Team 205 – Robotic Arm to Assist Motorized Chair Users

- Industry Sponsor: PPMD, Keith Van Houten
- Faculty Advisor: Stephen Moyer
- Team Lead: Brooke Harrington
- Team Members: Cavan Moriarty, Omar Abuljobain, Justin Lee, and Andrew Baum

Agenda

System Decomposition	• Background, Problem, Value Proposition • System Architecture • System Requirements
Conceptual Design	• Team Concepts • Concept Screening and Scoring • Final Concept
Preliminary Design	• System Diagram, Electrical Diagram • CAD Models • Prototypes, Engineering Calculation
Project Management	• Risk and Mitigation Strategies • Budget • Project Timeline

Background on Duchenne Muscular Dystrophy (DMD)

- DMD is a progressive disorder that deteriorates muscles over time
- Requires those with DMD to use motorized wheelchairs such as the Permobil M3 and Quantum
- People with DMD have limited range of motion (ROM) and often require a caretaker or robotic device to help with everyday tasks

Figure 1: Robotic Arm Mounted on Wheelchair

Figure 2 Permobil M3 Corpus

Problems with the Current ROM Assistive Robot

Current solutions such as the Kinova JACO robotic arm are:

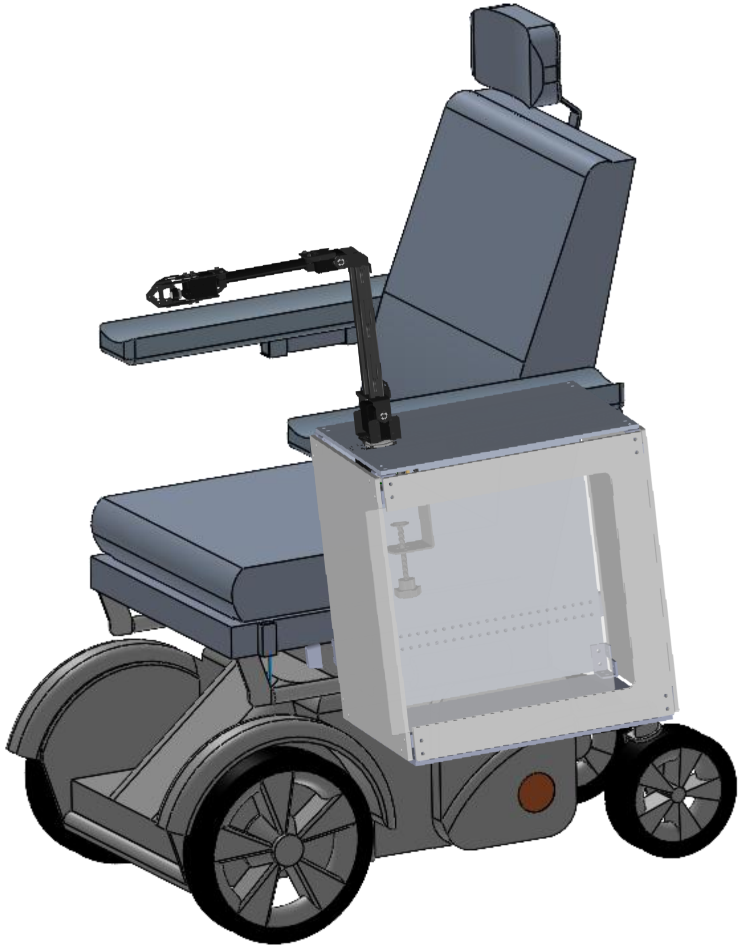
- Too Expensive (>$60,000)
- Difficult to Control
- Large/Bulky
- Difficult to remove for travel

Team 205 will develop an affordable, simple to control robotic arm that will accomplish two high value functions: pushing handicap door and elevator buttons, and bringing a cup to the user's face

Figure 3: Kinova JACO robotic arm

Figure 4: Robotic Arm Mounted on Wheelchair

For individuals with DMD who require ROM assistance, an affordable robotic aid would provide assistance with everyday tasks



- Perform high value functions such as pushing a handicap door button
- Simple controls allow easier access to ROM assistance
- Integrate robotic manipulation capabilities onto powered wheelchairs at an affordable price

System Level Objectives

Technical Requirement ID	Requirement	Verification Method
TR 1.1.0	The robot shall be controlled manually by a joystick and should have the ability to program automatic functions accessed through a button push or voice activation	Test
TR 1.2.0	The robot shall have no more than six degrees of freedom to reduce the complexity of controls	Inspection
TR 1.3.0	The robot shall have an operating radius that spans a minimum of 5 inches to a maximum of 2 feet from mount location with 180 degrees of rotation total	System Test
TR 1.4.0	The robot should receive power from the motorized wheelchair battery and should include a backup battery	Analysis

Derived Requirements

Technical Requirement ID	Requirement	Verification Method
TR 1.1.1	The joystick shall be attached to the wheelchair such that the user can comfortably manipulate the controls within their range of motion	User Testing
TR 1.1.2	Automatic functions such as bringing a water bottle to the user shall be independent of the joystick and should operate without any joystick inputs, utilizing buttons instead	System Test
TR 1.1.3	The arm shall mount in a location that does not interfere with the users seating or ability to pass through an ADA compliant door	Physical Inspection
TR 1.3.1	The device should be able to reach and depress handicap and elevator buttons between 34” and 48” off the floor as specified by ADA standards	System Test
TR 2.1.0	The robot electronics shall be contained in a weather resistant enclosure	Material Test
TR 3.1.1	The robot shall be disassembled and reassembled for the inspection and cleaning of parts	Timed Test or PM/M Plan Development
TR 4.1.0	The system shall be optimized to contain minimum safety hazards including sharp edges and pinch points for user safety	Visual/Physical Inspection
TR 5.1.0	The robot shall have an accessible kill switch between the battery and circuitry to protect against unexpected energization	System Test
TR 5.2.0	The robot shall have physical/program limiters to prevent the robot from intrusively interacting with the user	System Test

Changes to Requirements Upon Further Discussion and New Information

Requirement ID	Old Requirement Description	Updated Requirement Description	Reason
TR 1.1.0	The robot shall be controlled manually by a joystick and should have the ability to program automatic functions accessed through a button push or voice activation	The robot shall be controlled **manually by a joystick** and should have the ability to program automatic functions accessed through a button	Voice activation exceeds the scope of the project Manual joystick control was emphasized

Breaking the System Down – 3 Subsystems

System	Assistive Robotic for Motorized Wheelchair
Subsystem	Robot Frame

Configuration Item

ages

Mount

ffector

Function

Prov Structure to the Arm

Defines geometry used in software development

ttaches bot and controller ass electric heelchair

Allows interaction with environment nd provides method r completing high value functions

End-Effector

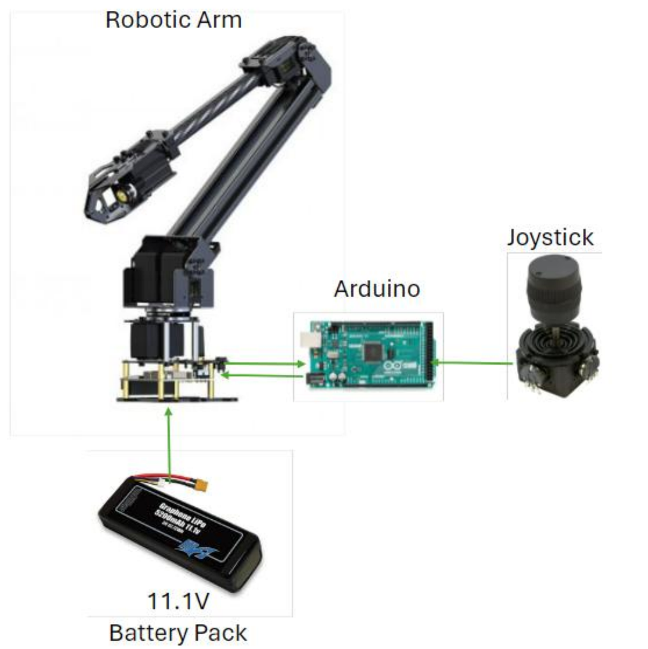
Robot Frame

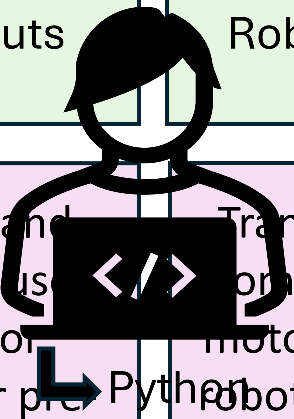
Mount

Linkages

Breaking the System Down – 3 Subsystems

System	Assistive Robotic for Motorized Wheelchair			
Subsystem	Electronics / Circuitry		Software / Programming	
Configuration Item	Servo / Stepper Motors	als /	User Inputs	Robot Inputs
Function	Moves the linkages o the robot for precise positionin in 3-D	for trol, for g nds user	Receives and translates us inputs fo position or pre programmed actions	Translates user commands into motor inputs for robot interaction with environment





Team Members Generated Individual Concepts to be Considered

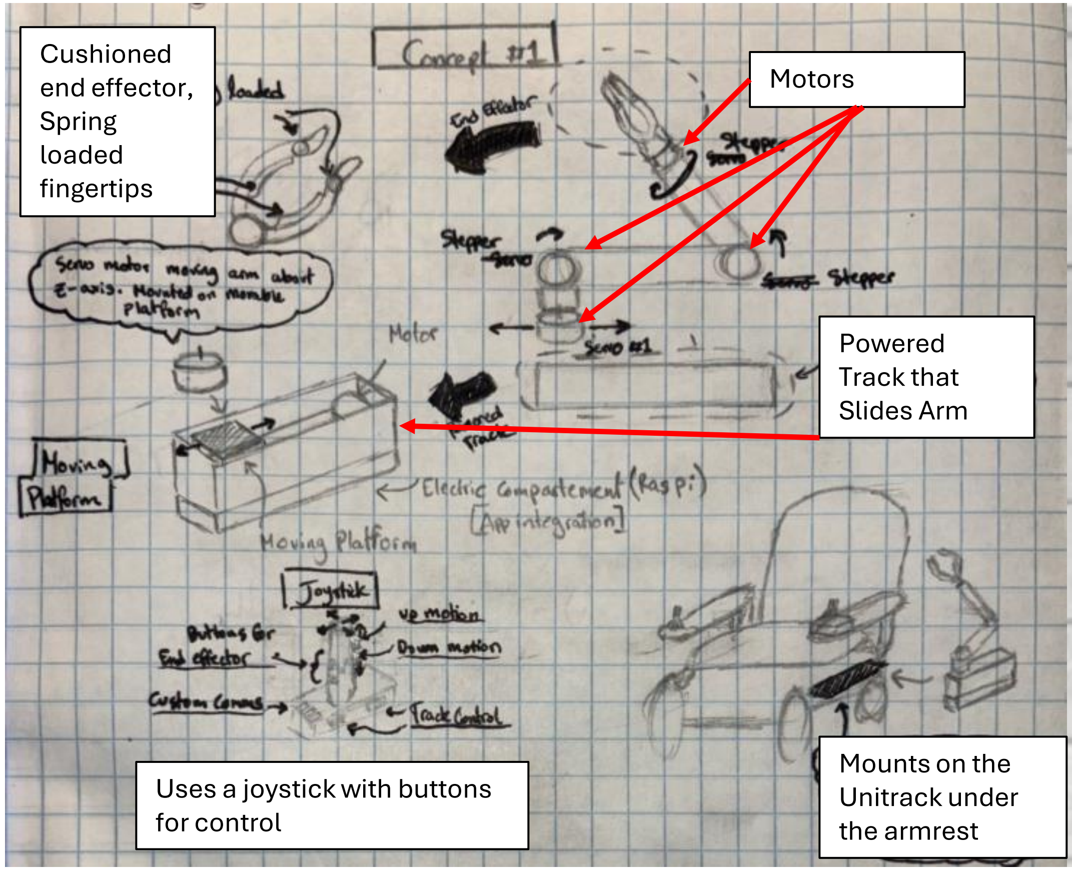


Figure 6: Justin Omar Combo Robotic Arm

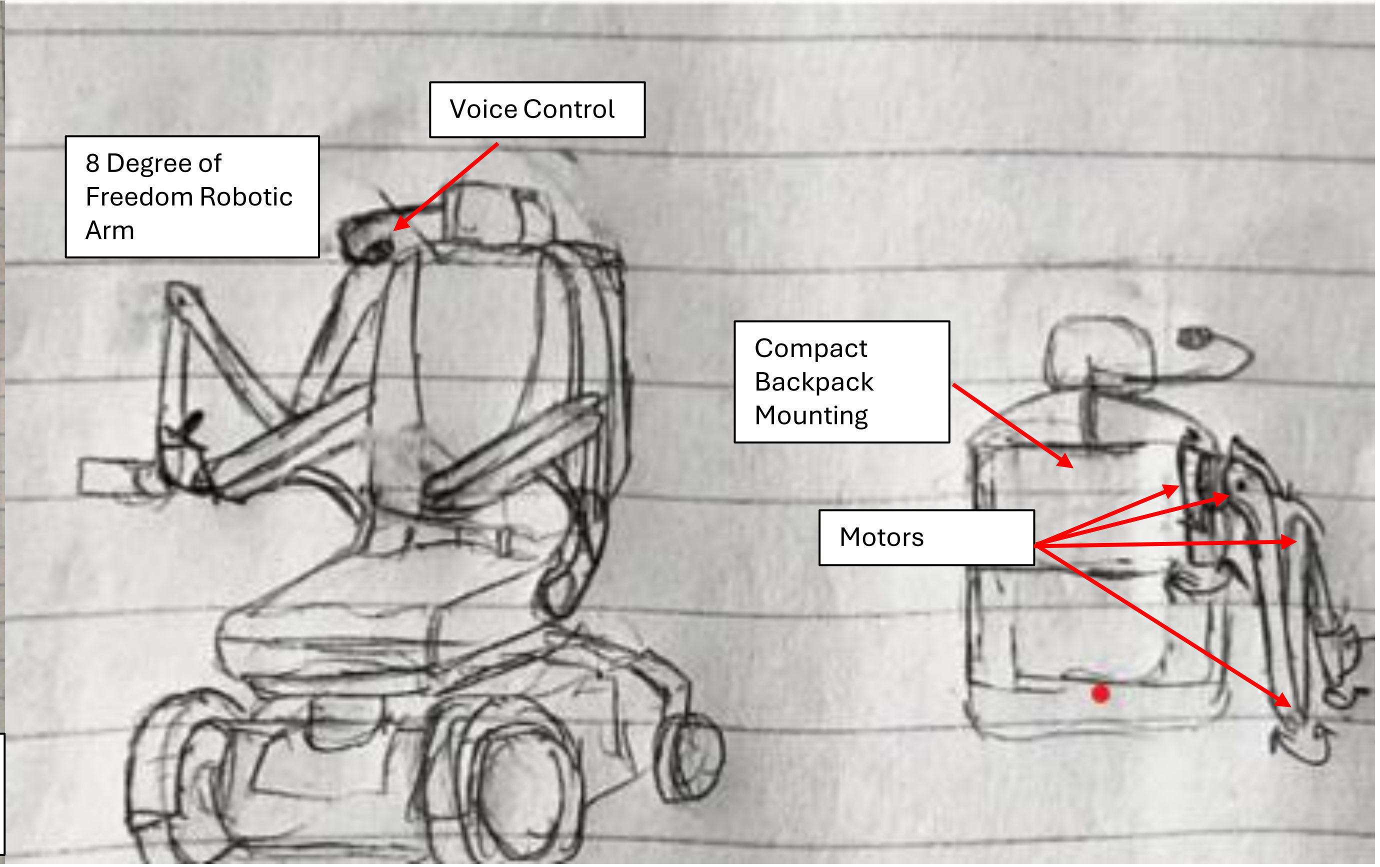


Figure 7: Brooke Cavan Over the Shoulder Robotic Arm

Team Members Generated Individual Concepts to be Considered

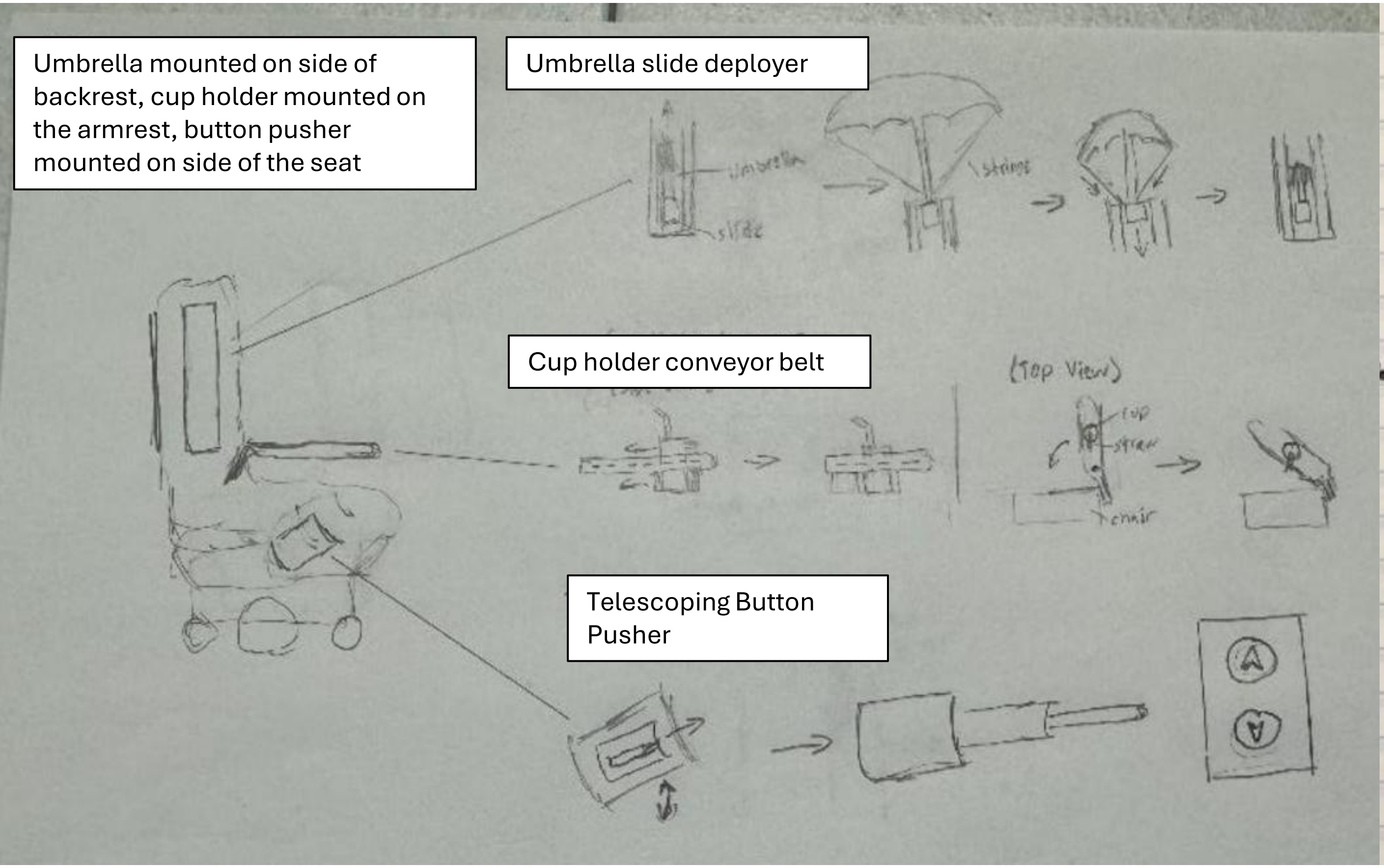


Figure 8: Justin AJ Combo Assistive Toolbelt

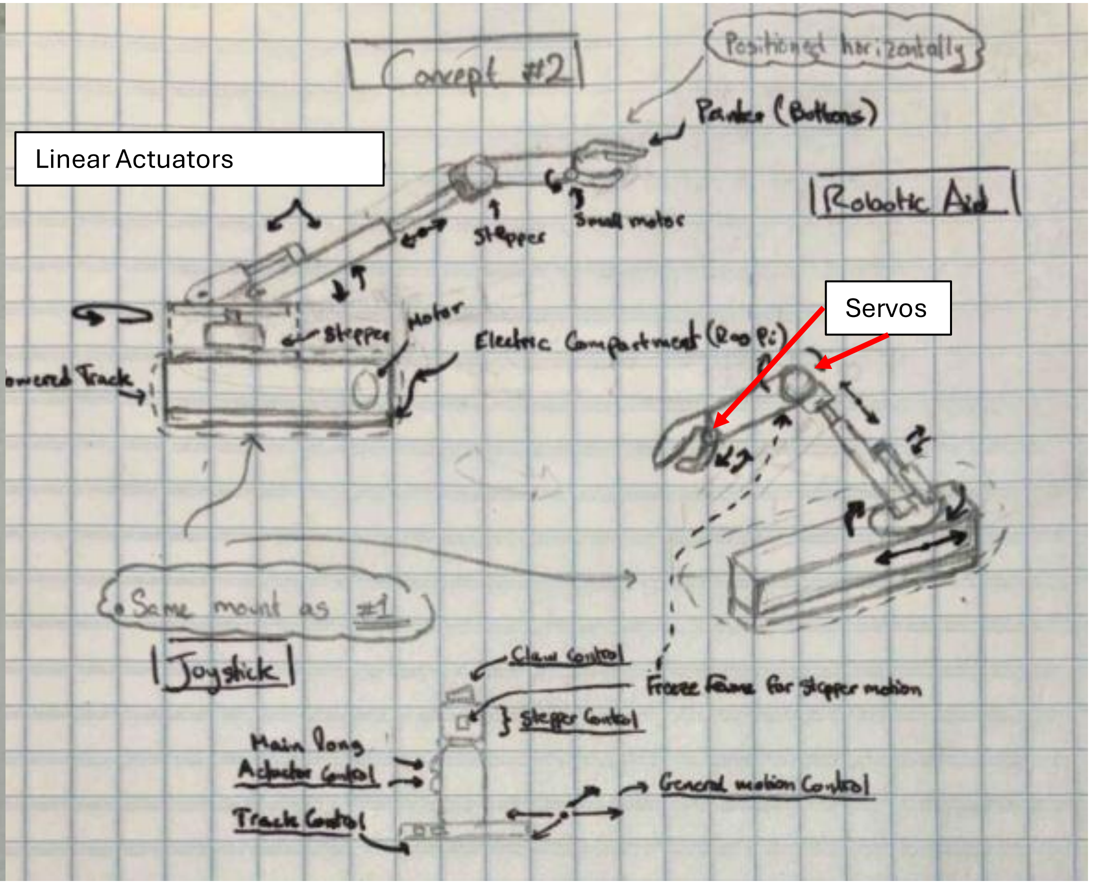


Figure 9: Omar Track/Pneumatic Arm

Team Members Generated Individual Concepts to be Considered

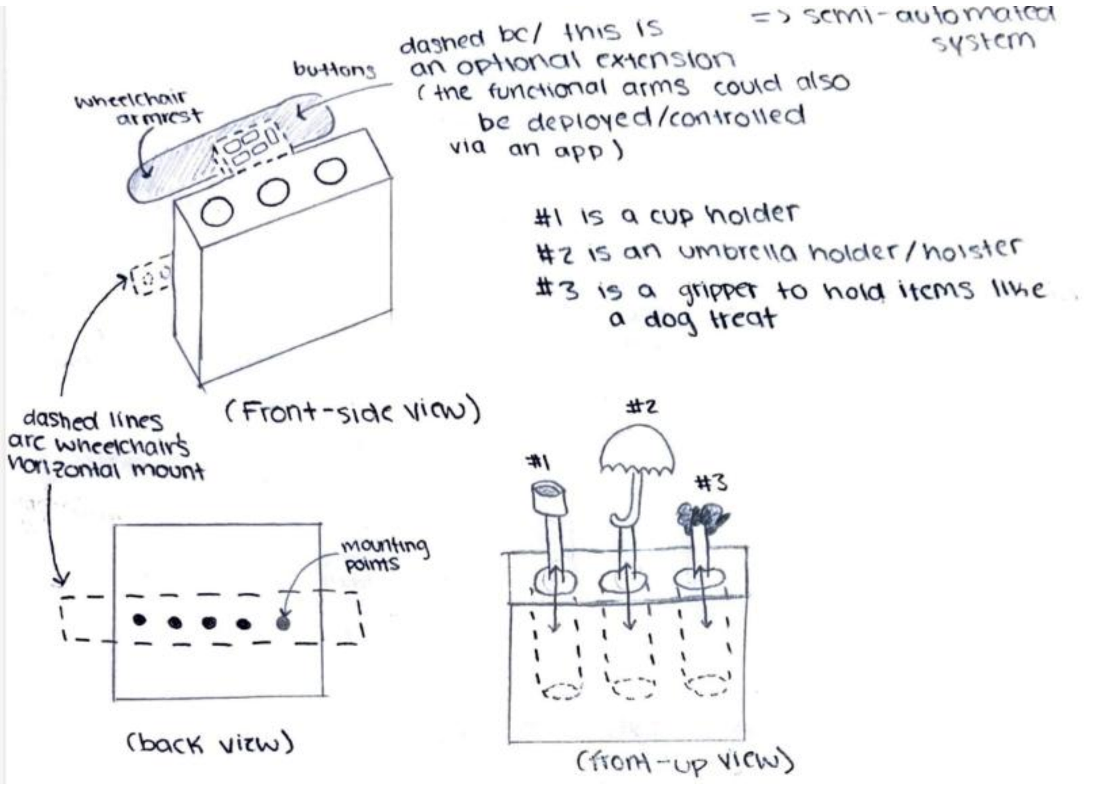


Figure 10: Combo Utility Box

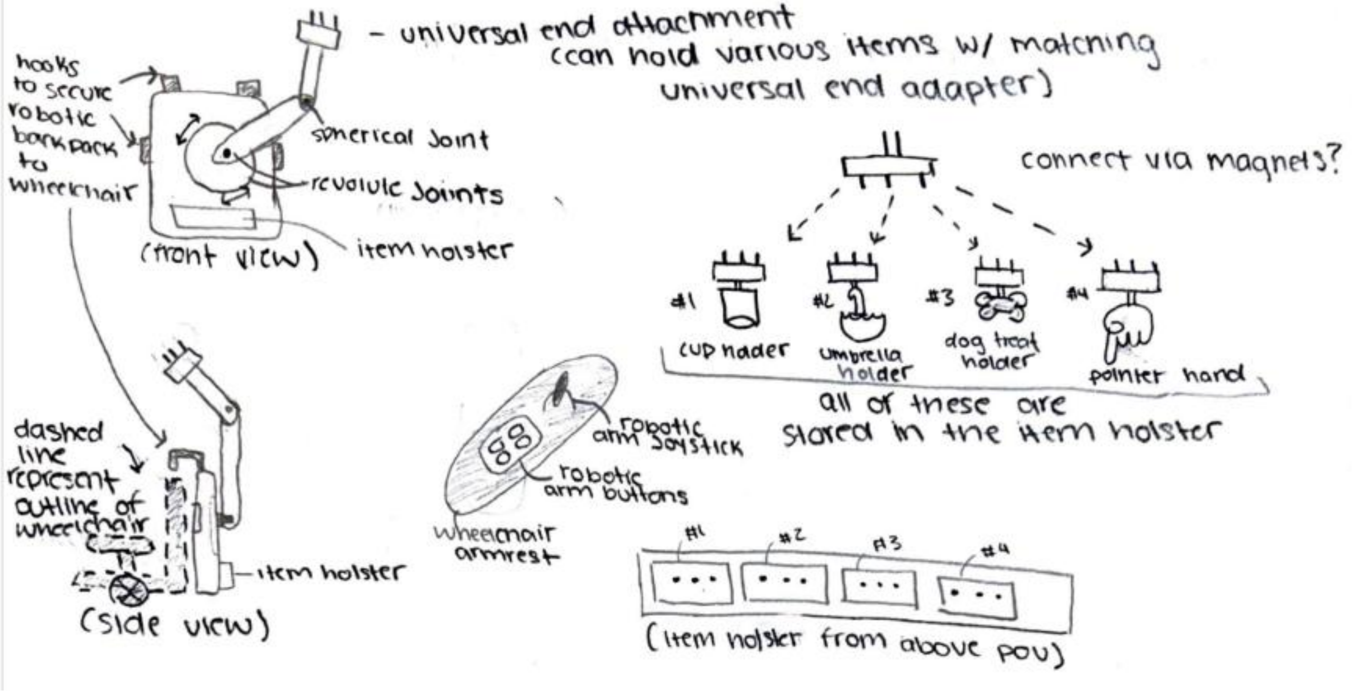


Figure 11: Brooke Multi End Effector

Concept Screening Narrowed Down the Teams Concepts

CONCEPT SCREENING						
Criteria	Justin Omar Combo Robotic Arm	Brooke Cavan Combo Over the Shoulder Arm	Justin AJ Combo Assistive Toolbelt/Button Pusher	Omar Track Pneumatic Arm	Combo Utility Box (all in one)	Brooke Multi End Effector
Operating Radius						
Number of Inputs to control device						
Number of actuators to control device						
Size						
Cost						
Safety						
Failure Modes						
Device Integration into chair						
Ease of Installation						
Net "+"						
Net "-"						
Net						
Rank						
Continue?						

A "+" indicates that the concept is better than the reference for that criteria

A "0" indicates it is equal in performance as the reference

A "-" indicates the concept is worse than the reference for that criteria

Concept Scoring Weighed the Importance of Each Criteria for Final Selection

Rated on a 1-4 scale where 1 and 2 are worse than the reference and 4 is better than the reference. Reference is 3

CONCEPT SCORING							
		Justin Omar Combo Robotic Arm		Brooke Cavan Combo Over the Shoulder Arm		Justin AJ Combo Assistive Toolbelt/Button Pusher	
Criteria	Weight	Rating	Score	Rating	Score	Rating	Score
Operating Radius	10%						
Number of Inputs to control device	15%						
Number of actuators to control device	10%						
Size	15%						
Cost	10%						
Safety	15%						
Failure Modes	10%						
Device Integration into Chair	10%						
Ease of Instillation	5%						
	Total Score						
	Rank						
	Continue?						

Assumptions for the Robotic Arm Concept

- An off the shelf robotic arm will be purchased and integrated into the wheelchair
- The Waveshare robotic arm is controlled by connecting to a website, but an Arduino can be connected allowing for other methods of control

Figure 12: Waveshare Low-Cost Robotic Arm

- Wheelchair donations from QL+ will be modified to resemble the structure of the Permobil M3 for testing purposes

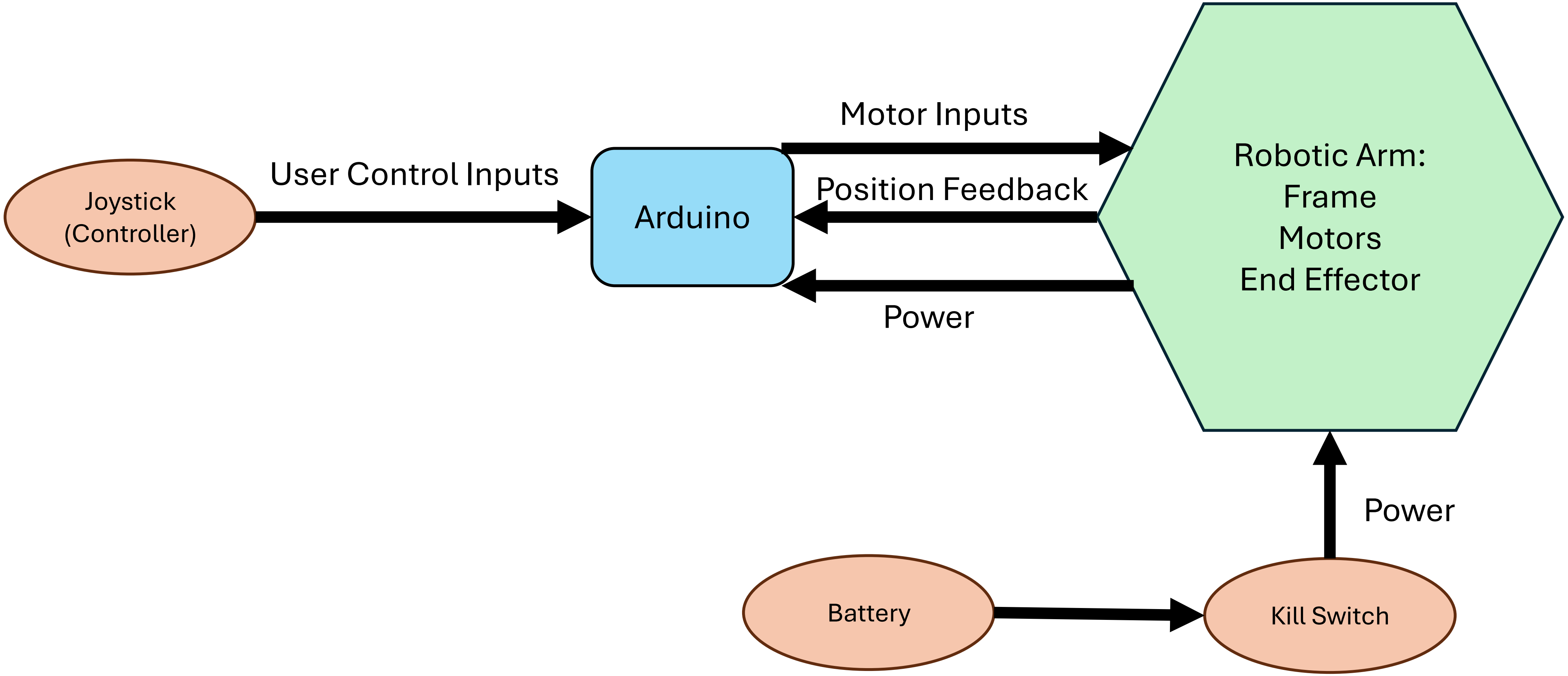
Figure 13. Donated Hoveround Chair

Figure 14. Donated Jazzy Chair

- The concept will mount to the Permobil Unitrack which is screwed into the seat of their motorized wheelchairs

Figure 15: Permobil M3 Corpus Unitrack

System Diagram



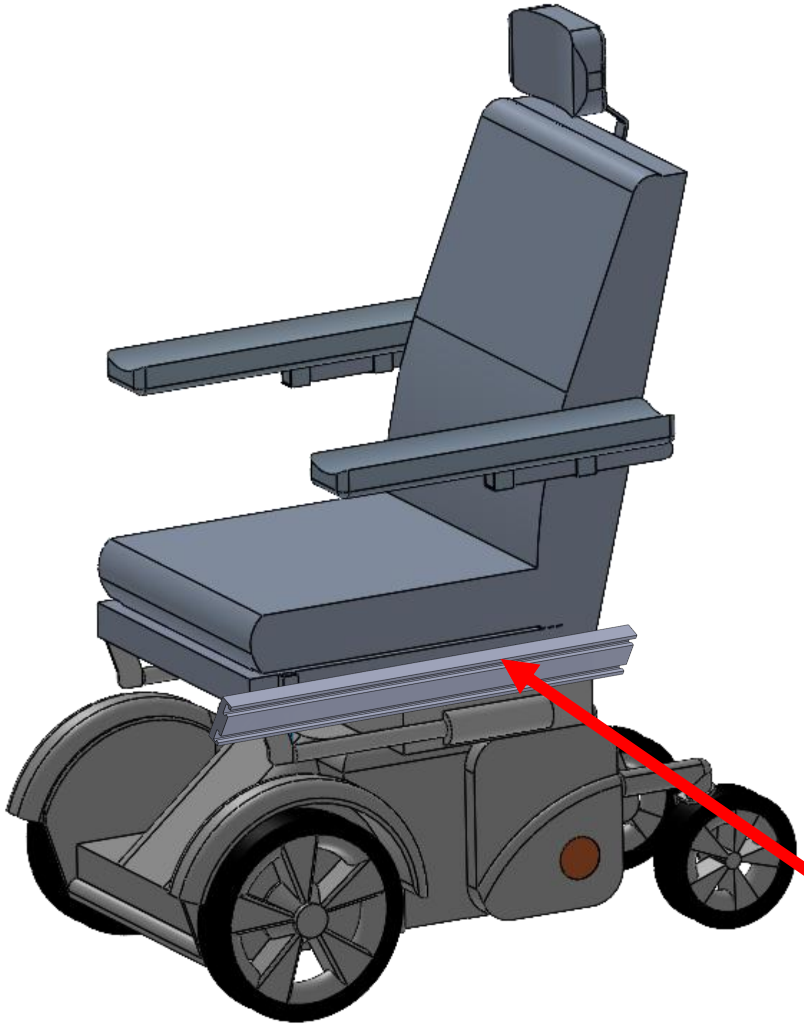
Benchmarking

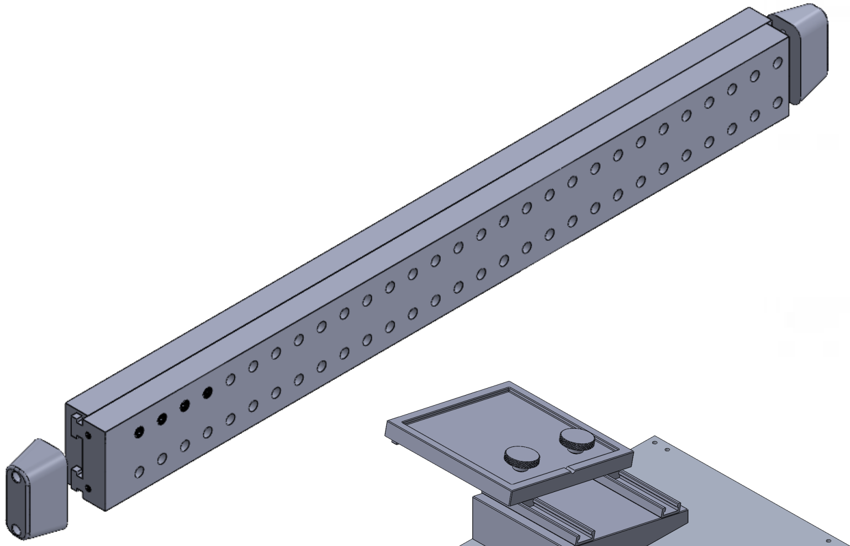
	[Waveshare RoArm-M2]()
Price	$189.99
Payload Capacity	500g
Weight	826g
DOF	4
Reach	500mm (19.6in)
Programming Language	Open source
End Effector	Included

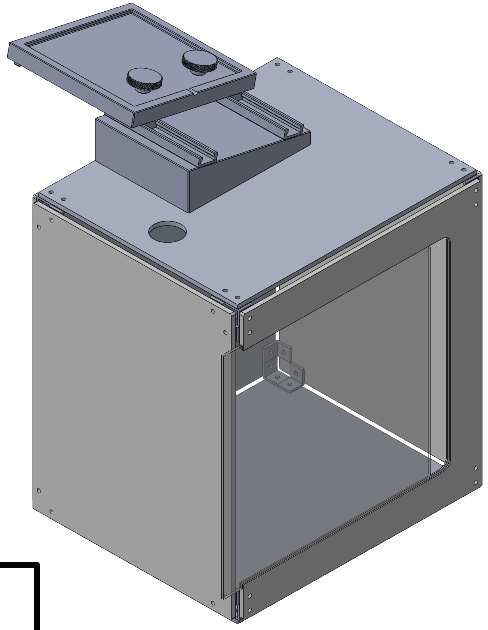
Figure 16:Wa

Figure 17: Tonifshi STR400 Robotic Arm

CAD Models

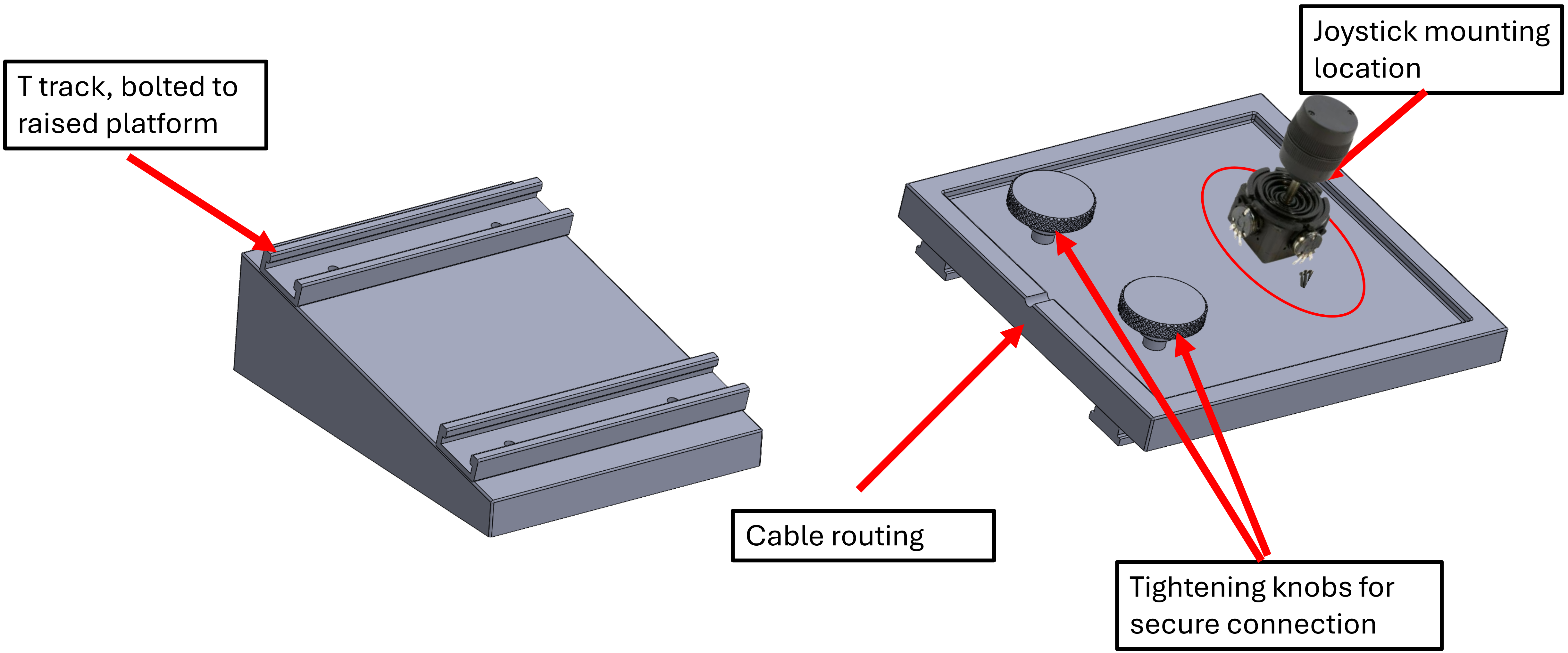




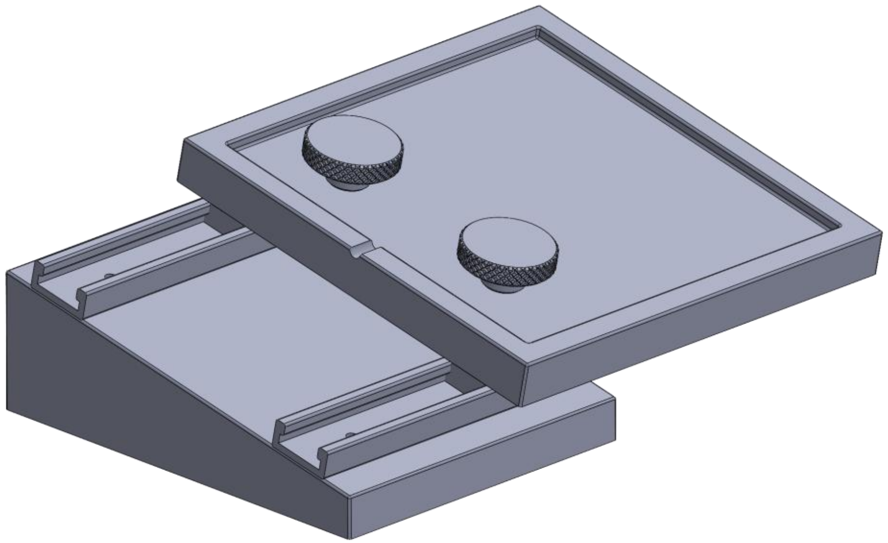


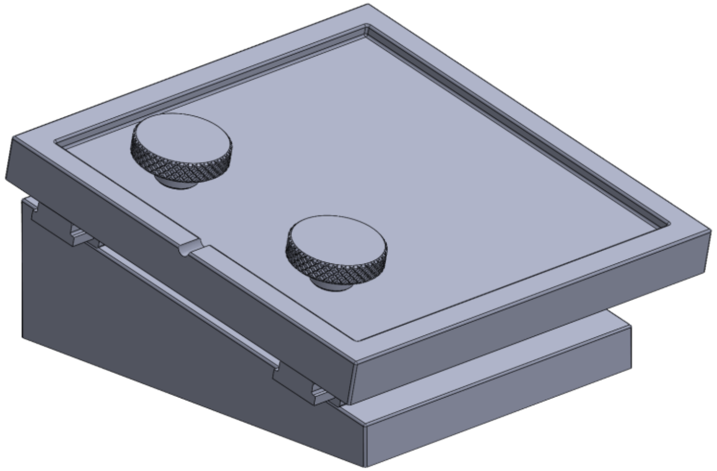
Unitrack, bolted to the wheelchair

Joystick Mount CAD Model

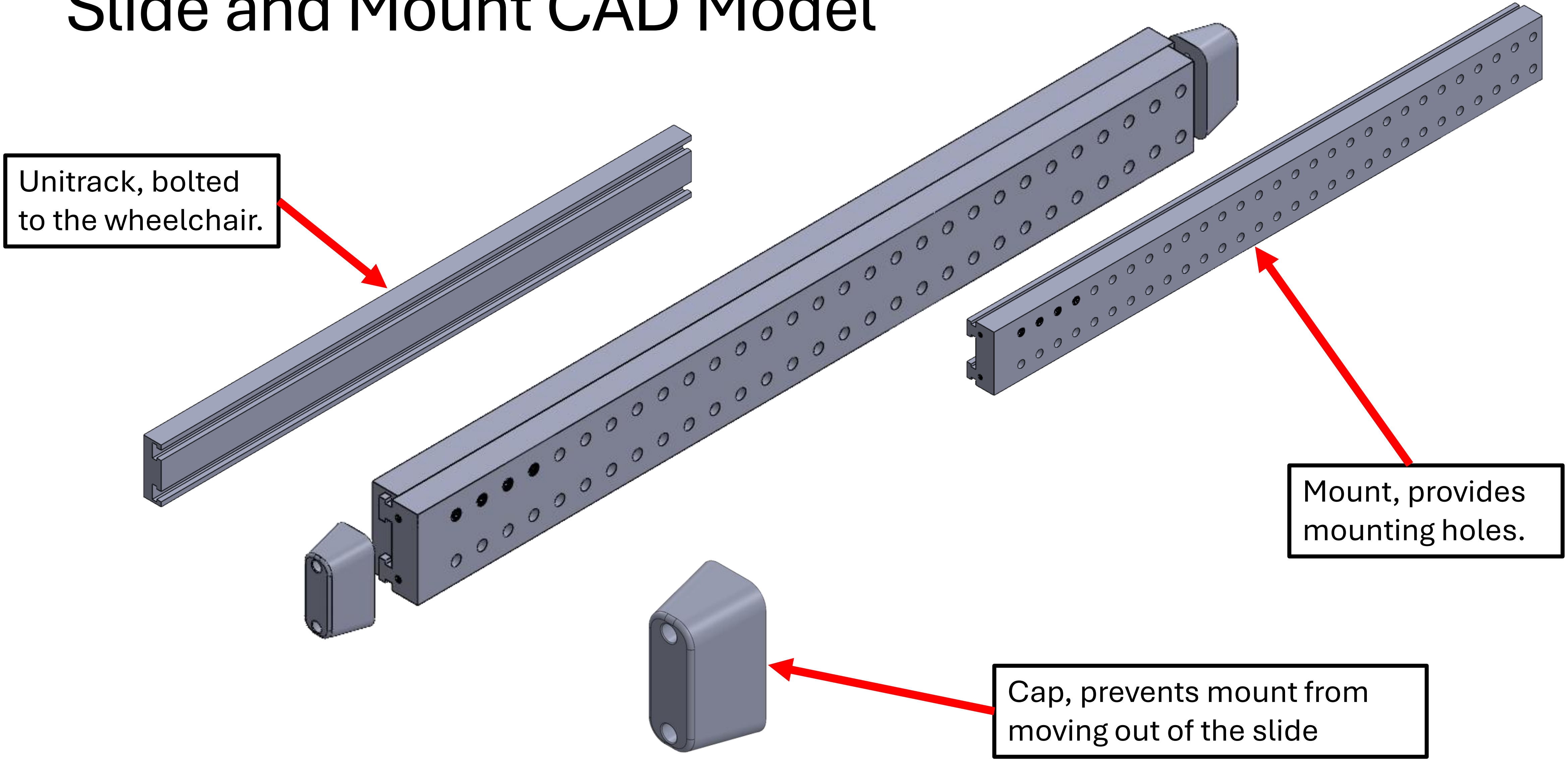


Joystick Mount CAD Model





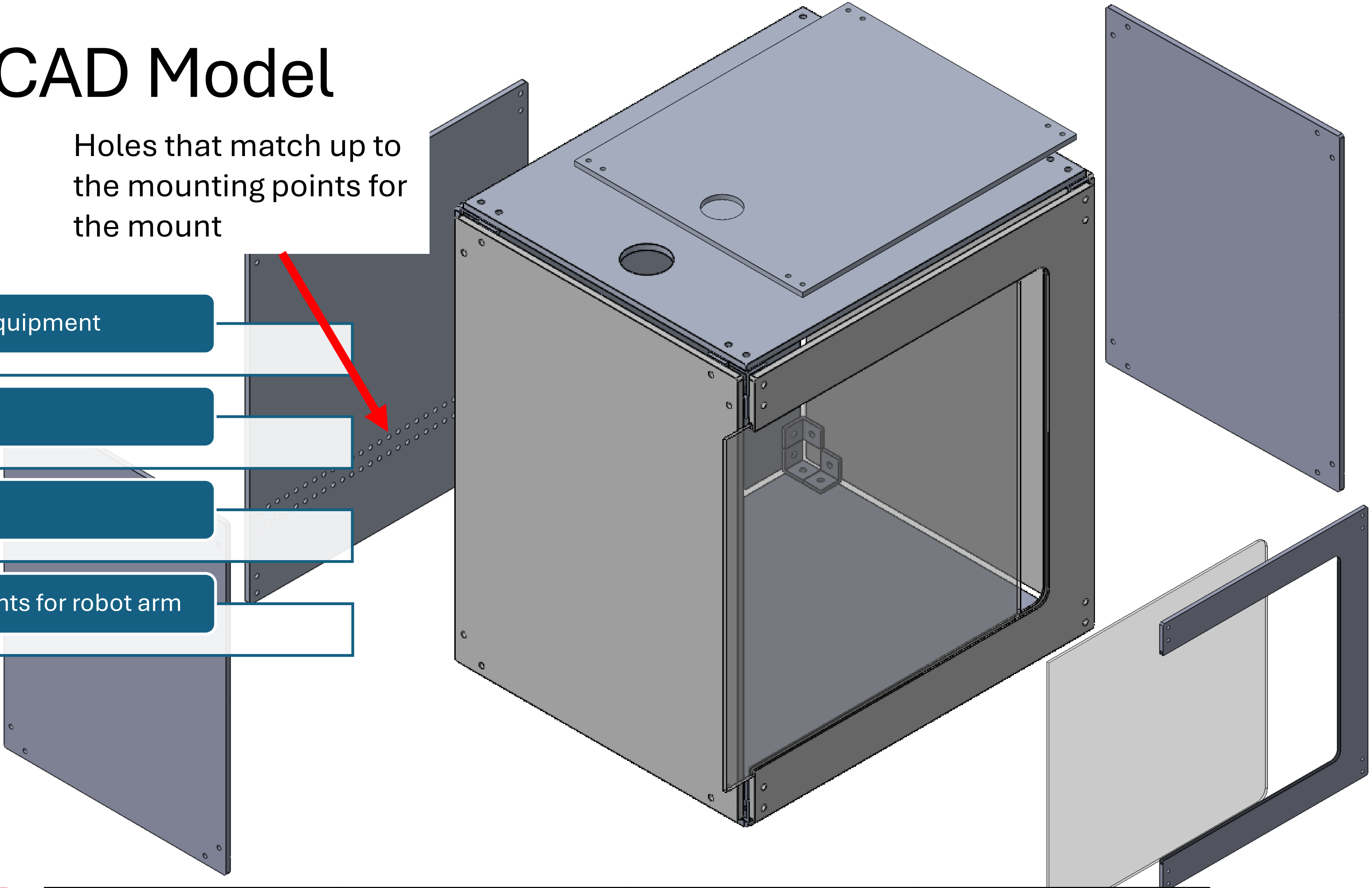
Slide and Mount CAD Model



Case CAD Model

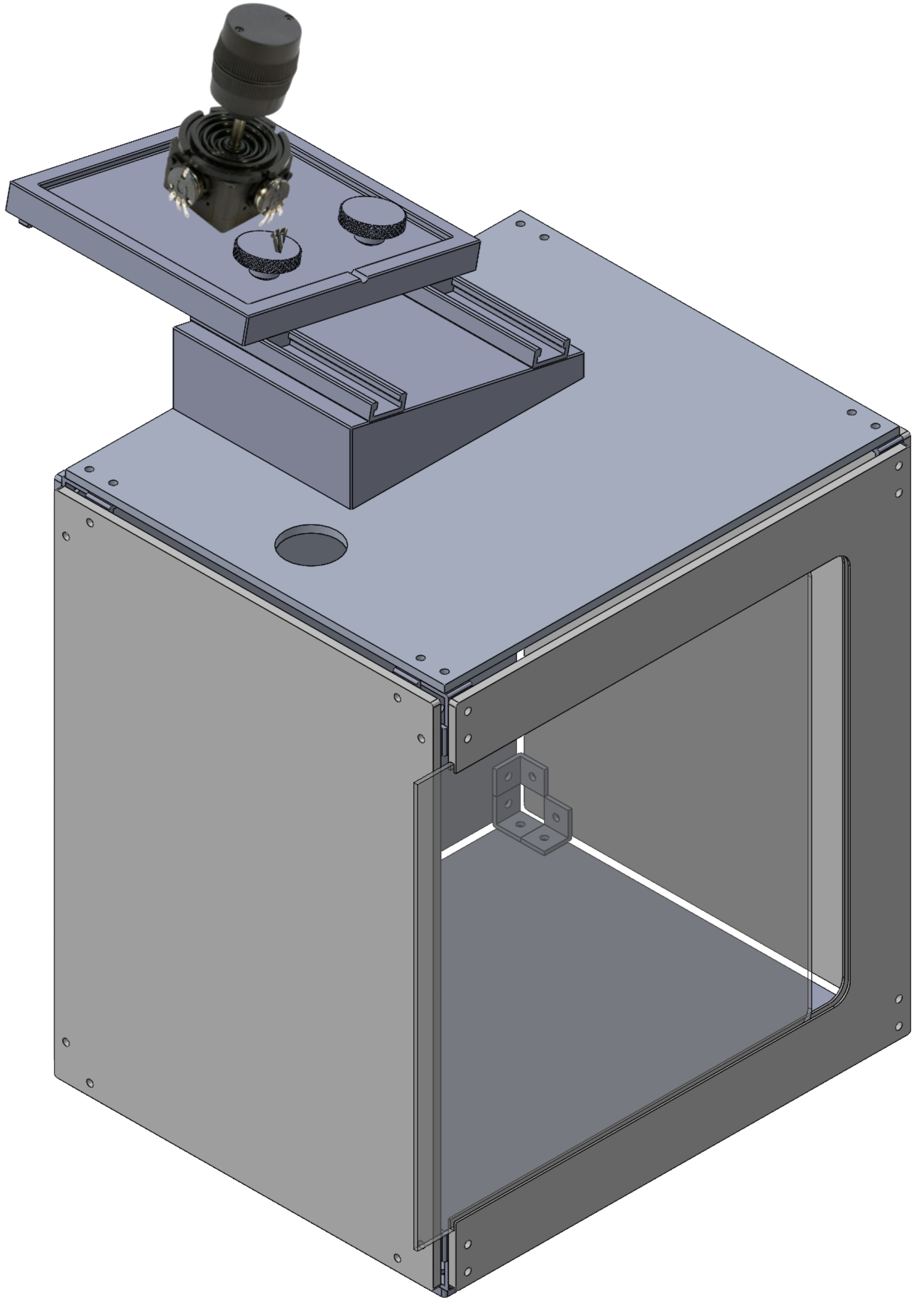
Holes that match up to the mounting points for the mount

- Processing Equipment
- Circuitry
- Batteries
- Mounting points for robot arm

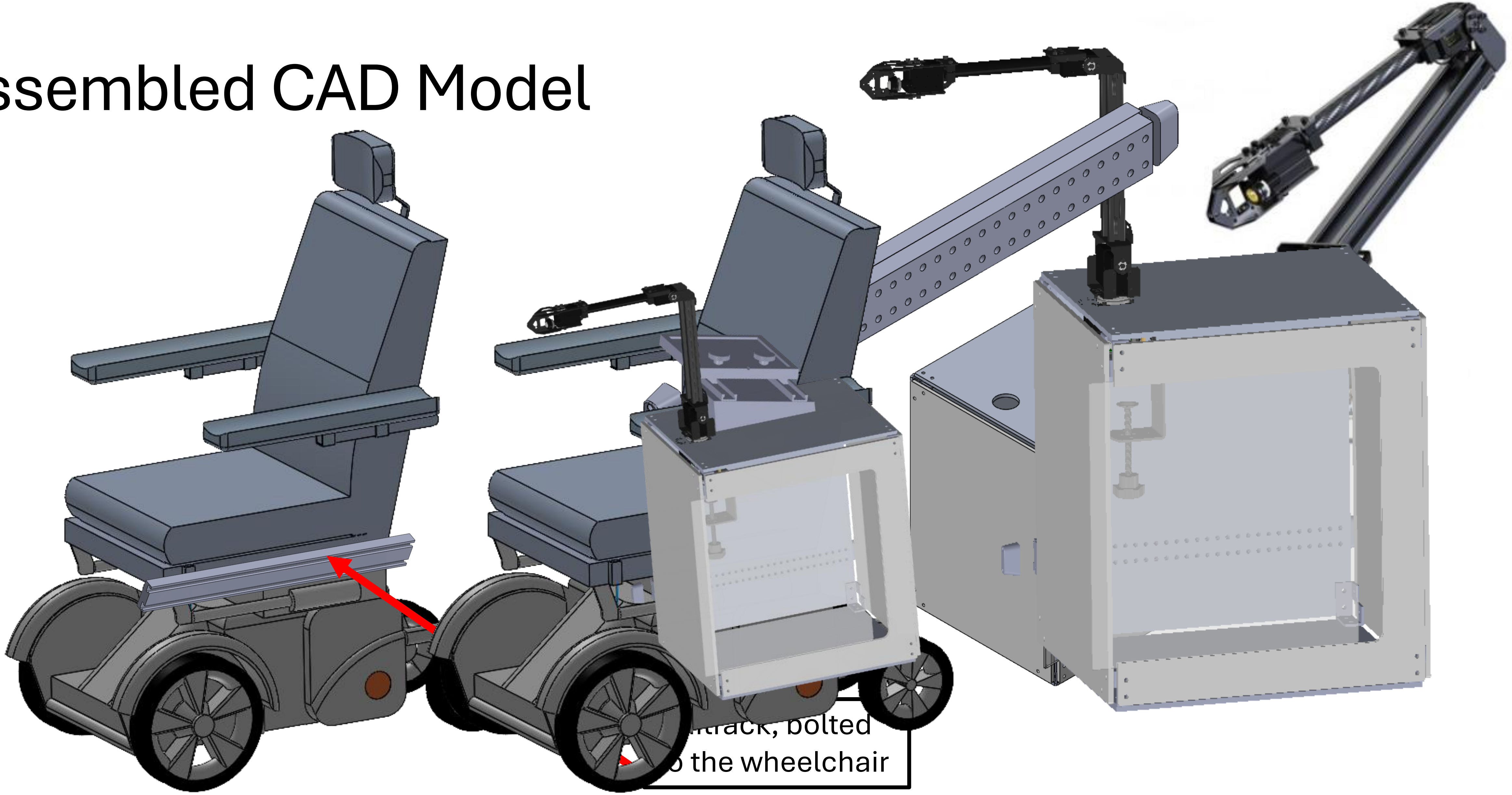


Case CAD Model

- Processing Equipment
- Circuitry
- Batteries
- Mounting points for robot arm



Assembled CAD Model



Risk and Risk Mitigation

Risk	Mitigation
End Effector and Arms Intrusively Interacting With User	Mechanical and Electronic Stops to Ensure User Safety
Water Contamination of Electrical Components	Tolerate Ingress Protection (IP) Ratings of Enclosures and Seals – IP 65
Electrical and Component Overheating Leading to Heat Sustained Damage	Material Analysis, Proper Ventilation, Active Cooling

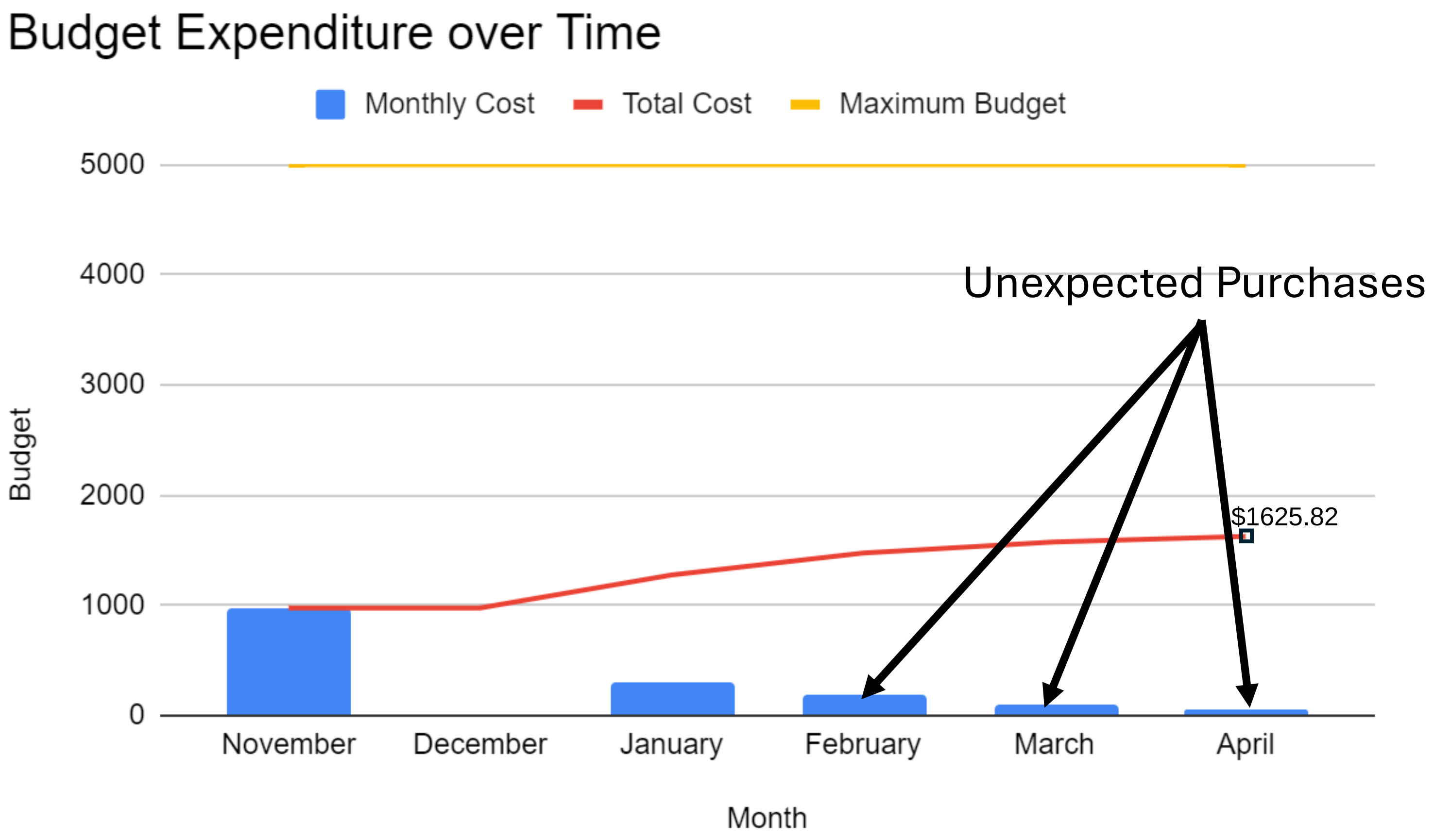
Unmitigated Risks

Likelihood \ Severity	1	2	3	4	5
5	1	0	0	0	0
4	0	0	0	0	1
3	0	0	1	1	1
2	0	1	1	1	1
1	0	0	0	1	0

Mitigated Risks

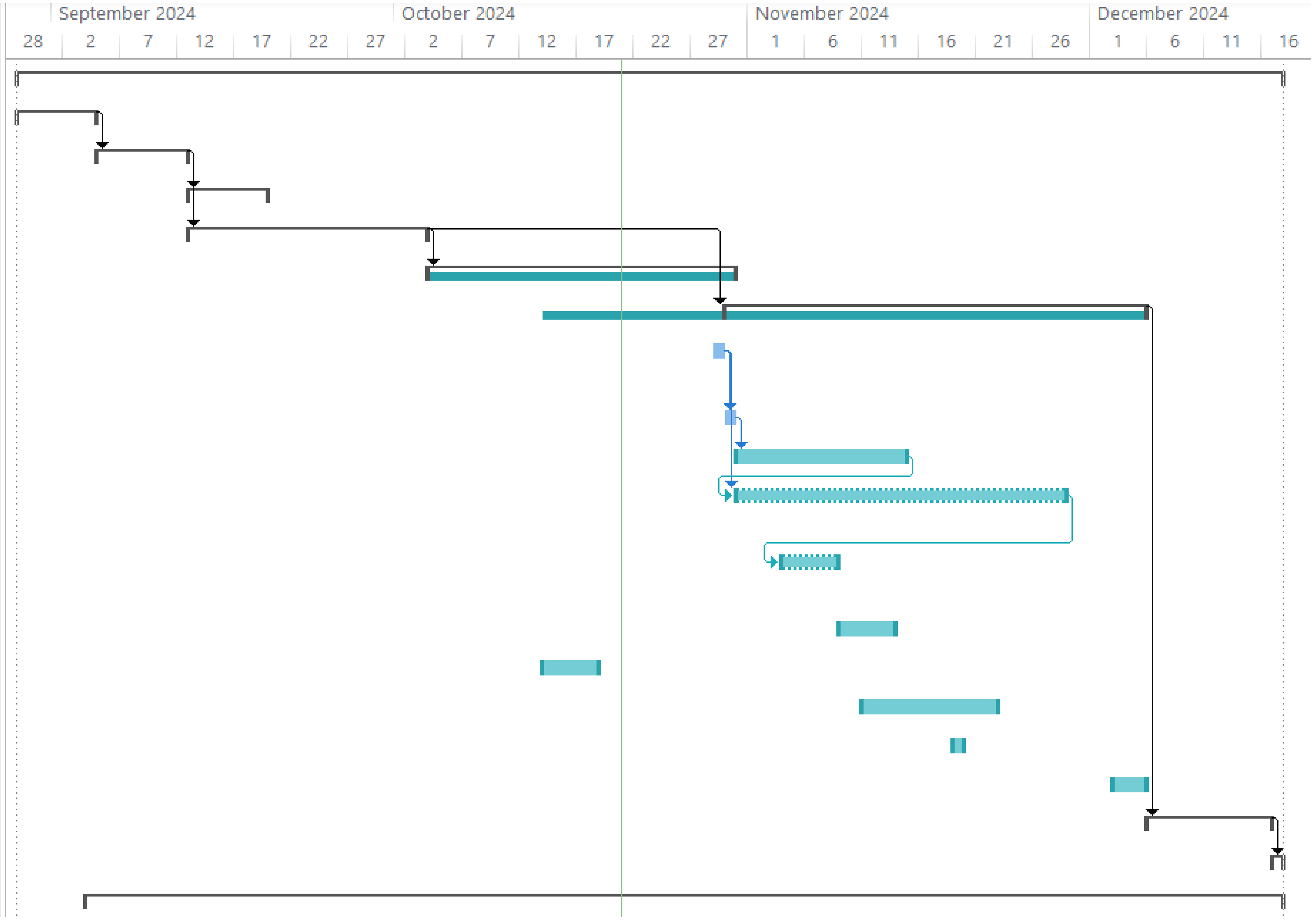
Likelihood \ Severity	1	2	3	4	5
5	0	0	0	0	0
4	0	0	0	0	0
3	0	0	0	0	0
2	1	3	1	0	0
1	1	4	0	0	0

Team 205’s Maximum Budget is $5000



Team is Currently on Schedule for CDR Preparation

Task Name	% Complete
Team Actions - ME4015	**37%**
Planning	**100%**
Concept Development	**100%**
System Readiness Review	**100%**
Preliminary Design	**100%**
PDR Preparation	**80%**
Critical Design	**0%**
Meet with advisor to discuss proposed plans	0%
Clean Power Wheelchairs	0%
Order Adruino (~2 weeks shipping)	0%
Order WaveShare Robotic Arm (~4 weeks shipping)	0%
Generate more precise CAD models (robotic box)	0%
Perform FEA analysis	0%
Familarize team with Python	0%
Prepare CDR Report and Presentation	0%
Review CDR with Advisor	0%
Present CDR	0%
CDR Preparation	**0%**
Spring Semester Preparation	**0%**
Course Deliverables	**0%**



Conclusions and Future Work

The Team Has:

- Discussed customer needs and high value functions with end user – informing requirements
- **Developed and down selected a concept to move forward**
- **Assessed feasibility and risk associated with selected concept**
- Began developing CAD models and researching material selection
- Acquired chairs to begin modifying
- Determined which arm will be purchased

The Team Will:

- Modify a Jazzy wheelchair to replicate mounting structure of a Permobil M3 wheelchair
- Begin Prototyping
  - **Design mounting bracket that attaches the robotic case to the side of the wheelchair**
  - Order the robot arm and control systems
  - **Integrate the Waveshare robotic arm and control systems onto robotic case**
  - Learn syntax and program robotic arm,
  - Learn Arduino integration with ESP32

Conclusions:

- Team is on track to meeting the high value functions of pushing an elevator and handicap door button
- The team will continue to work closely with our customers from PPMD to ensure our prototyping process gets constant feedback from the end user

Thank you for your time!

Questions?

Backup Slides, Additional Information

REQUIREMENTS VERIFICATION TRACEABILITY MATRIX (RVTM)

Project Name:	Robotic Arm to Assist Motorized Chair Users	Customer Approval	
Program/Customer:	PPMD	Signature Keith Van Houten	09/19/2024
Project Manager Name:	Brooke Harrington		
Project Description:	Robotic arm that attaches to a motorized chair to aid people with mobility restrictions due to Duchenne Muscular Dystrophy		

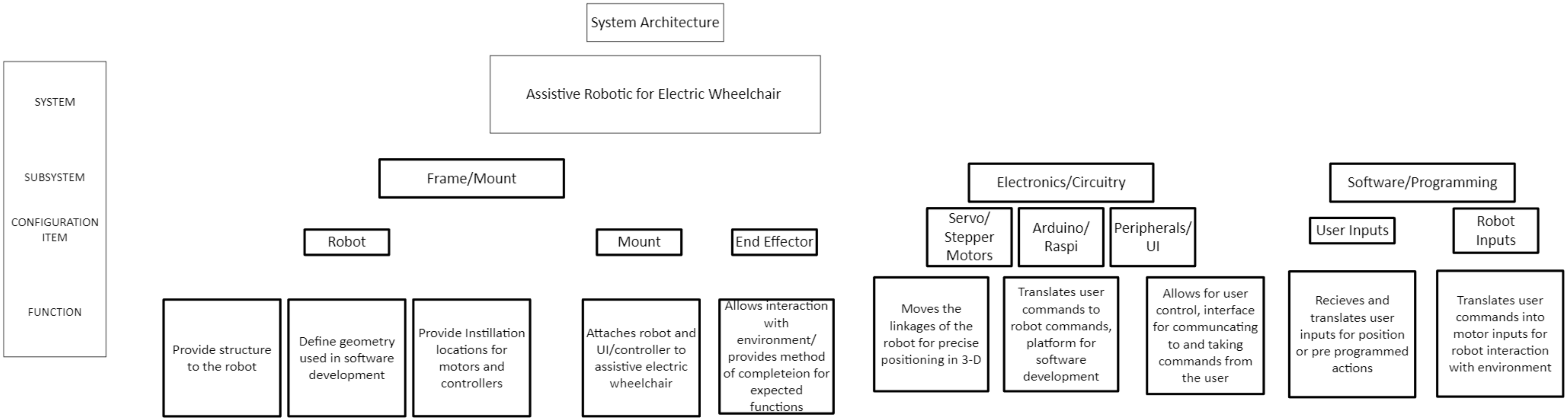
Technical Requirement ID #	Requirement	Requirement Origination	Comments	Verification Method
TR 1.0.0	The team shall research, design, develop, integrate, and test an assistive robotic device modified for a motorized wheelchair including a custom mounting device, electronics, and software.	Customer Requirement	The robot should be able to preform one well defined task. More task can be undertaken as the main task is completed.	
TR 1.1.0	The robot shall be controlled manually by a joystick and should have the ability to program automatic functions accessed through a button push or voice activation	Customer Requirement	The control system should be able to attach to either left/right side (dependent on user's dominant side)	Test
TR 1.1.1	The joystick shall be attached in a location near the motorized wheelchair armrest	Customer Requirement	Customer stated postioning the control interface near the non dominant hand so the wheelchair and robot system can be used simulataneously	Visual Inspection
TR 1.1.2	Any automatic functions shall be independent of the joystick and should operate without any joystick inputs	Customer Requirement	Automatic functions are to be determined if main function is properly adressed	System Test
TR 1.1.3	The arm shall not mount in a location that infringes on the user's seating space, and must be small enough that as installed on wheelchair, the user can still pass through a standard door opening	Customer Requirement		Physical Inspection
TR 1.2.0	The robot shall have no more than six degrees of freedom	Customer Needs	Developed from "ease of use" customer need	Inpection
TR 1.3.0	The robot shall have an operating radius that spans a minimum of 5 inches to a maximum of 2 feet from mount location with 180 degrees of rotation total	Customer Needs	Developed from high value functions discussion with customer	System Test
TR 1.4.0	The robot should receive power from the motorized wheelchair battery and should include a backup battery	Customer Needs		Analysis
TR 2.0.0	The robot shall operate in dry, arid conditions and should operate under rainy, humid conditions	Customer Needs		System Test
TR 2.1.0	The robot electronics shall be contained in a weather resistant enclosure	Customer Needs	Devloped from 2.0.0	Material Test
TR 2.1.1	The robot motors shall be secured in a weather resistant sleeve	Customer Needs	Devloped from 2.0.0	Material Test
TR 3.0.0	The robot shall be installed in less than one hour and should be operational within thirty minutes of installation	VT Design Team	In order for multiple people from PPMD to test the system when they visit, it is ideal to have the install/unsinstall and time till operation be minimized without sacrificing safety or quality **(subject to change once robot and assistive wheelchair have been acquired)**	Timed Test
TR 3.1.1	The robot shall be disassembled and reassembled for maintenance in less than three hours	VT Design Team		Timed Test or PM/M Plan Development
TR 3.2.0	The robot shall require maintenance every year and should be cleaned and inspected every 3 months	VT Design Team	**(Subject to change once robot and assistive wheelchair have been acquired)**	Analysis / PM/M Plan Development
TR 4.0.0	The system shall be neutral in color and should blend into the motorized wheelchair structure	VT Design Team	Talk this over with customer once robot has been acquired/developed	Visual Inspection
TR 4.1.0	The system shall contain no sharp edges and should minimize sharp corners on frame, end effector, and joystick	VT Design Team		Visual/Physical Inspection
TR 5.0.0	The robot shall not cause harm to the operator in any way.	VT Design Team		System Test
TR 5.1.0	Upon startup, the robot shall have safeguards against unexpected energization	VT Design Team		System Test
TR 5.2.0	The robot shall have physical or program safeguards to prevent it from reaching undesired locations	VT Design Team		System Test

Requirements Verification Traceability Matrix

VIRGINIA TECH

Parent Project Muscular Dystrophy

System Architecture



Concept Screening and Scoring

CONCEPT SCREENING						
Criteria	Justin Omar Combo Robotic Arm	Brooke Cavan Combo Over the shoulder Arm/Backpack (REF)	Justin AJ Combo Assistive Toolbelt/Button Pusher	Omar Track/Pneumatic Arm	Combo Utility Box (all in one)	Brooke Multi end effector
Operating Radius	+	0	-	0	-	+
Number of inputs to control device	0	0	+	0	-	-
Number of actuators to control device	0	0	+	+	+	-
Size	+	0	0	-	-	-
Cost	+	0	0	-	+	-
Safety	+	0	+	0	-	+
Failure Modes	0	0	0	-	+	-
Device Integration onto Chair	0	0	0	+	0	+
Ease of Installation	0	0	0	-	0	+
Net "+"	4	0	3	2	3	4
Net "-"	0	0	1	4	4	5
Net	4	0	2	-2	-1	-1
Rank	1	3	2	6	4.5	4.5
Continue ?	Continue	Continue	Continue	Eliminate	Eliminate	Eliminate

CONCEPT SCORING							
	100%	Justin Omar Combo Robotic Arm		Brooke Cavan Combo Over the shoulder Arm/Backpack		Justin AJ Combo Assistive Toolbelt/Button Pusher	
Criteria	Weight	Rating	Score	Rating	Score	Rating	Score
Operating Radius	10%	4	0.4	3	0.3	2	0.2
Number of inputs to control device	15%	3	0.45	3	0.45	4	0.6
Number of actuators to control device	10%	3	0.3	3	0.3	4	0.4
Size	15%	3	0.45	3	0.45	3	0.45
Cost	10%	3	0.3	3	0.3	3	0.3
Safety	15%	4	0.6	3	0.45	4	0.6
Failure Modes	10%	3	0.3	3	0.3	4	0.4
Device Integration into Chair	10%	3	0.3	3	0.3	3	0.3
Ease of Installation	5%	3	0.15	3	0.15	4	0.2
Total Score		3.25		3		3.45	
Rank		2		3		1	
Continue?		Develop		Discard		Develop	

Risk and Mitigation Plan

Risk ID #	Risk Description	Risk Category	Likelihood	Severity	Risk Level	Owner	Mitigation Plan	Mitigated Likelihood	Mitigated Severity	Mitigated Risk Level	Status
1	Sheering of bolts/welds at mounting location of robotic arm due to deformation or excessive force	Technical	2	4	6	Justin	Stress analysis between bolts and track rail	1	2	3	Open
2	Bending and buckling of robotic members at critical points along arm	Technical	5	1	6	Justin	Material selection with higher stress standards	2	1	3	Open
3	End effector and arms exceeding range of operation	Technical	4	5	9	Cavan	Mechanical and digital stops	2	3	5	Open
4	Electrical components overheat, causing technical or electrical failure and deformation	Technical	3	4	7	Cavan	Material analysis and proper ventilation	2	2	4	Open
5	Excessive weight load on robotic arm	Technical	2	3	5	Omar	Incorporate verbal weight load capacity - Factor of Safety	2	2	4	Open
6	Programmed function exceeding operating time (Loop)	Technical	2	2	4	AJ	Program failsafe function that stops all current functions by comparing operation time	1	1	2	Open
7	Water damage	Technical	3	5	8	Brooke	Tolerate Ingress Protection (IP) ratings of enclosure and seals	2	2	4	Open
8	Sensitivity / Delay between robotic arm and joystick (controller)	Program	3	3	6	Omar	Adjusting sensitivty thorugh analysis and testing	1	2	3	Open
9	Electical overload when powered on	Technical	2	5	7	AJ	Include a breaker between the battery and processing components	1	2	3	Open
10	Robotic arm operation is systematic (out of control)	Technical	1	4	5	Brooke	Implement emergency stop	1	2	3	Open

Budget Decomposition

	A	B	C	D	E	F	G	H	I	J	K	L	M
1–2	Budget - 205 - Robotic Arm to Assist Motorized Wheelchair Users												
3	Starting Budget =	$ 5,000.00											
4	Projected Budget =	$ 4,024.18				Projected Used Budget =	$ (975.82)	Verification					Any other i
5	Available Budget =	$ 5,000.00				Used Budget =	$ -	$ -					
6	Item description	Part #	URL	Vendor	Quantity	Price Per Unit (No ship or tax)	Tax	Shipping	Shipping Method	Total Cost	Status (OPEN/PURCHASED)	Received (Y/N)	Purchase Month
7	Permobil UniTrack Bar 14-16" seat depth	SKU: 321434	https://buildmywheelchair.com/unitrack-bar-14-15-16-seat-depth-corpus-3g-vs/	Build My Wheelchair	1	$ 48.00	$ -	$ 14.99	Standard	$ 62.99	OPEN	N	November
8	Permobil UniTrack Bar 17-19" seat depth	SKU: 321440	https://buildmywheelchair.com/unitrack-bar-17-18-19-seat-depth-corpus-3g-vs/	Build My Wheelchair	0	$ 48.00	$ -	$ 14.99	Standard	$ -	OPEN	N	November
9	Lipo Battery Charger Hitec		https://maxamps.com/collections/lipo-battery-charger/products/lipo-battery-	Maxamps	1	$ 79.00	$ 4.19	$ 8.25	standard	$ 91.44	OPEN	N	November
10	Arduino Uno R3 USB Microcontroller	SKU: RB-Ard-34	https://www.robotshop.com/products/arduino-uno-r3-usb-microcontroller	RobotShop	1	$ 27.60	$ 1.47	$ 4.74	USPS Ground Advantage	$ 33.81	OPEN	N	November
11	Arduino Uno Rev4 Wifi	SKU: RB-Ard-187	https://www.robotshop.com/products/arduino-uno-rev4-wifi	RobotShop	0	$ 30.07	$ 1.59	$ 4.74	USPS Ground Advantage	$ -	OPEN	N	November
12	Arduino Mega 2560 Microcontroller REv3	SKU: RB-Ard-33	https://www.robotshop.com/products/arduino-mega-2560-microcontroller-rev3	RobotShop	0	$ 48.40	$ 2.56	$ 4.74	USPS Ground Advantage	$ -	OPEN	N	November
13	Waveshare High-torque Serial Bus Servo, RoArm-M2-S Desktop Robotic Arm Kit, Based On ESP32, 4-DOF	SKU:25118 Part No.:RoArm-M2-S	https://www.waveshare.com/product/robotics/robot-arm-control/roarm-m2/roarm-m2-s.htm?sku=25118	Waveshare	1	$ 189.99	$ -	$39.60	USPS	$ 229.59	OPEN	N	November
14	Graphene LiPo 5200 3S 11.1v Battery Pack	SKU: Graphene- Lipo-5200-3S-Pack-2	https://maxamps.com/collections/3s-lipo-battery-11-1v/products/graphene-lipo-	Maxamps	2	$ 134.00	$ 7.10	$ 8.25	Standard	$ 298.70	OPEN	N	November
15	6061 Aluminum Sheet & Plate	P314T6	https://www.metalsdepot.com/aluminum-products/6061-aluminum-sheet-plate	Metals Depot	1	$ 87.76	$ -	$ -		$ 87.76	OPEN	N	January
16	Aluminum Stick Electrode	E4043	https://www.forneyind.com/forney-45889-e4043-aluminum-electrode-1-8-in-x-1-2-pound	Forney	1	$ 31.99	$ -	$ -		$ 31.99	OPEN	N	January
17	Gorilla All Weather Outdoor Waterproof Duct Tape	6009002	https://www.amazon.com/stores/page/BE8CB2B1-203E-	Gorrila	1	$ 25.96	$ 2.31	$ 6.99	Standard	$ 35.26	OPEN	N	January
18	3 Function Joystick	SKY: 605616	https://www.servocity.com/3-function-joystick/	Servocity	3	$ 29.99	$ 4.77	$ -	Standard	$ 104.28	OPEN	N	November

Forward Kinematics

- Transformation matrix (T) displays the position (p) and orientation (R) of the end effector in reference to the base of the robot

$$T = \begin{bmatrix} R & p \\ 0 & 1 \end{bmatrix} = \begin{bmatrix} r_{11} & r_{12} & r_{13} & p_1 \\ r_{21} & r_{22} & r_{23} & p_2 \\ r_{31} & r_{32} & r_{33} & p_3 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

- Screws (S1,S2,S3,S4) are determined through robot geometry
- M is the initial transformation matrix, showing the initial position and orientation of the end effector

$$T = e\hat{}([S_1]*\theta_1)*e\hat{}([S_2]*\theta_2)*e\hat{}([S_3]*\theta_3)*e\hat{}([S_4]*\theta_4)*M$$

- Given desired θ values, the position and orientation of the end-effector can be determined

VIRGINIA TECH. Parent Project Muscular Dystrophy

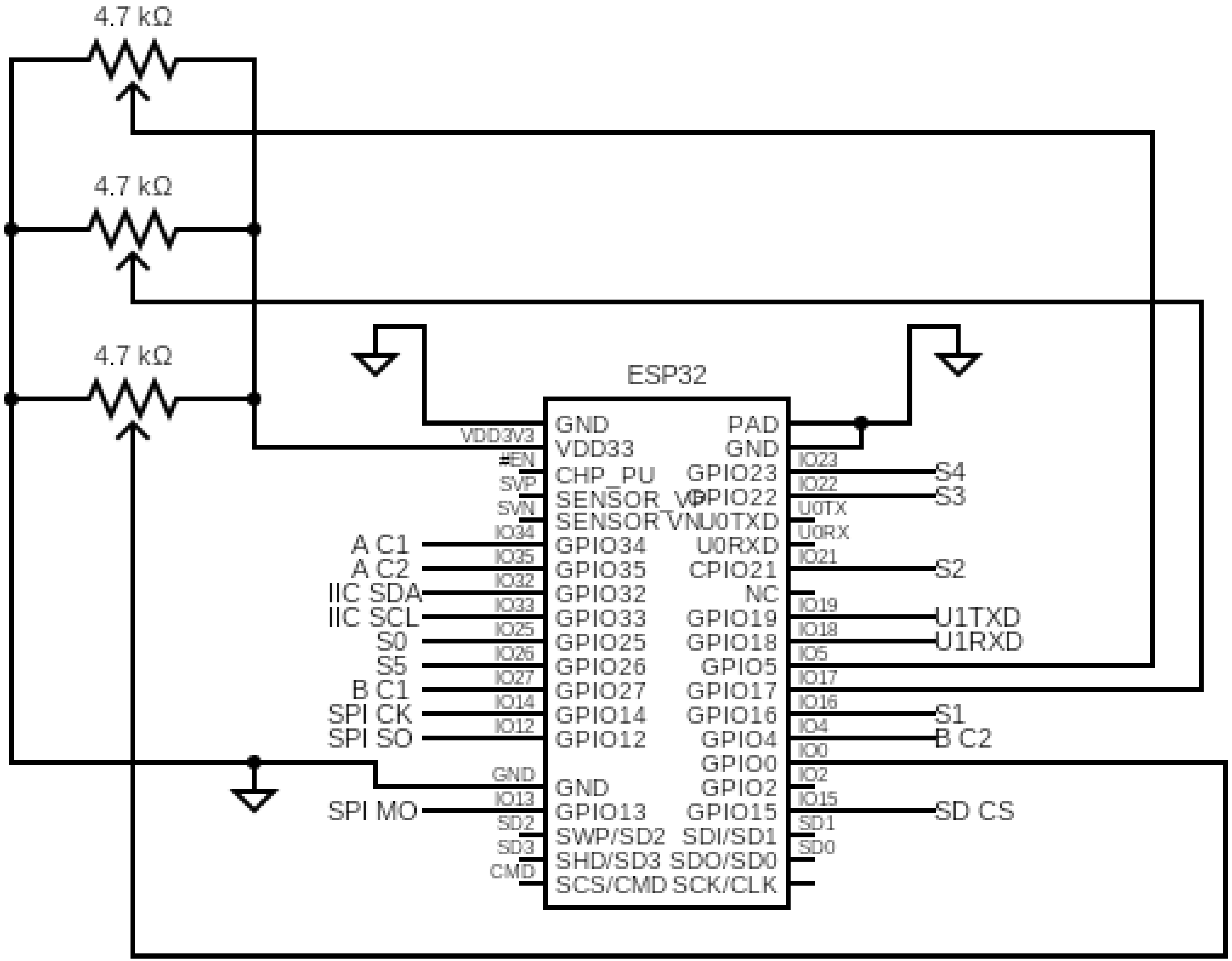


Figure XX: Circuit Diagram