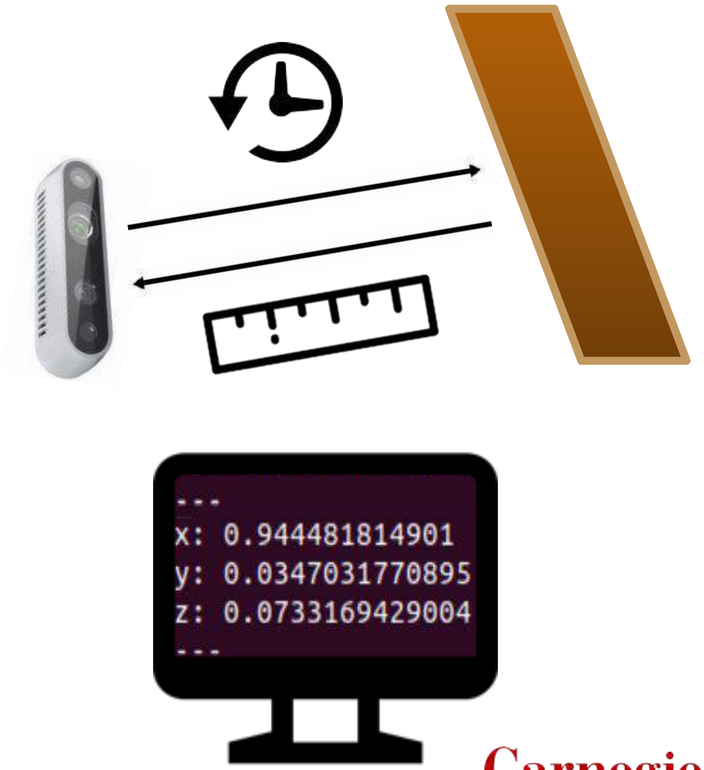
- **Location:** Newell Simon Hall - B512




https://www.google.com/url?sa=i&url=https%3A%2F%2Fwww.clipartkey.com%2Fview%2FiRbRTbi_validatorerrorsgraphic-cpsi-ltd-data-validation-automation%2F&psig=AOvVaw275_w1jDIzb4NLuXA7lgY8&ust=1616452312449000&source=images&cd=vfe&ved=0CAIQjRxqFwoTCIDBj6e4wu8CFQAAAAAdAAAAABAD

# PM: SVD - Vision Subsystem

| Functionality | Test Plan |
|---|---|
| PM1.1, PD1.3: Correctly and accurately detect part | Compare measurement to ground truth |
| PM1.2: Minimal lag time | Time process |
| PD1.1, PD1.2: Detect part while occluded and despite different surface finishes | Cover with hands, paint part |

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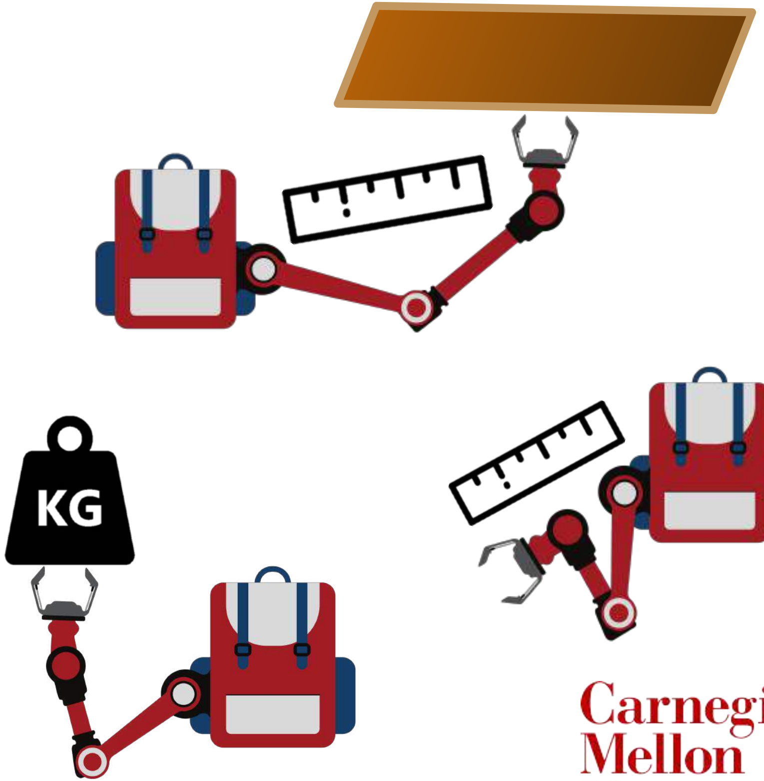
https://tinyurl.com/45tujufu https://tinyurl.com/249dv6m3 https://tinyurl.com/3w4pz3dy https://i.pinimg.com/originals/19/2b/94/192b948b78f2d84747596152816f27df.png

# PM: SVD - Actuation and Manipulation Subsystem

| Functionality | Test Plan |
|---|---|
| PM2: Reach Target with low error | Compare results to ground truth |
| PM3.2: Will be able to lift at least 2 lbs. at full extension | Perform strength test |
| PM6: Will bring arm to within 20” of the attachment point | Measure resulting position |

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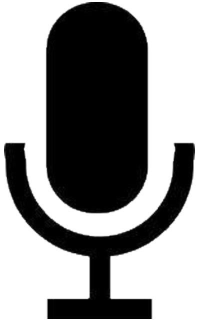
# PM: SVD - Voice Subsystem

| Functionality | Test Plan |
| --- | --- |
| PM4.1: Will interpret voice commands with a high accuracy | Record results |
| PM4.2, PM4.3: Will be able to understand multiple commands of multiple words | Inherent to commands list |
| PD2.1: Speaker will alert user to state changes | Record results |
| NM9: Audio feedback will be clearly audible | By observation |



https://tinyurl.com/4d49hjnx
https://tinyurl.com/3x5t4vzd

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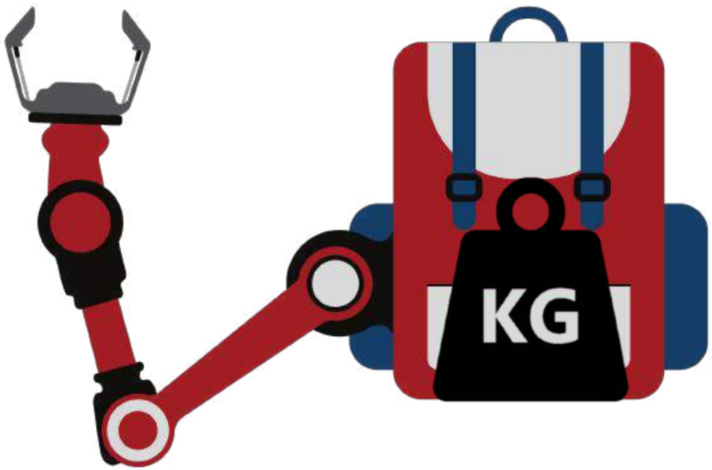
# PM: SVD - Nonfunctional

| Functionality | Test Plan |
|---|---|
| NM1: Will be ergonomic and comfortable to wear | By qualitative assessment and by nature of base frame |
| NM2: Will weight less than 40 lbs. | Indirect weight measurement |

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https://tinyurl.com/3jety3s6
https://tinyurl.com/y3wtxraf

# Project Management: FVD - Full Use Case

| **Functionality** | **Test Plan** |
|---|---|
| All of the previously listed requirements | By nature of successful use case, record times, etc. |
| PM3.1: Will maintain the target location with ≤ 6” of error | By nature of successful use case |
| PM5: Will release the object within 5 seconds of command issue | Time Process |
| NM4, NM5, NM8, ND1: Will be safe, simple, portable | By nature of successful use case and product (estop, torque limits, etc.) |
| NM6: Battery life ≥ 20 minutes | By nature of successful use case |
| NM7: Part Invariant | By nature of product |

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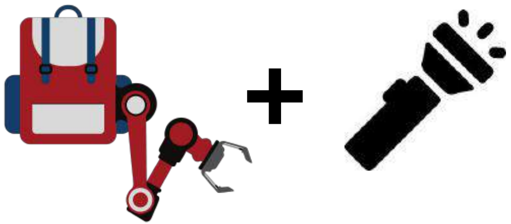
https://tinyurl.com/45tujufu
https://tinyurl.com/249dv6m3
https://tinyurl.com/3w4pz3dy

# Project Management: FVD - Non Functional

| Month | Functionality | Test Plan |
|---|---|---|
| September | PM3.2: Will be able to lift at least 2 lbs. at full extension | Strength test |
| September | NM2: Will weigh less than 40 lbs. | Indirect weight measurement |
| October | Hardware Framework: Fabricate a new enclosure for the robot system | By observation |
| November | Added Tasks: Test out new use case using robot system | Variable, but similar to Full Use Case testing plan |



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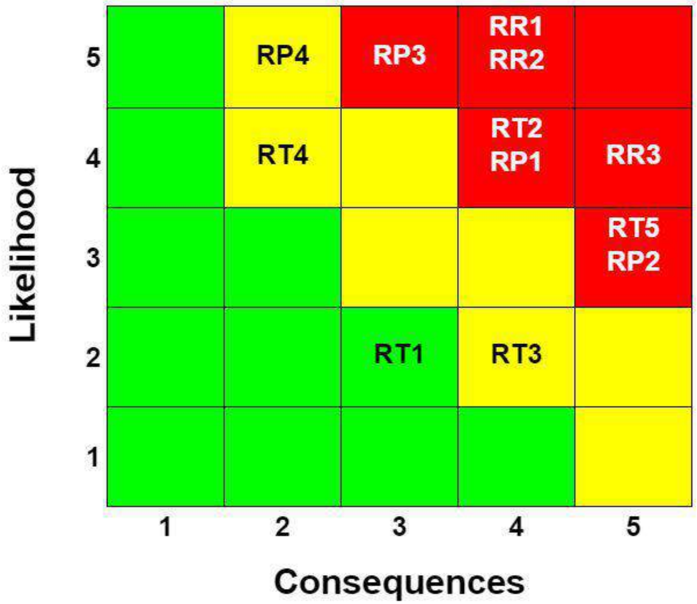
# Project Management: Risk

| Risks | Title |
|---|---|
| 'T' = Technical, 'R' = Resource, 'P' = Programmatic | |
| RT1 | Hebi motor module dies |
| RT2 | Main computer dies or does not perform per our requirements |
| RT3 | Estop devices malfunction |
| RT4 | TCP/IP connectivity is lost |
| RT5 | Salus Robot disinfects CoBorg with a generous coat of liquid |
| ~~RR1~~ | ~~Team lacks ROS fundamentals by start of spring semester~~ |
| RR2 | Unable to work 10hrs/week/member on MRSD project |
| RR3 | Hazard occurs on user while wearing robot |
| RP1 | Member contracts COVID-19 |
| RP2 | MRSD program gets disrupted due to COVID-19 pandemic |
| RP3 | Our sponsor graduates in the spring of 2020 |
| RP4 | End Effector Breaks |




| Level | Likelihood | Consequences |
|---|---|---|
| 5 | 100% | 1 Month/$2,000/Injury |
| 4 | 80% | 2 Weeks/$1,000 |
| 3 | 60% | 1 Week/$500/Loss of function |
| 2 | 40% | 3 Days/$200 |
| 1 | 20% | 1 Day/$50 |

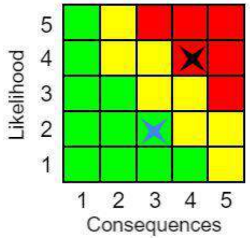
# Project Management: Risk

| Risk Title: | Risk Owner: | Date Submitted: | Date Updated: |
|---|---|---|---|
| Main computer dies or does not perform per our requirements | Husam | 11/12/2020 | 11/27/2020 |

| Description of Risk: | Risk Type? | | Consequence | Likelihood |
|---|---|---|---|---|
| Critical hardware or OS software malfunction renders the main computer inoperable and unbootable. Zotac PC as provided does not perform to our expectations. | ☑ | Technical | 4 | 4 |
| | ☐ | Schedule | **Mitigated Consequence** | **Mitigated Likelihood** |
| | ☑ | Cost | | |
| **Consequence if Risk is Realized:** | ☐ | Programmatic | 2 | 3 |
| ROS framework, and by extension the robot, will no longer function. | | | | |

**Risk Reduction Plan Summary:**

| Action/Milestone | Date | Success Criteria | Consequence Reduction | Likelihood Reduction | |
|---|---|---|---|---|---|
| Work out of Cloud, Github Repository | 11/27/2020 | If computer fails, only hardware is affected | 0 | 1 | ☑ |
| Ensure spare workstation is available | 1/21/2021 | Hot swap failed computer parts when needed | 1 | 0 | ☑ |
| Budget ~$1300 to purchase new laptop | 1/31/2021 | Reduce budget to afford spare | 1 | 0 | ☑ |
| | | | | | ☐ |
| | | | | | ☐ |

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# Project Management: Budget

| No. | Part Name | Cost |
| --- | --- | --- |
| 1 | Voice Subsystem Parts | $34.98 |
| 2 | Robot Hardware | $28.76 |
| 3 | Miscellaneous Items | $180.37 |
| 4 | Intel Realsense T265 | $199.99 |
| 5 | Computer Parts | $152.46 |
| 6 | Computer Replacement | $1351.83 |
| **Total Costs** | | **-$1948.39** |
| **Budget Remaining** | | **+$3051.61** |

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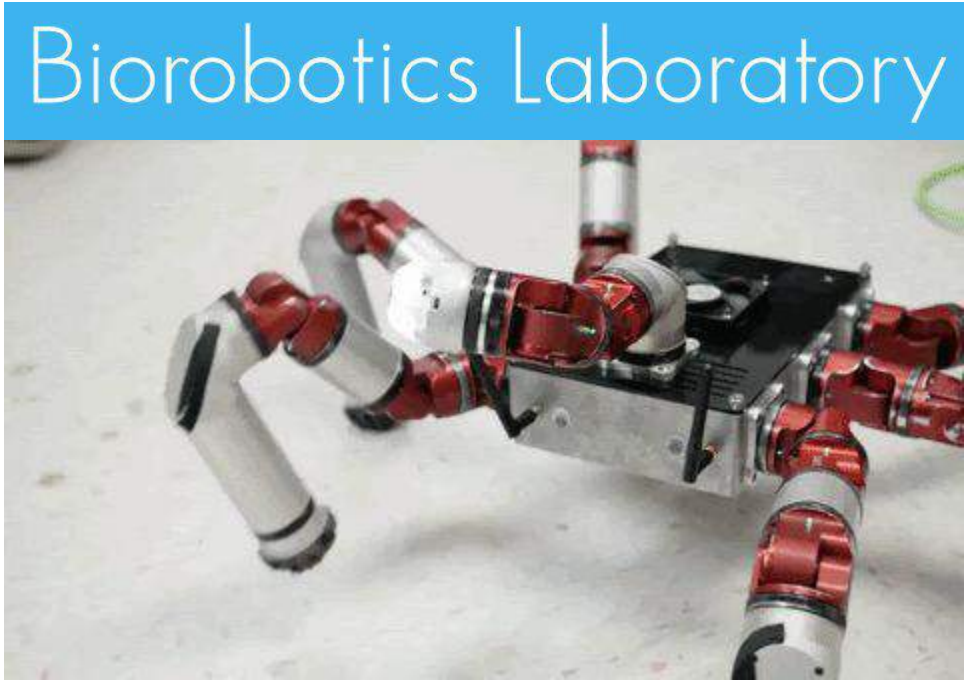
# Questions?



# Appendix

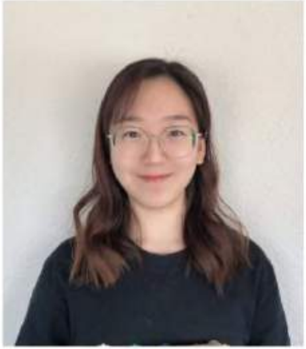
# Agenda

1. Project description
2. Use case/System graphical representation
3. System-level requirements
4. Functional architecture
5. Cyberphysical architecture
6. Subsystem descriptions
7. Current system status
8. Project management

# Team Structure

**Feng Xiang**

Actuated Manipulation



**Yuqing Qin**

Vision Subsystem

**Gerry D'Ascoli**

Voice Subsystem / Electrical Design

**Jonathan Lord-Fonda**

Integration / Validation Software Framework

**Husam Wadi**

Project Management / Hardware Design

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