Collaborative Cyborg Backpack Platform (CoBorg)

Critical Design Review

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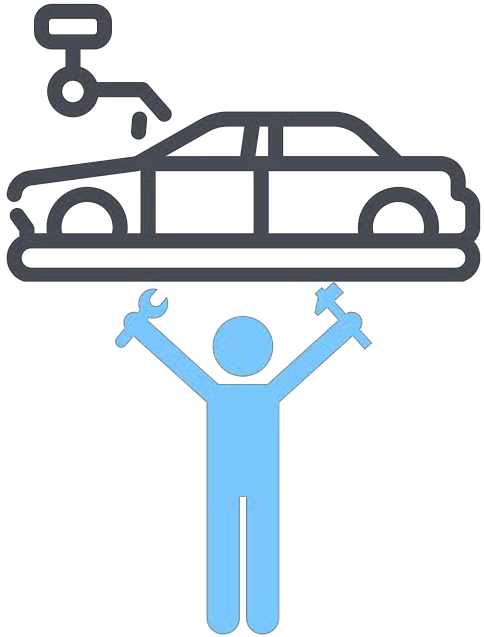
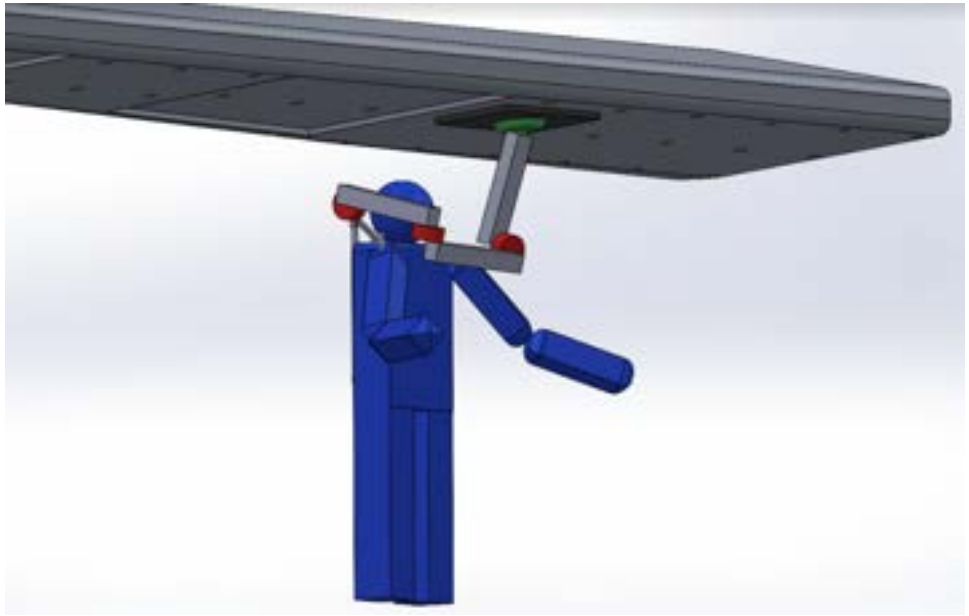
Project Description

Productivity
Safety

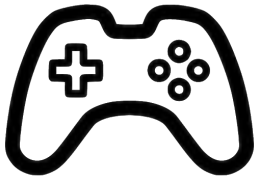
Injuries
Low Impact Roles

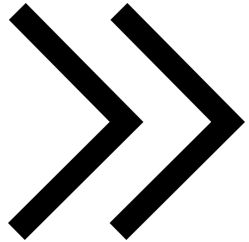


Industrial Manufacturing Use Case

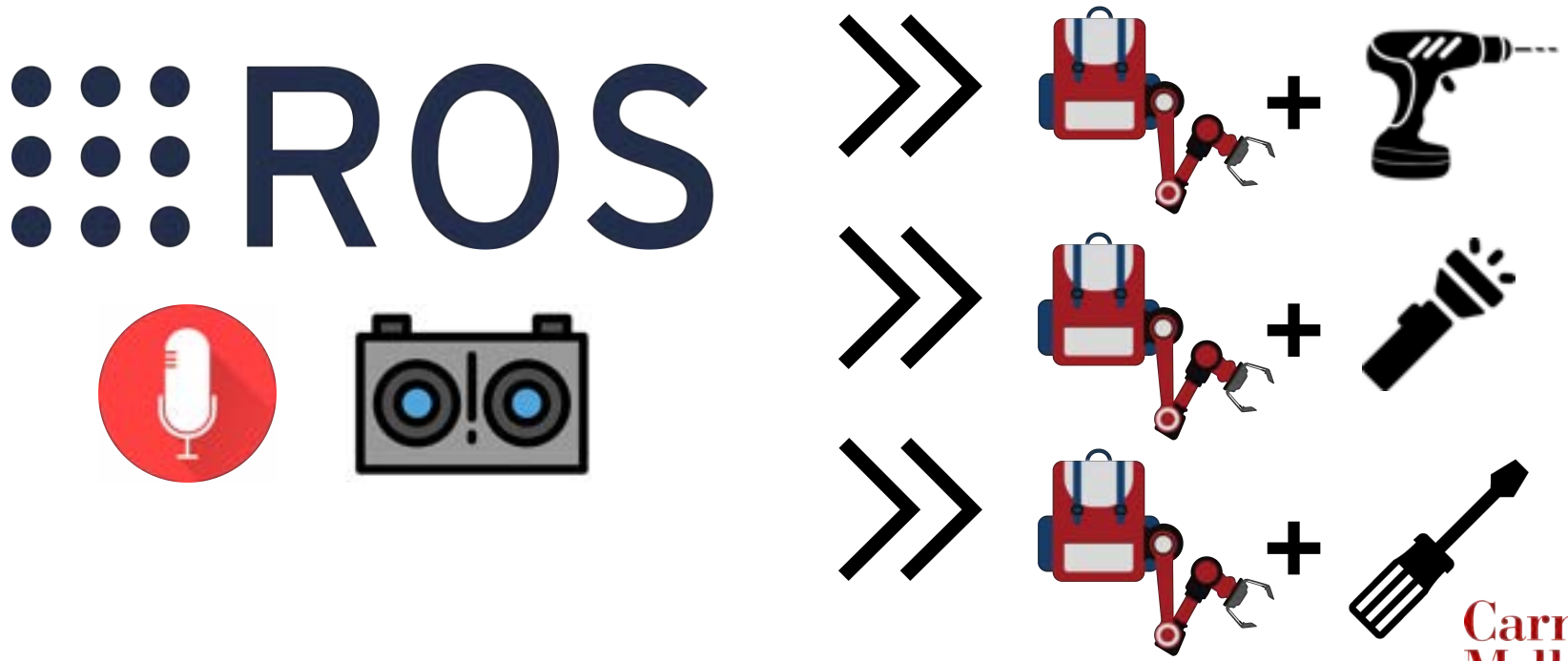


Project Description: Spring 2021





Project Description: Fall 2021



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 compact arm to “home” position.

Mandatory Performance Requirements

PM-1.1:	Will have 60% accuracy of detecting indicated location with 6” in 3D space, and always within 12”.
PM-1.2:	Will detect intended object within 5 seconds of when the move command is issued.
PM-1.3:	Will detect the surface normal of part with error no greater than 45°.
PM-2:	Will reach within 6” of planned target position 60% of the time, and always within 12”.
PM-3.1:	Will maintain target’s spatial position with less than 6” of error margin.
~~PM-3.2:~~	~~Will lift at least 2 lbs at full horizontal extension.~~
PM 3.2:	Will be able to hold a representative part overhead
PM-4.1:	Will be able to understand the voice command 60% of the time.
PM-4.2:	Will be able to understand at least 2+ unique voice commands, up to 8.
PM-4.3:	Will be able to understand commands of at least 2 words in length, up to 8.
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” of the point of attachment to the backpack.

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Mandatory Non-functional Requirements

NM-1:	Will be ergonomic for spinal comfort. Will be comfortable to wear for 30 consecutive minutes.
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 to assist with assigned tasks.
NM-8:	Will be operable on a portable computer.
NM-9:	Audio feedback will be clearly audible in representative work environment.

Spring Semester Targeted System Requirements

Vision Subsystem (~100%):

- PM1.1 - Will have **60%** accuracy of detecting indicated location within **6" in 3D space**, and **always within 12".**
- PM1.2 - Will detect intended object **within 5 seconds** of when the move command is issued.
- PM1.3 - Shall detect the **surface normal** of the part with error no greater than **45°**.
- PD1.2 - Must be **invariant to part texture**, specifically matte finish and gloss finish.

Voice Subsystem (~100%):

- PM4.1 - Will be able to understand the voice command **60%** of the time.
- PM4.2 - Will be able to understand at least **2 unique** voice commands, **up to 8**.
- PM4.3 - Will be able to understand commands of at least **2 words** in length, **up to 8**.
- PD2.1 - Speaker will alert user to state changes with an **80%** success rate.
- NM9 - Audio feedback will be **clearly audible** in representative work environment.

Actuated Manipulation Subsystem (~75%):

- PM-2 - Will reach within **6"** of the planned target position **60%** of the time, and always **within 12"**.
- PM-3.2 - Will be **able to hold** a representative part overhead.
- PM-6 - Will bring full robot arm to within **20"** of the point of attachment to the backpack.

Hardware (~20%):

- NM-1 - Will be ergonomic for spinal comfort.
- NM-2 - Will weigh less than 40 lbs.

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Overall System

Input:

Sensing data

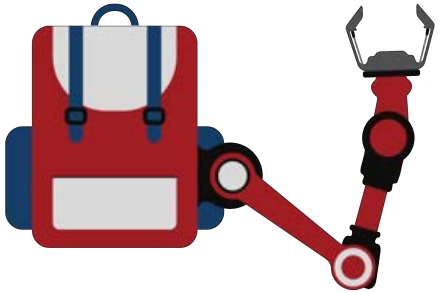
(voice, depth camera)

Coborg System

Sensing, Vision, Voice,
Motion Planning,
Actuated Manipulation

Output:

Stabilizing part /
Compact mode



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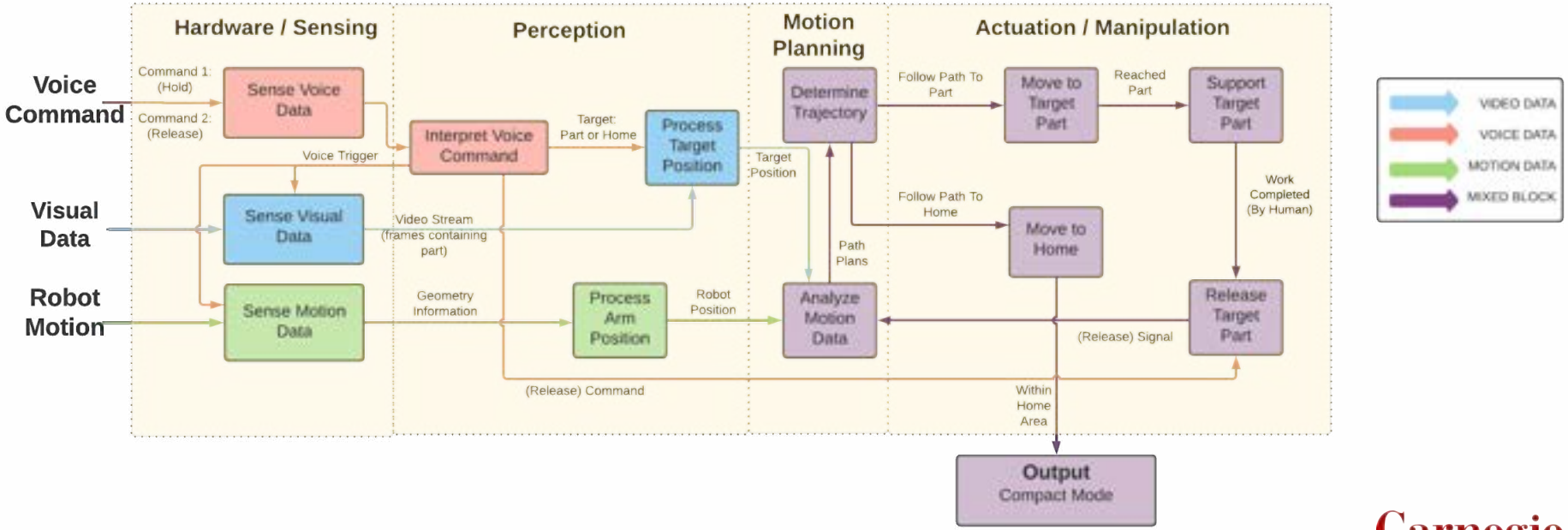
Functional Architecture



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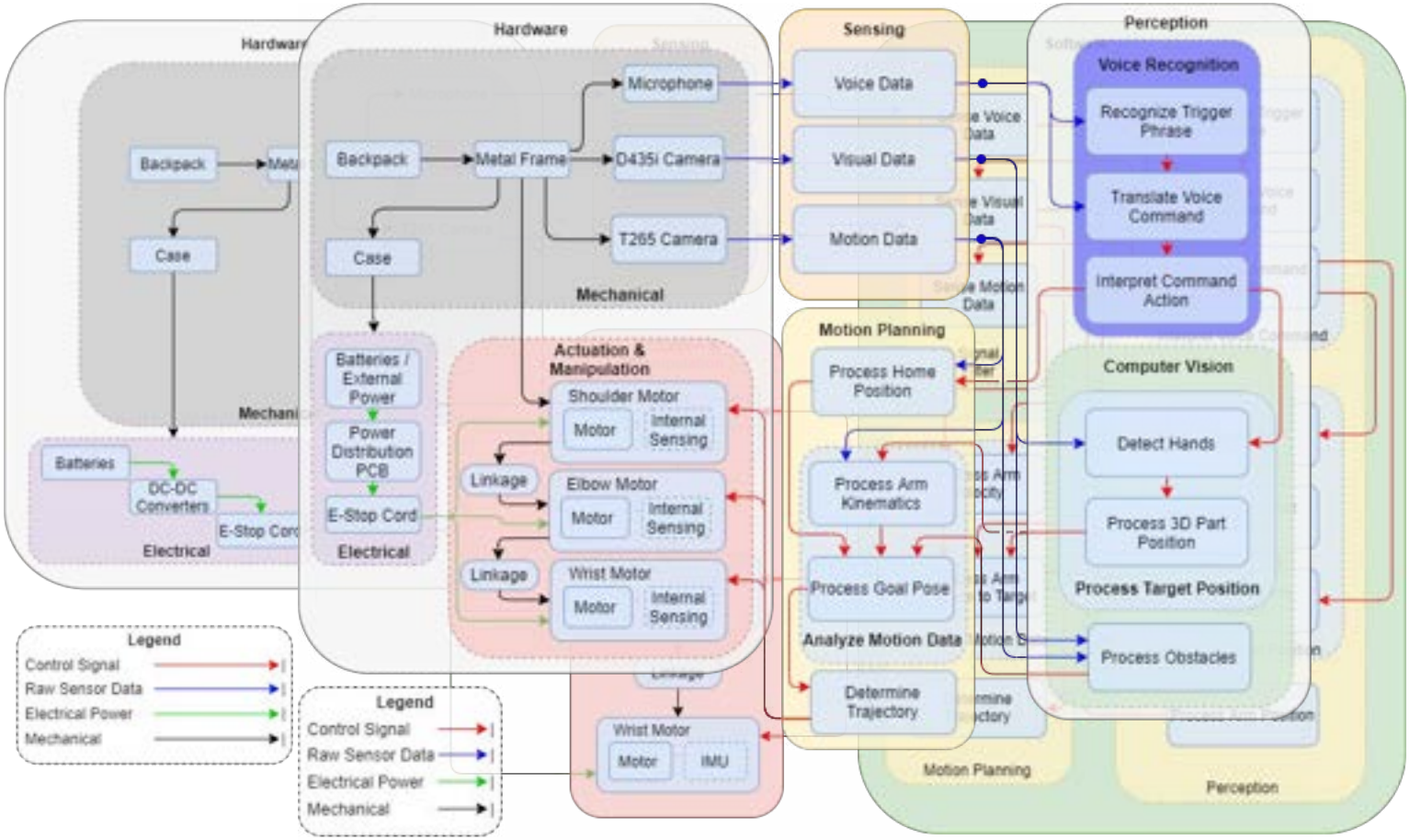
Cyber-Physical Architecture



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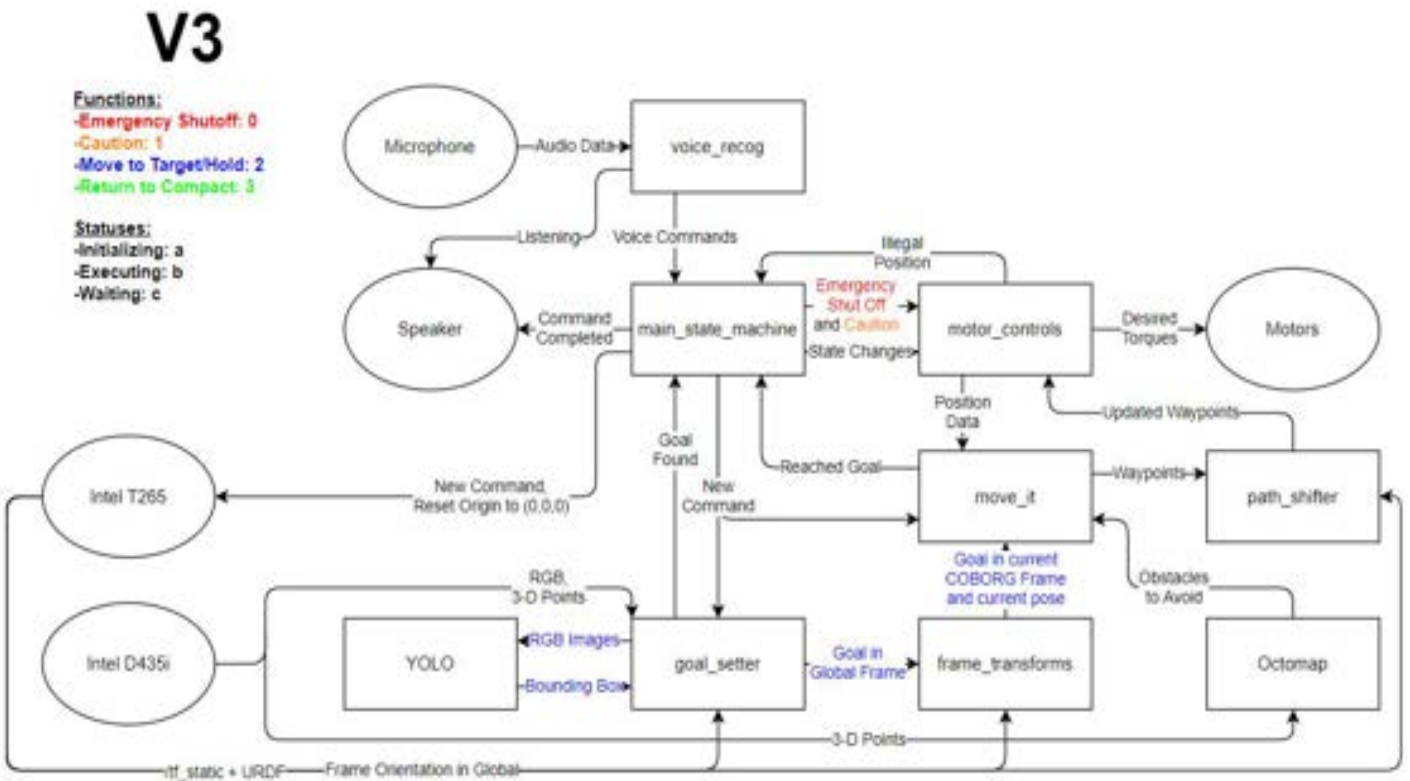
Subsystem: Software Framework



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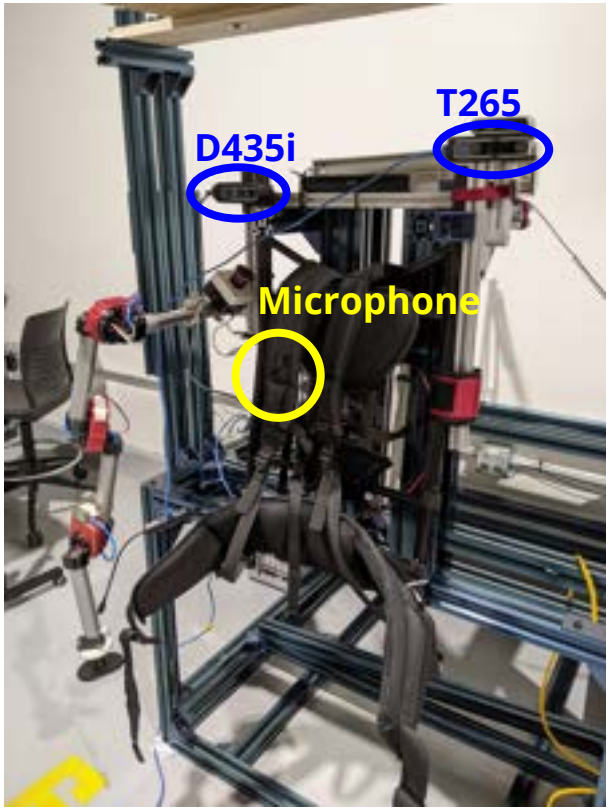
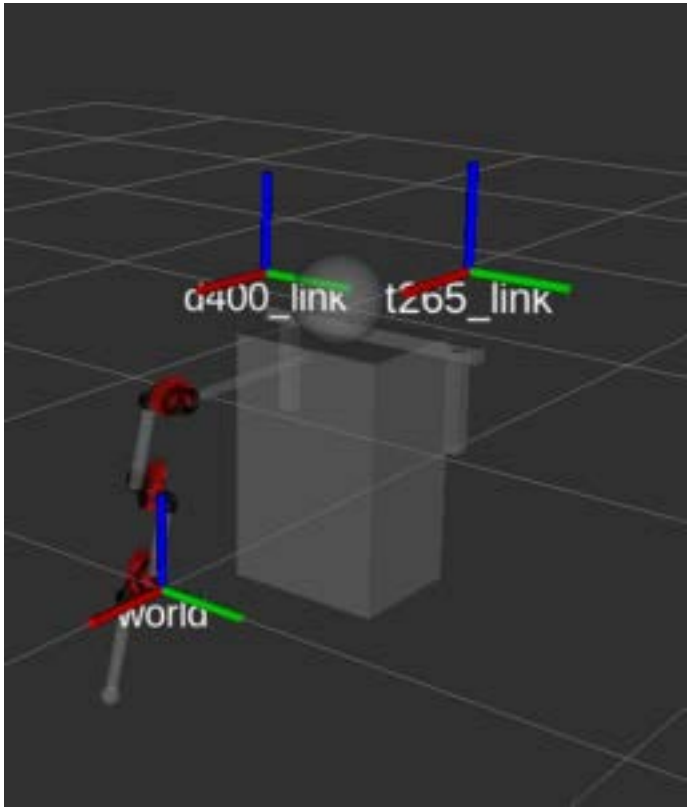
Subsystem: Hardware Framework





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Subsystem: Perception (Voice Recognition)

Input: **Audio stream from Microphone**

Output: **Commands to the ROS framework main_state_machine**
Audio feedback to system speaker

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
- Play audio sound related to success/failure of command recognition

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Current Status: Perception (Voice Recognition)

Statistics

Number of Commands	150
Number of Successes	147
Number of False Positives	1
60%?	<1.303e-27
92%?	0.004
94%?	0.030

Method: Binomial Test

Sample Video

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SVD: Performance Evaluation

Targeted Requirements:

PM4.1 - Will be able to understand the voice command **60%** of the time.
PM4.2 - Will be able to understand at least **2 unique** voice commands, **up to 8**.
PM4.3 - Will be able to understand commands of at least **2 words** in length, **up to 8**.
PD2.1 - Speaker will alert user to state changes with an **80%** success rate.
NM9 - Audio feedback will be **clearly audible** in representative work environment.

SVD Demo Video:

SVD results summary:

- **(PM4.1)** **100% command accuracy**
- **(PM4.2)** **Recognizes 5 unique phrases for 4 unique commands (2 phrases for stop)**
- **(PM4.3)** **Commands include 2-4 words in length**
- **(PD2.1)** **100% accurate audio feedback**
- **(NM9)** **Audio feedback was clearly heard**

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Subsystem: Perception (Vision)

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

- D435i will outputs RGB raw image and also point cloud

Output: **3D target part position + part surface normal**

Hand Detection

Process:

- 2D YOLO v3 hand detection to extract 2D bounding box
- 3D hand bounding boxes using point cloud data
- Post-process to get averaged 3D position of hands
- Post-process to get surface normal of averaged target position
- Integrate each component into ROS

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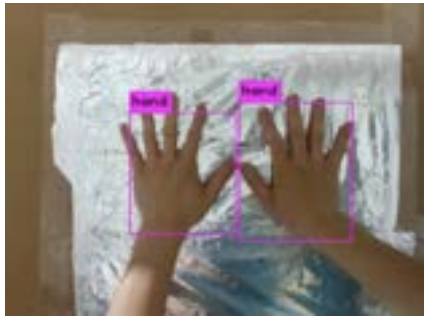
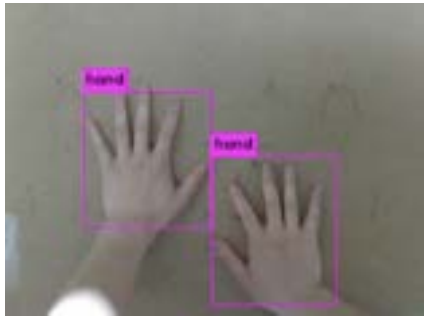
Current Status: Perception (Vision)

- Vision subsystem development completed!
- Validated performance





Validation Results:

Distance Error		Surface Normal Angle Error	
Sample Size	36	Sample Size	36
Sample Mean (m)	0.042m	Sample Mean (deg)	4.4deg
0.305m (12”)?	<1e-30	45 deg?	<1e-30
0.1524m (6”)?	<1e-30	10 deg?	0.0086
0.059m?	0.0093	9 deg?	0.0308
0.056m?	0.034		

Method: 2-tail z-score

```
Class: Avg on 2 hands
x: 0.576678
y: -0.0473136
z: -0.0196843
normal_x: 0.998124
normal_y: 0.024003
normal_z: -0.0563149


Angle difference between ground truth and measured normals:
3.50967 degrees
Time: 1 seconds
```

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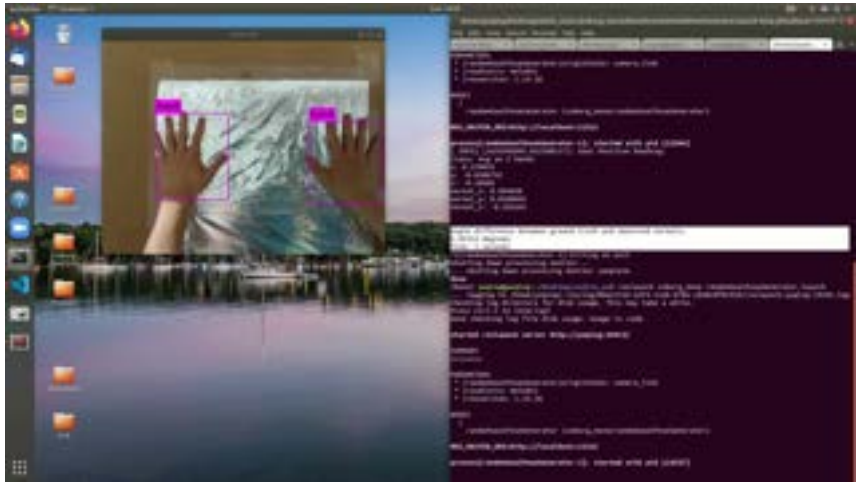
SVD: Performance Evaluation

Targeted Requirements:

PM1.1 - Will have **60%** accuracy of detecting indicated location within **6” in 3D space**, and **always within 12”.**
PM1.2 - Will detect intended object **within 5 seconds** of when the move command is issued.
PM1.3 - Shall detect the **surface normal** of the part with error no greater than **45°**.
PD1.2 - Must be **invariant to part texture**, specifically matte finish and gloss finish.

SVD Demo Video:



SVD results summary:

- **(PD1.2) 2 surfaces: shiny, matte**
- 10 positions tested in SVD
- **(PM1.1) 100% accuracy (10 test cases)** on detecting the indicated location
- **(PM1.1) Averaged 3D distance error: 3.74cm**
- **(PM1.3) Averaged surface normal angle error: 4.17°**
- **(PM1.2) Averaged executing time: 1.3s**

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Subsystem: Actuated Manipulation

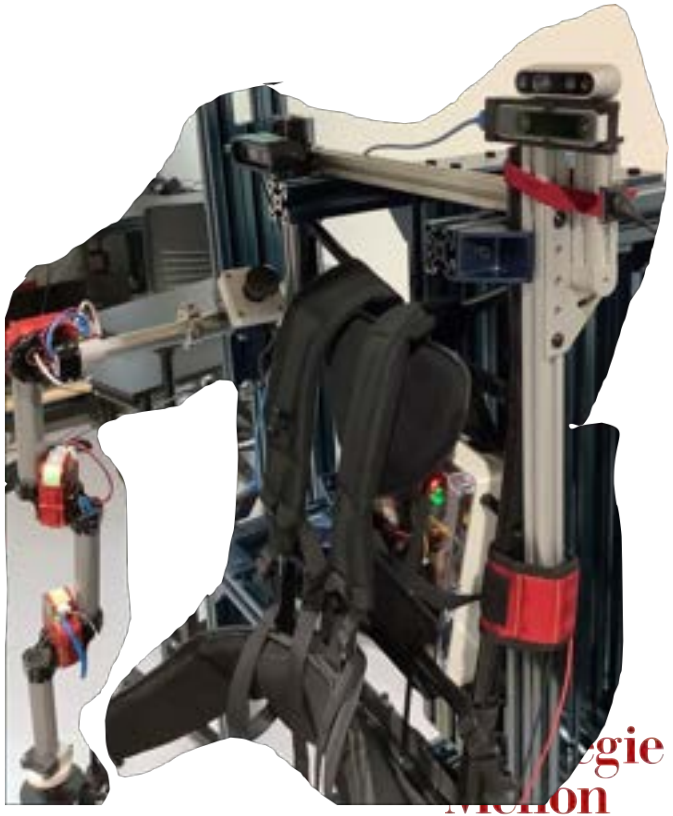
Input: Goal position from camera_link + obstacle mapping + frame transforms

- Vision subsystem outputted 3D position of hands
- D435i outputs depth point cloud that is converted to obstacles
- TF frame transforms between cameras and URDF frames

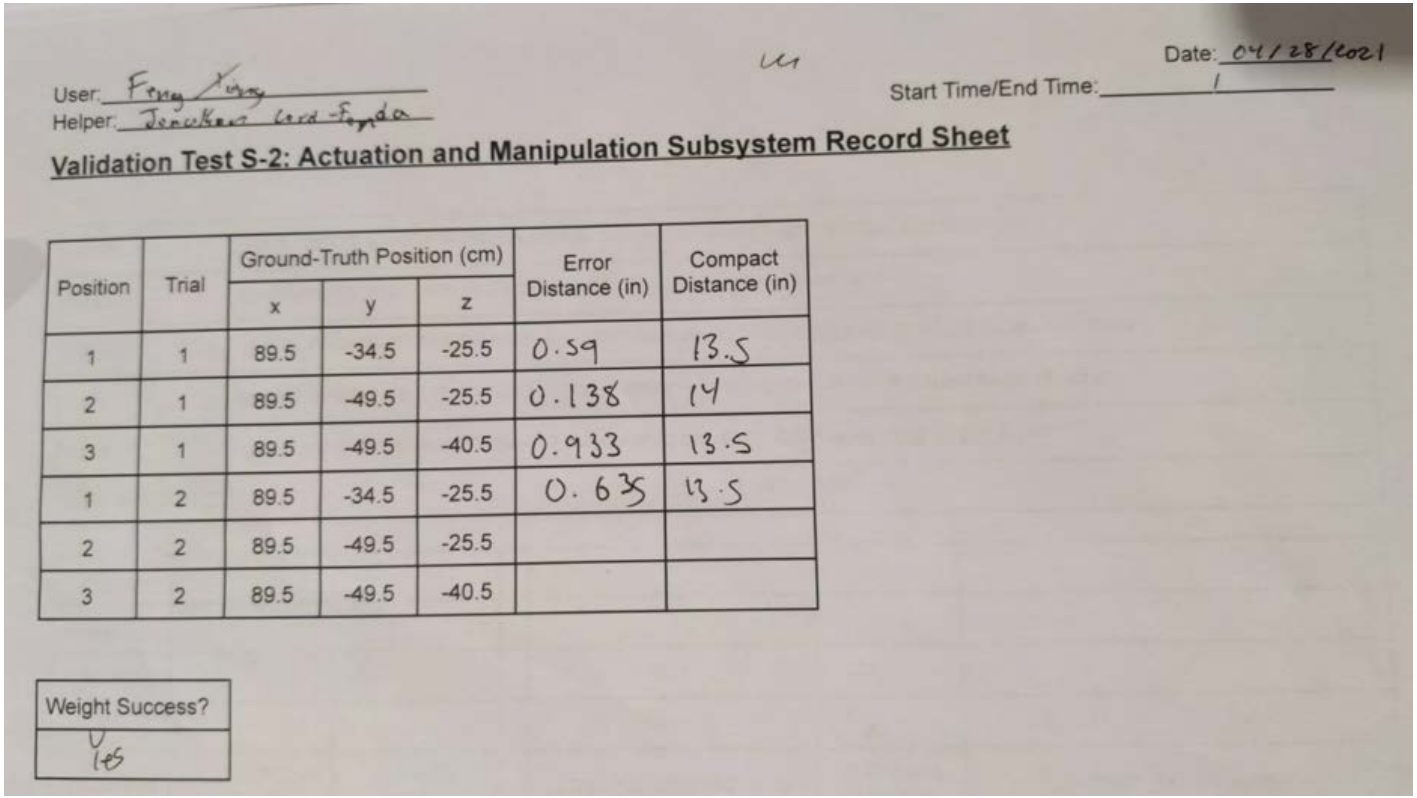
Output: Robot actuation to goal states

Process:

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



Current Status: Actuated Manipulation Validation



Date: 04/28/2021

User: Fang Xing

Helper: Jonathan Lord-Fonda

Start Time/End Time: /

Validation Test S-2: Actuation and Manipulation Subsystem Record Sheet

Position	Trial	Ground-Truth Position (cm)			Error Distance (in)	Compact Distance (in)
		x	y	z		
1	1	89.5	-34.5	-25.5	0.59	13.5
2	1	89.5	-49.5	-25.5	0.138	14
3	1	89.5	-49.5	-40.5	0.933	13.5
1	2	89.5	-34.5	-25.5	0.63	13.5
2	2	89.5	-49.5	-25.5		
3	2	89.5	-49.5	-40.5		

Weight Success?
Yes

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SVD: Performance Evaluation

Targeted Requirements:

PM-2 - Will reach within **6”** of the planned target position **60%** of the time, and always **within 12”**.

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

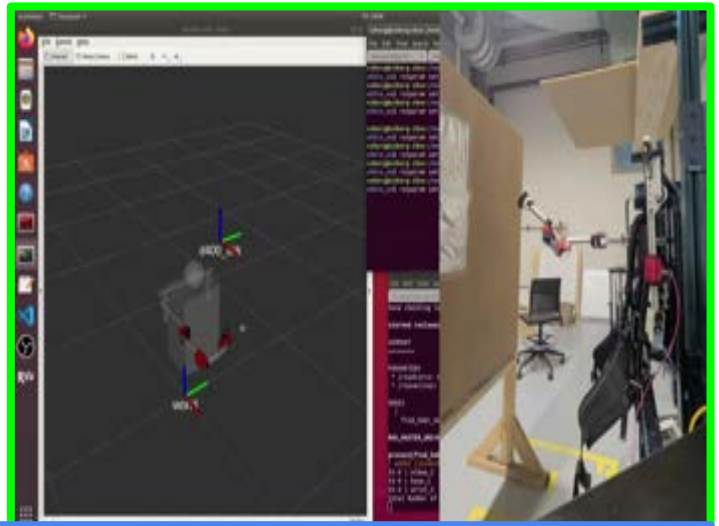
PM-3.2 - Will be **able to hold** a representative part overhead.

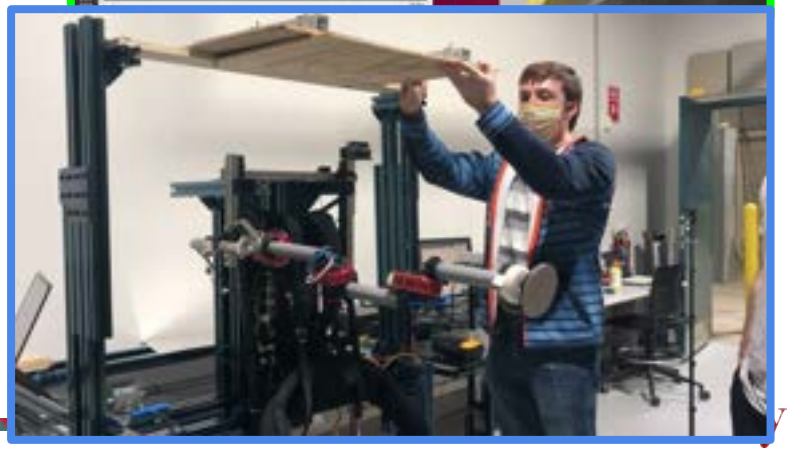
SVD results summary:

(PM-2) 3 predefined goal positions
Averaged 3D position error: **0.574in**

(PM-6) Base-to-end measured at home position
% requirement met at SVD: **100%**

(PM-3.2) ~3 lbs wooden board to hold overhead: **successful**





Overall System Status: SVD Encore Integration

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Conclusions on SVD

Vision Subsystem:

- **Strong points:** high detection accuracy, real-time detection, align with use cases
- **Weak points:** some false positives, color dependent, hand pose variant
- **Future work:** post-processing the pointcloud, filter out noises

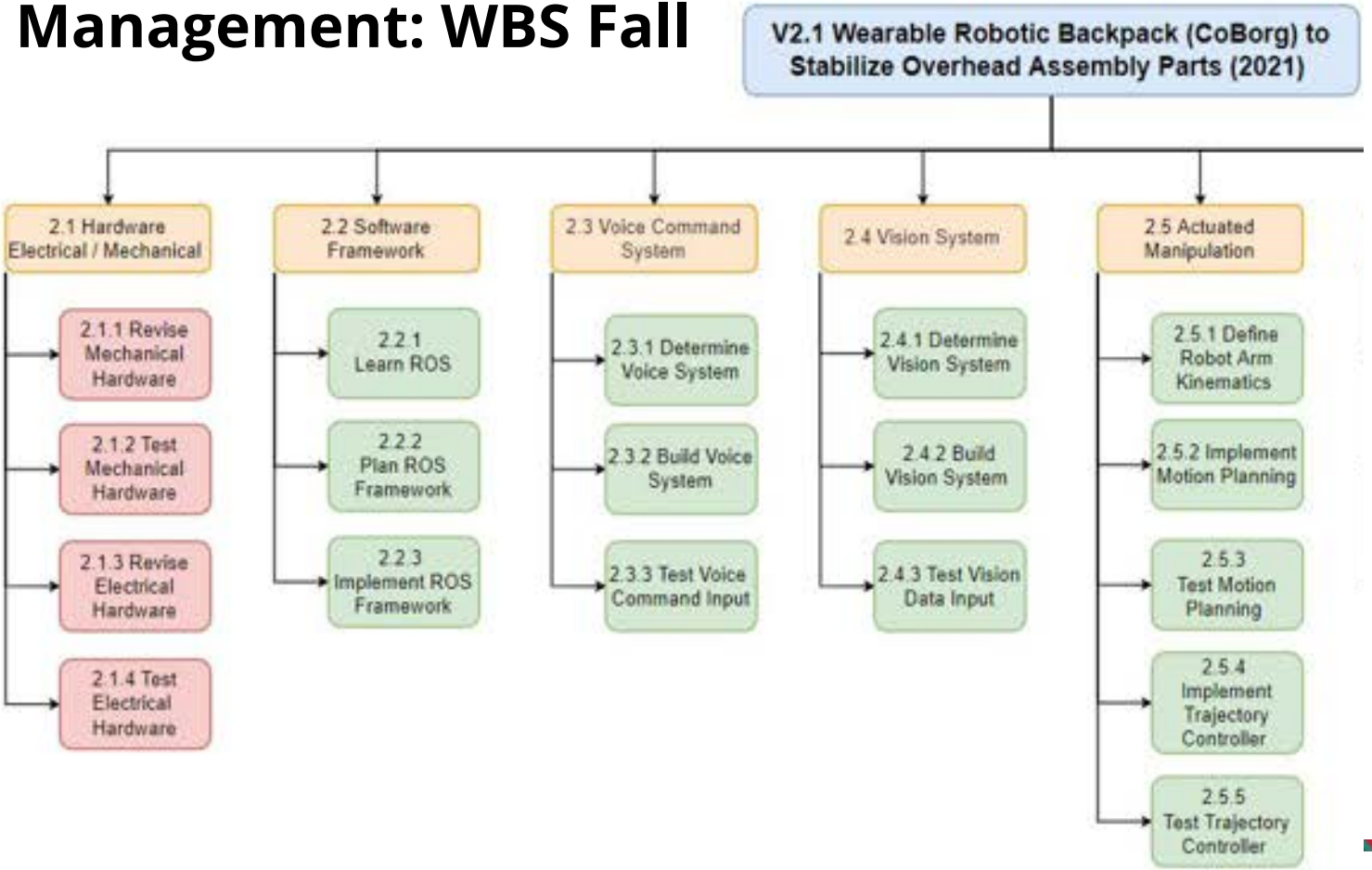
Voice Subsystem:

- **Strong points:** high recognition accuracy, flexible command structure, low/no false positives, no false commands sent to main_state_machine
- **Weak points:** not robust to excessive variable background noise
- **Future work:** Expand command dictionary, simplify existing commands, optimize dictionary for improved recognition, add command timeout function

Actuated Manipulation Subsystem:

- **Strong points:** high position accuracy, no hard collision with user
- **Weak points:** inconsistent performance, slow performance, position-only actuation
- **Future work:** global-frame stabilization, increase DoF to solve full pose, collision avoidance, perform multiple simple tasks

Management: WBS Fall



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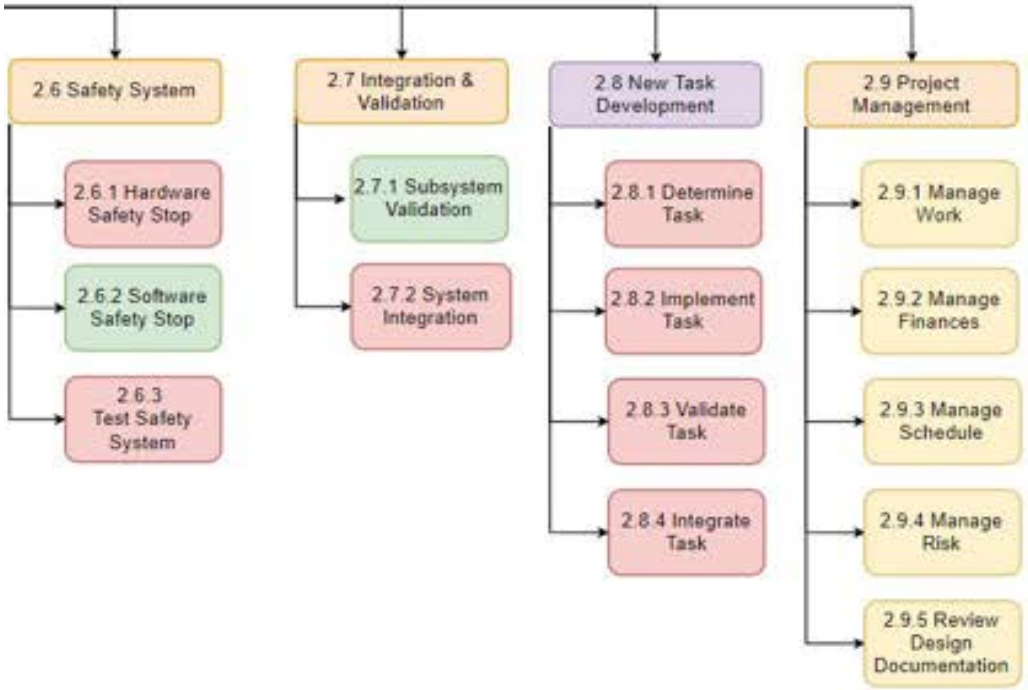
Management: WBS Fall



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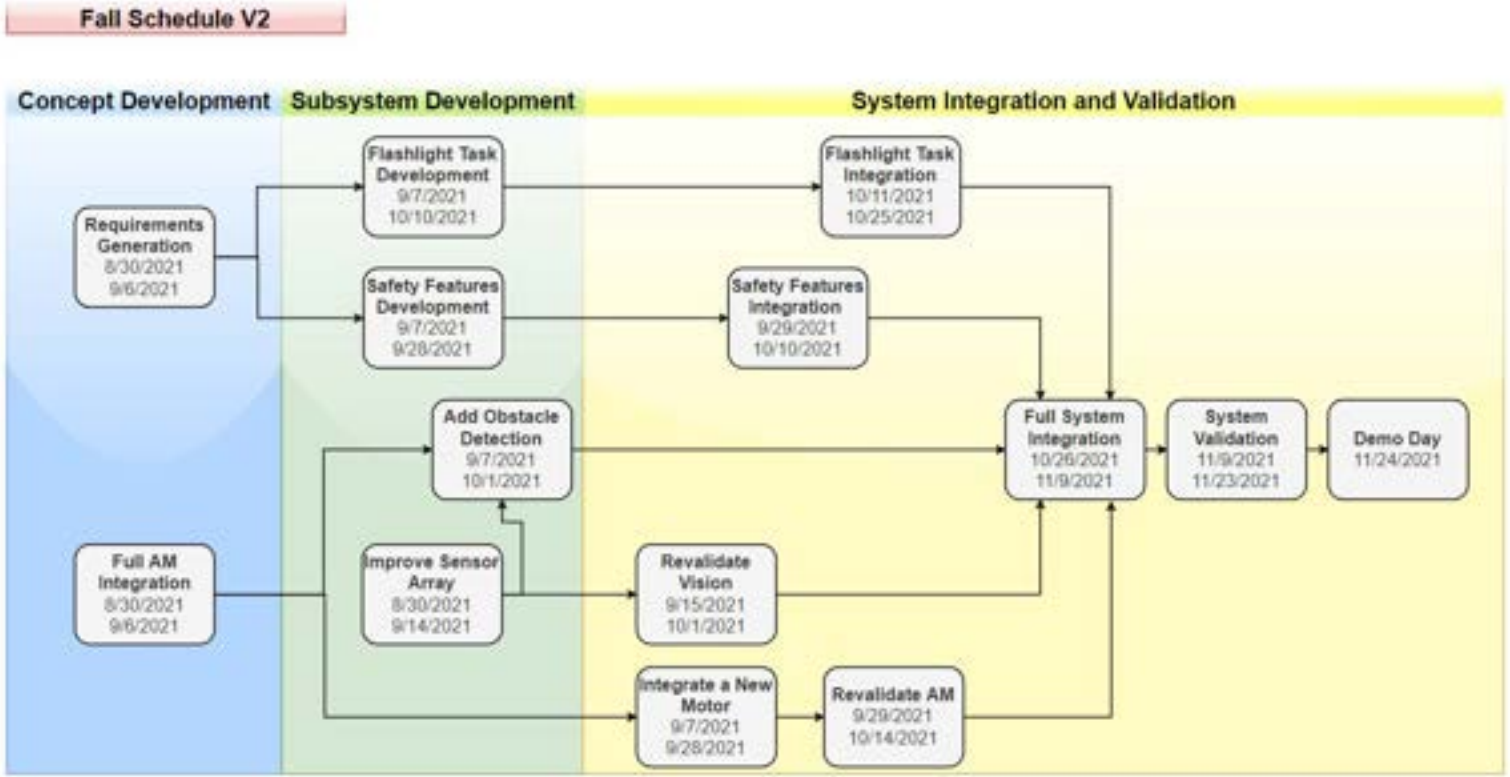
Management: Fall Schedule



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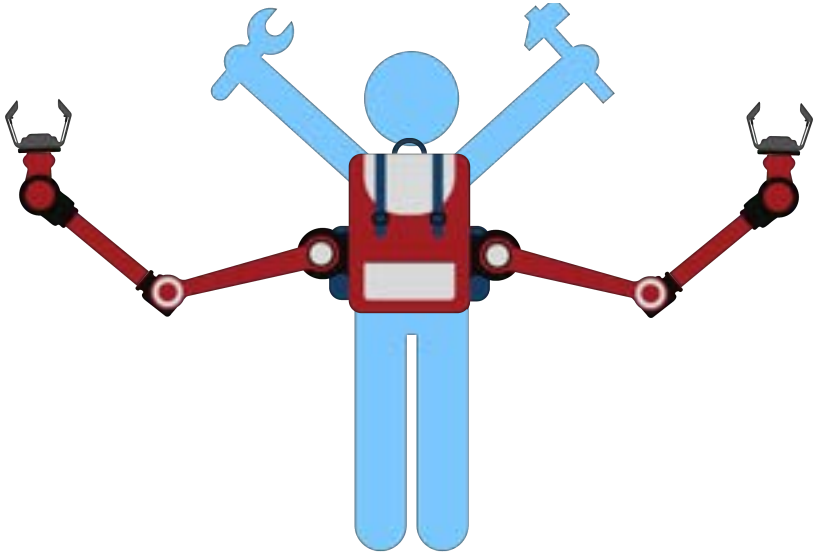
Management: Progress Reviews

Milestone	Description
PR 7: Early September	Requirements generation Full Actuated Manipulation Integration
PR 8: Mid-September	Improved Sensor Array
PR 9: Early October	Revalidate Vision System Safety Features Development Add Obstacle Detection Integrate New Motor
PR 10: Mid-October	Safety Features Integration Flashlight Task Development Revalidate Actuated Manipulation
PR 11: Mid-November	Flashlight Task Integration Full System Integration
PR 12: Late November	System Validation

Management: FVD Overview

- Validation of Flashlight Function
- Full Use Case Test
- Nonfunctional and Safety Test

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



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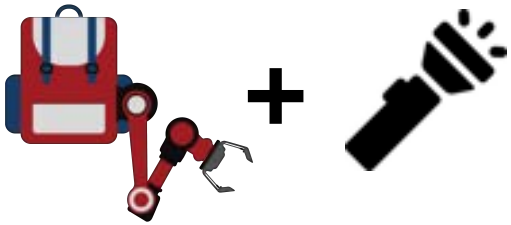
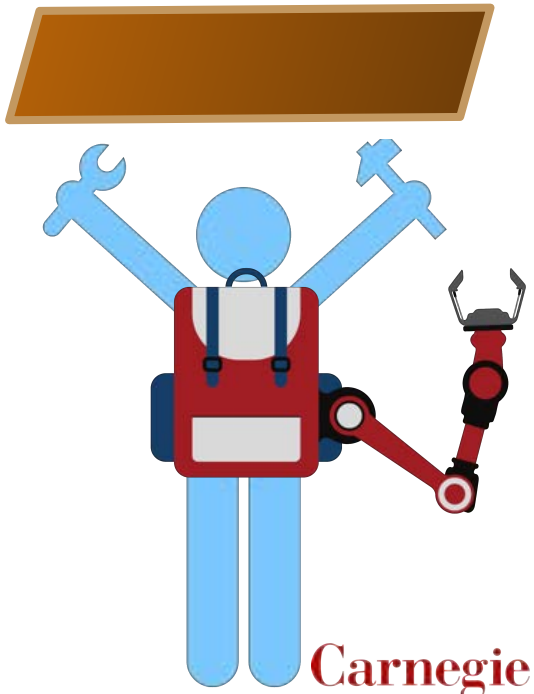
FVD - Validation of Flashlight Function

Proposed Functionality	Proposed Test Plan
Automatically point a flashlight at the work surface while the user is working	Ensure that the coborg will point a flashlight at the target position within the pose requirements currently set



FVD - Full Overhead 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/3w4pz3dv

FVD: Nonfunctional and Safety

Functionality	Test Plan
NM1: Will be ergonomic and comfortable to wear	By qualitative assessment and by nature of base frame
NM2: Will weigh less than 40 lbs.	Indirect weight measurement
NM4: Robot will operate safely	TBD

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

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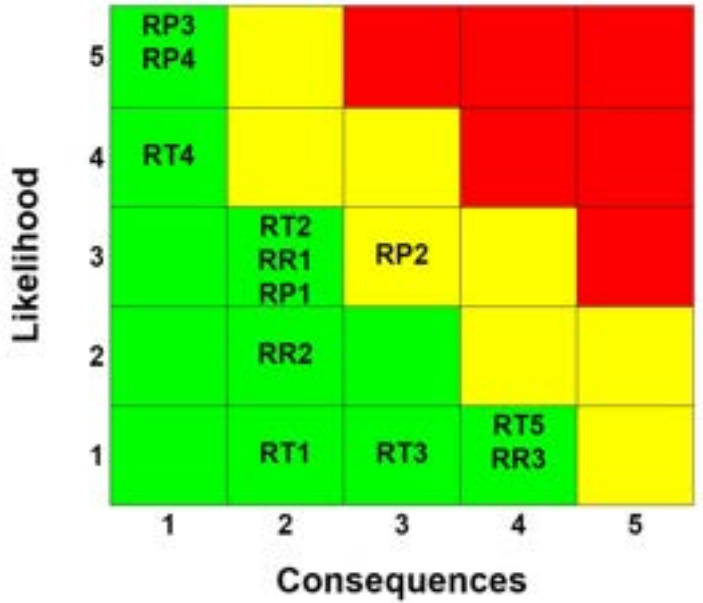
Management: Risk

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

Management: Risk

Management: Current Budget

No.	Part Name	Cost
1	Voice Subsystem Parts	$34.98
2	Robot Hardware	$119.71
3	Supplementary Items	$501.61
4	Intel Realsense T265	$199.99
5	Computer Parts	$152.46
6	Nvidia Jetson Xavier AGX	$699.99
Total Costs		**-$1708.74**
Budget Remaining		**+$3291.21**

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Management: Projected Fall Expenditures

No.	Part Name	Cost
1	Fiberglass Shell Assembly	$400.00
2	Laser Cut Acrylic Base	$200.00
3	Carbon Fiber Tubing	$125.00
4	Electrical Components	$300.00
5	T-Slotted Aluminium Assembly	$500.00
Total Costs		**-$1525.00**
Budget Remaining		**+$1766.21**

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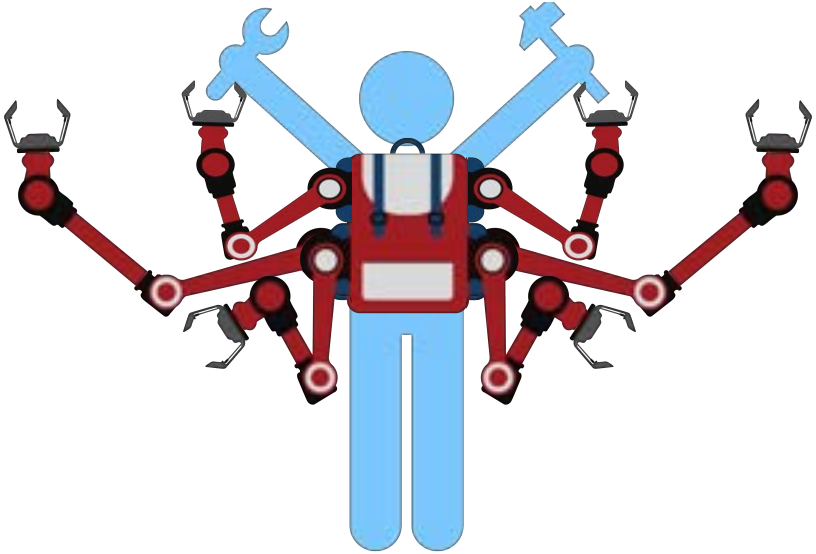
Conclusions

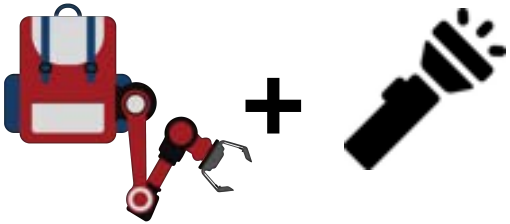
Lessons from Spring

Time management is critical

Document early and often



Plans for Fall



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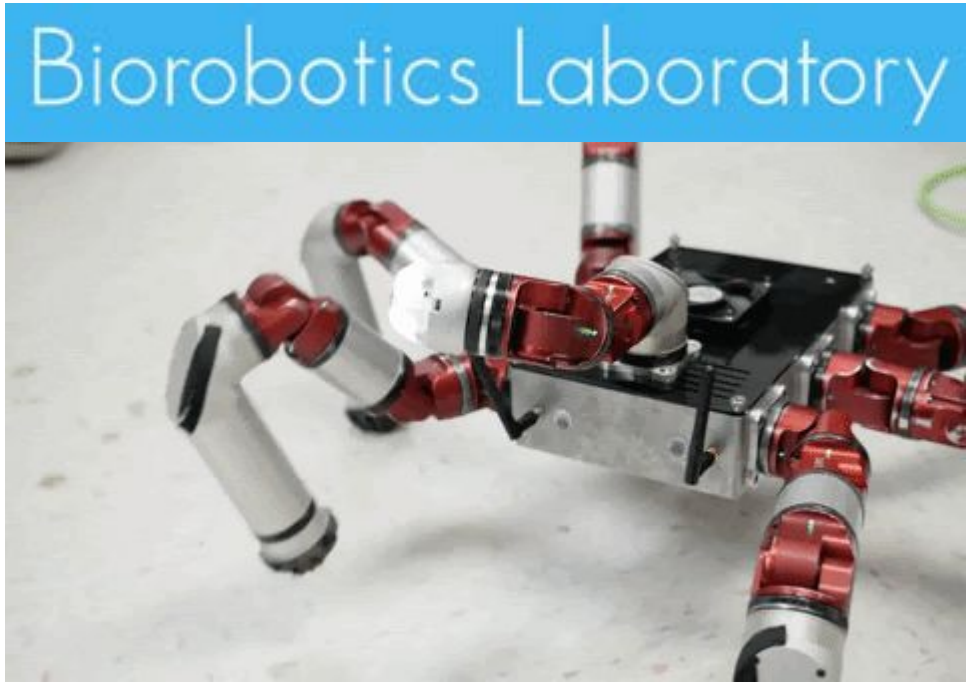
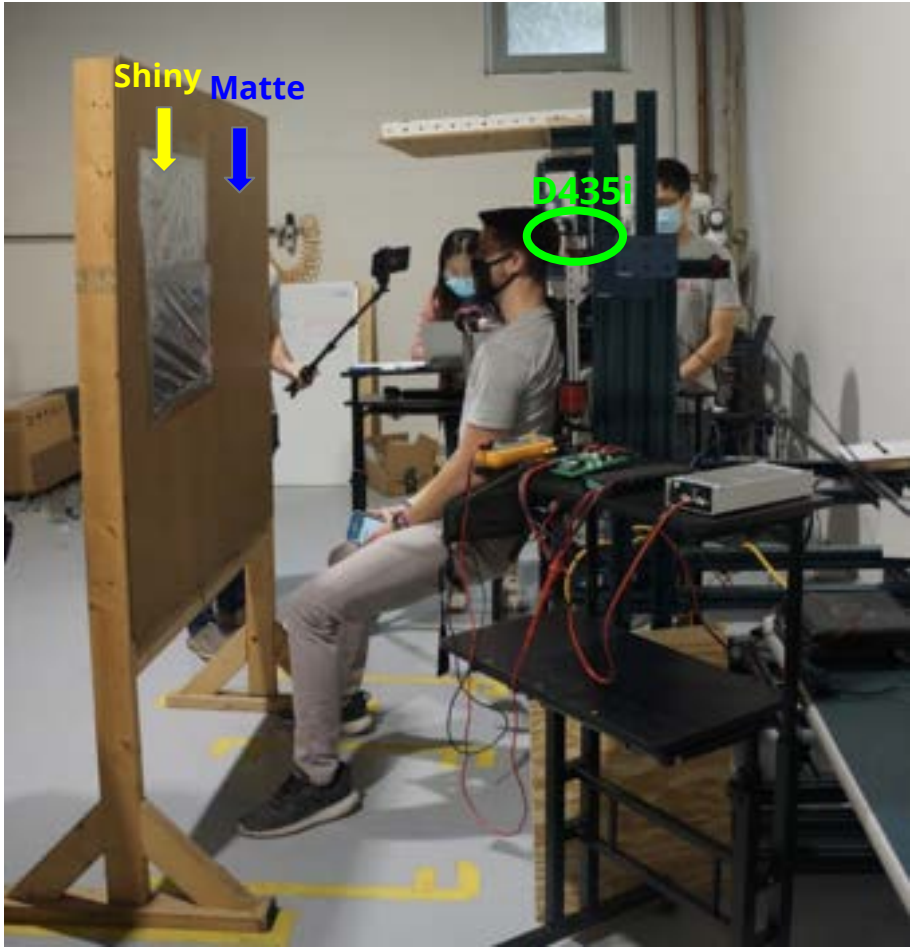
Questions?





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