TEAM 205 – ROBOTIC ARM TO ASSIST MOTORIZED CHAIR USERS

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Faculty Advisor: Prof. Jim Hess

Team Members: Brooke Harrington, Cavan Moriarty, Omar Abuljobain,
Justin Lee, and Andrew Baum

Agenda

Introduction	• Background • System Decomposition • System Level Objectives and Requirements
Design	• Initial Concepts and Down Selection • Key Elements and Engineering Analysis • Summary of CAD
Manufacturing	• Mounting • Electronic Casing • Software Functions
Test Results	• Teams Test Results and Implications • End User Testing and Feedback
Project Closure	• Meeting Our Objectives and End User Needs • Conclusions and Lessons Learned • Future Work Recommendations

Problem Background – Context for Future Design

Background

Duchenne Muscular Dystrophy (DMD) is a genetic disorder that mainly affects boys and causes progressive muscle weakness as they age

People with DMD require a motorized wheelchair for general movement and a caretaker or assistive device for other tasks throughout the day

Figure 1: Permobil M3 Corpus

Problem

As people with DMD get older and their muscles are significantly weakened, they require more sophisticated assistive devices that aid upper body mobility

These devices are often robotic aids that function as arms and hands which require complicated controls. Additionally, current assistive robotics on the market are priced >$60000 and are often not covered by insurance.

Figure 2: Kinova JACO Robotic Arm. Highly complex arm that requires toggle between which part is being controlled, which includes the fingers

Value Proposition

An affordable, easy to control robotic aid allows more people with DMD to have access to a device that provides range of motion (ROM) assistance for daily tasks that include pushing elevator buttons or grabbing a drink to bring to the user

Introduction | Design | Manufacturing | Test Results | Project Closure

Architecture - How the System Functions

Mechanical Systems

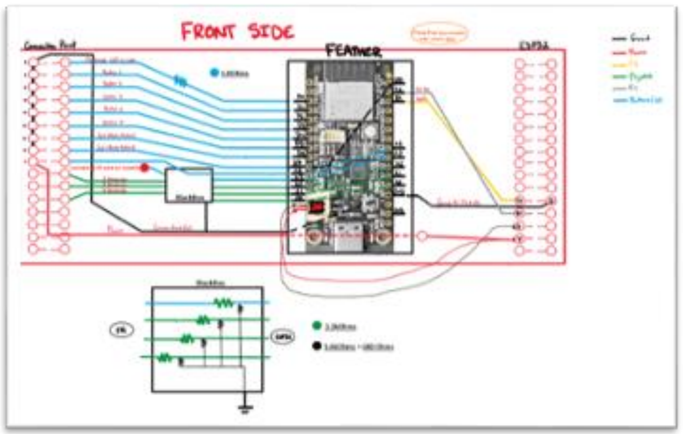
Mounting Structure

Function:
- Connects to the Permobil Unitrack for easy installation/removal
- Adjustment of system position for comfortability
- Mounting for the case

Case

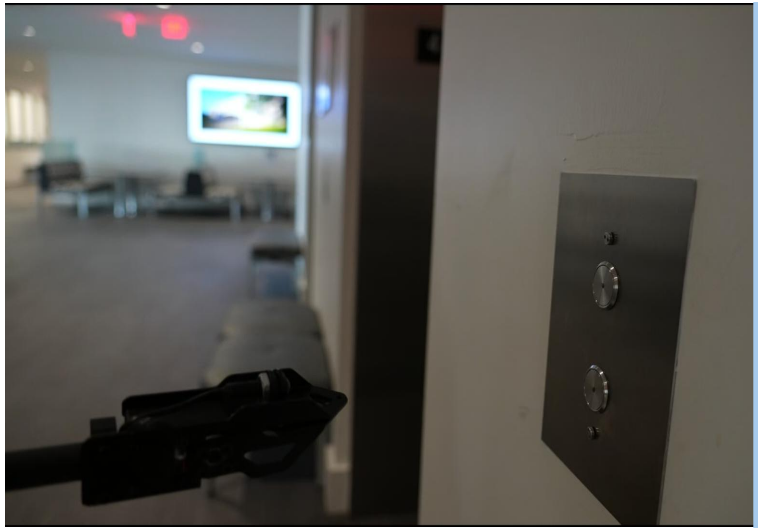
Function:
- Provides structure and mounting for the Waveshare robotic arm
- Contains and protects the electronics
- Mounting for control devices and interface (joystick, buttons, switches, and LEDS)

Electrical/Software Systems



Control Panel (JSTK, BTN, SW, LED) → Analog and Digital Signals → Adafruit Feather → JSON Document → ESP32 Board on Robot → Motor Control → End Effector Coordinate Control

Sys Objs – Two Key Functions Desired by End Users



Pushing Elevator Buttons:

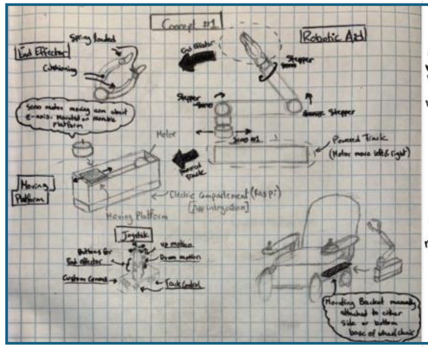
- System is capable of depressing common elevator buttons, both call and destination buttons
- A "ready" position can be saved so that a single button push will bring the end effector near the location of the buttons, then, the joystick will be used to fine tune the position and hit the correct button

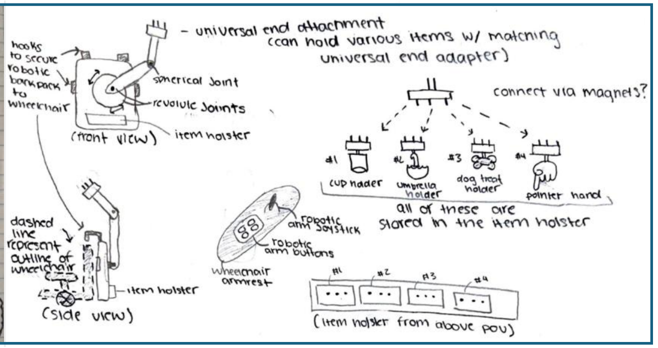
Automatic Drink Functions:

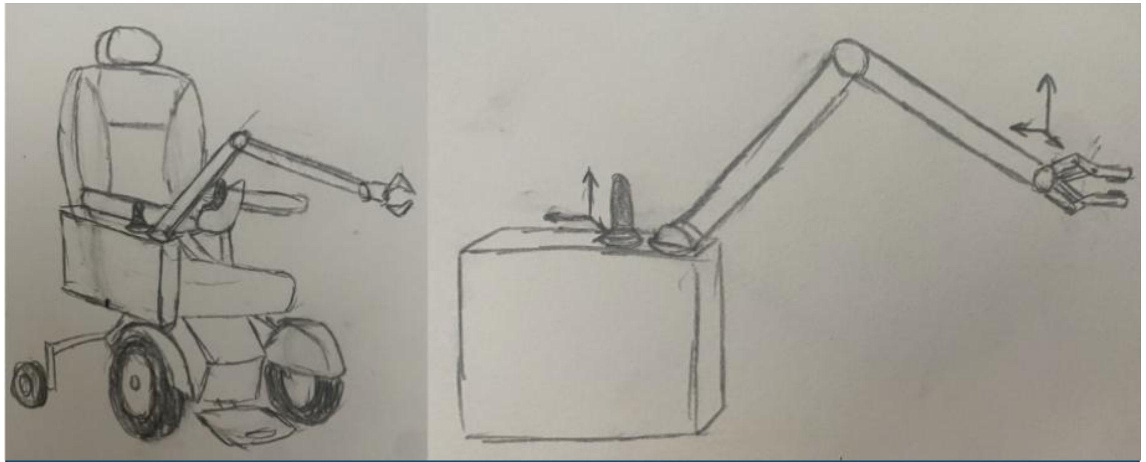
- Automatic drink function where the user programs the path the end effector should take to the drink and user. This function can be later recalled through the push of a button
- End effector control through the joystick buttons which allows the user to retrieve a drink in a specific portable cupholder

Initial Concepts and Down Selection Process

Criteria for Screening and Scoring	Weight
Operating Radius	10%
Number of Inputs	15%
Number of Actuators (DOF)	10%
Size	15%
Cost	10%
Safety	15%
Failure Modes	10%
Integration into Chair	10%
Ease of Installation	5%







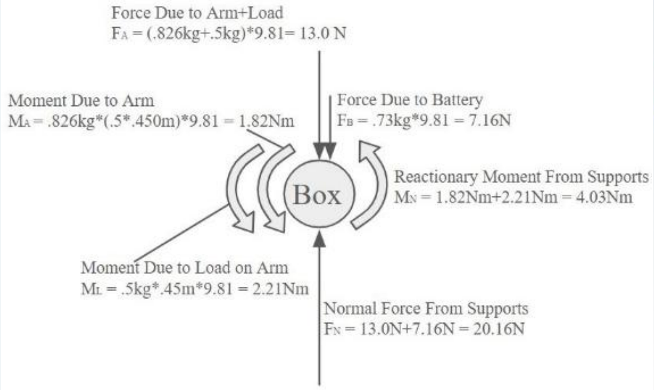
Final Concept and Key Features

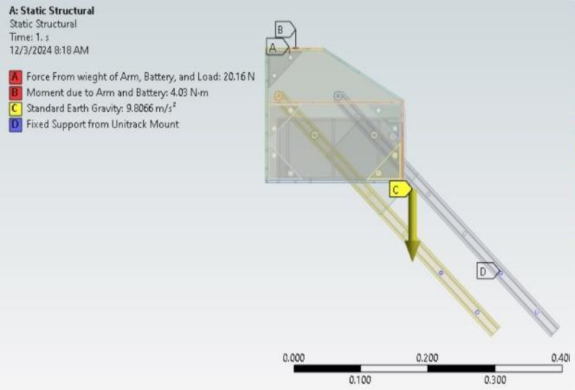
- Combination of some of the concepts developed by members
- Joystick, robot, battery and all accompanying electronics contained in the same box that is easily removed
- Simple robot, max five degrees of freedom
- Mounts near/under the armrest on the Permobil wheelchair and uses the Unitrack as the attachment point

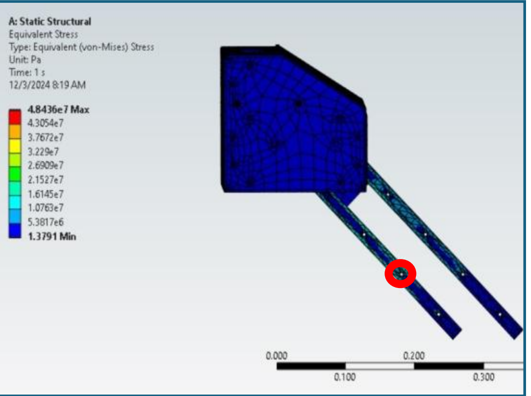
Key Factors, Engineering Analysis

Structure:

- Initial FEA analysis completed for the vertical rails to ensure system would not fail under its own weight
- FEA showed a max stress of 48.436 MPa (FOS 5.67 when compared to yield strength of anodized aluminum)







End Effector Accuracy:

- Calculations for accuracy at different points along the robotic arm based on advertised motor accuracy
- Calculations showed that the selected robot would be able to accurately push elevator buttons compliant with ADA standards

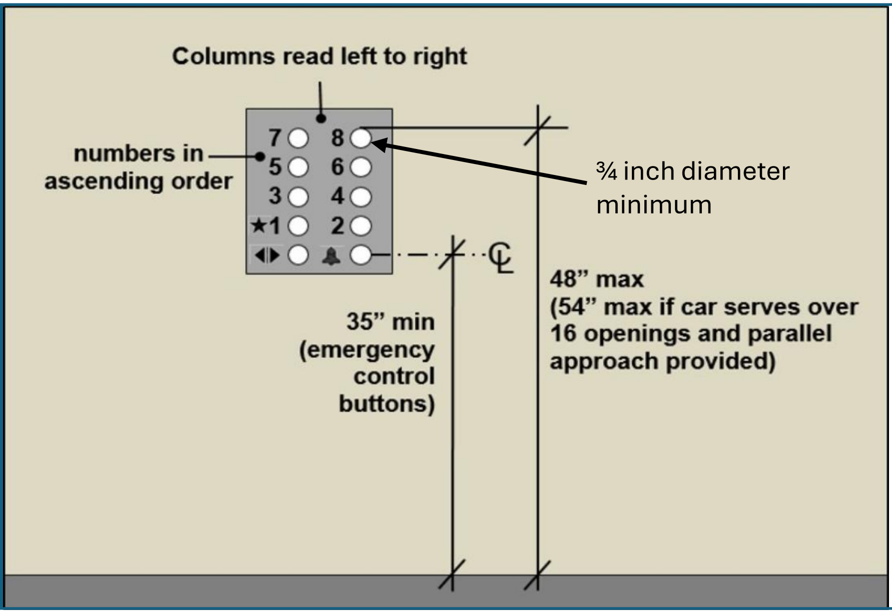
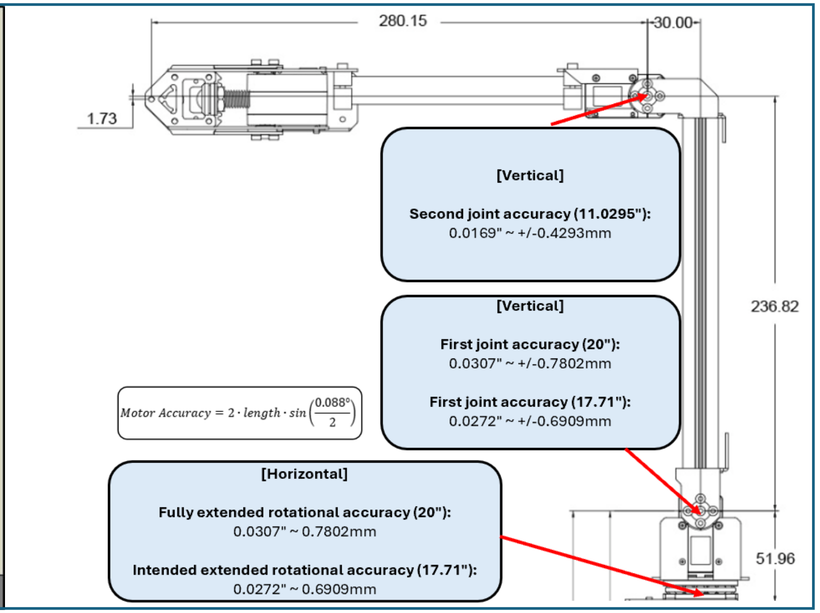


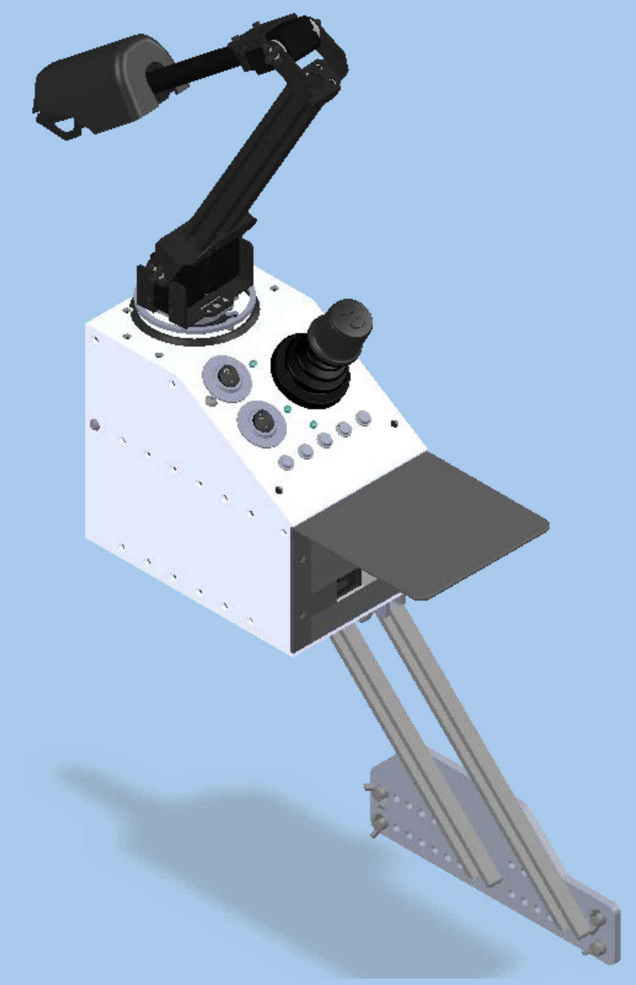
Figure 3: ADA standards for elevator buttons



CAD Breakdown: Overall System

Key Components

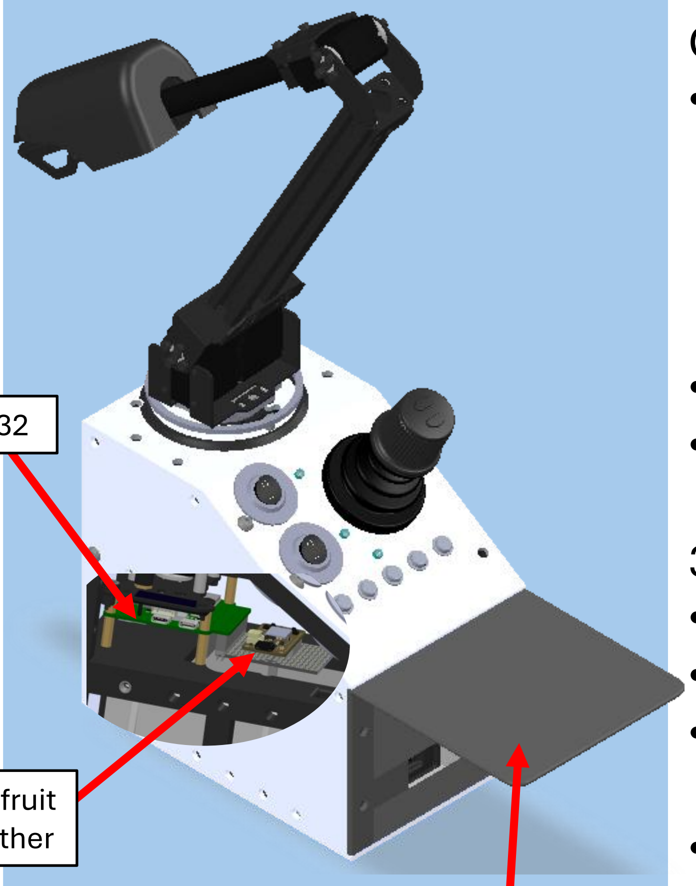
- Unitrack Mounting System
- Electronics Case
- Control Panel
- 3D Printed Armrest
- Waveshare Ro-Arm



Key Features

- Permobil Wheelchair Mounting
- Horizontal and Vertical Adjustment
- Protected Electronics
- Intuitive and Familiar Controls
- Arm support
- Interactions with Surroundings

CAD Breakdown: Case



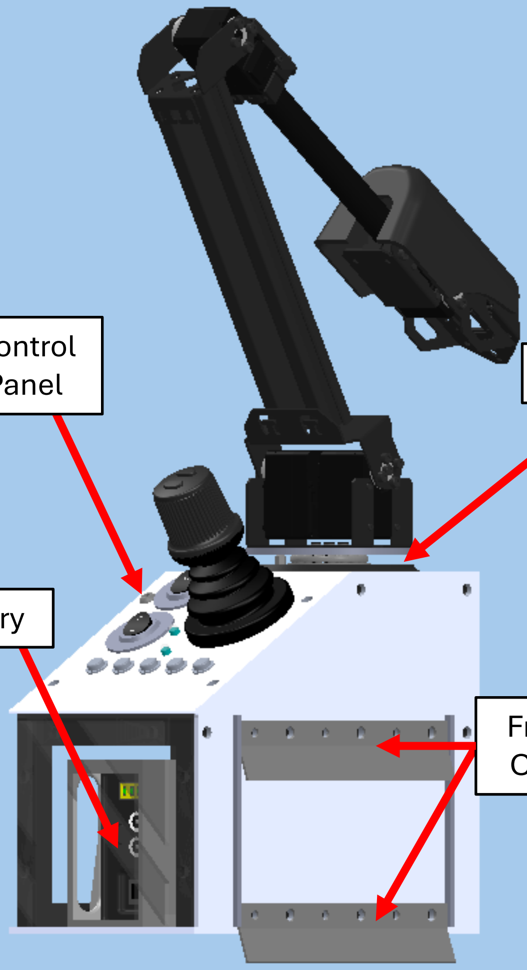
Key Components

Outer Acrylic Plates:

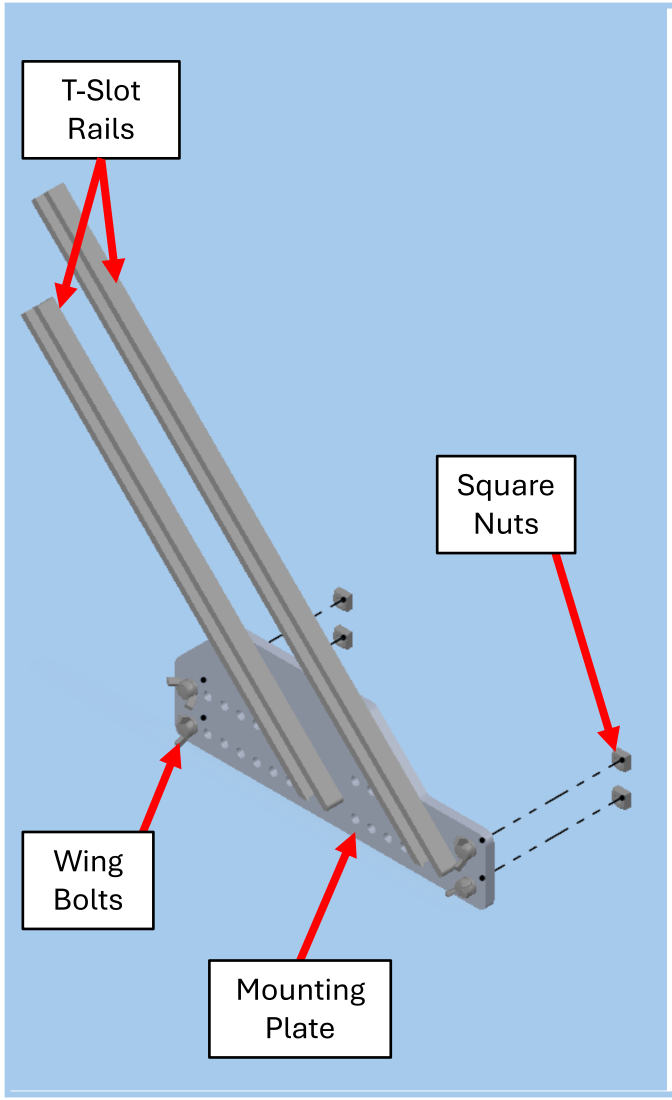
- Control Panel
    - Joystick
    - Switch (x2)
    - Buttons (x5)
    - LED (x3)
- Lithium Ion Battery and Battery Case
- Waterproofing Well

3D Printed Frame:

- Upper French Cleats
- Armrest
- Protoboard Assembly mounting
    - Adafruit Feather
- Waveshare Ro-Arm mounting
    - ESP 32



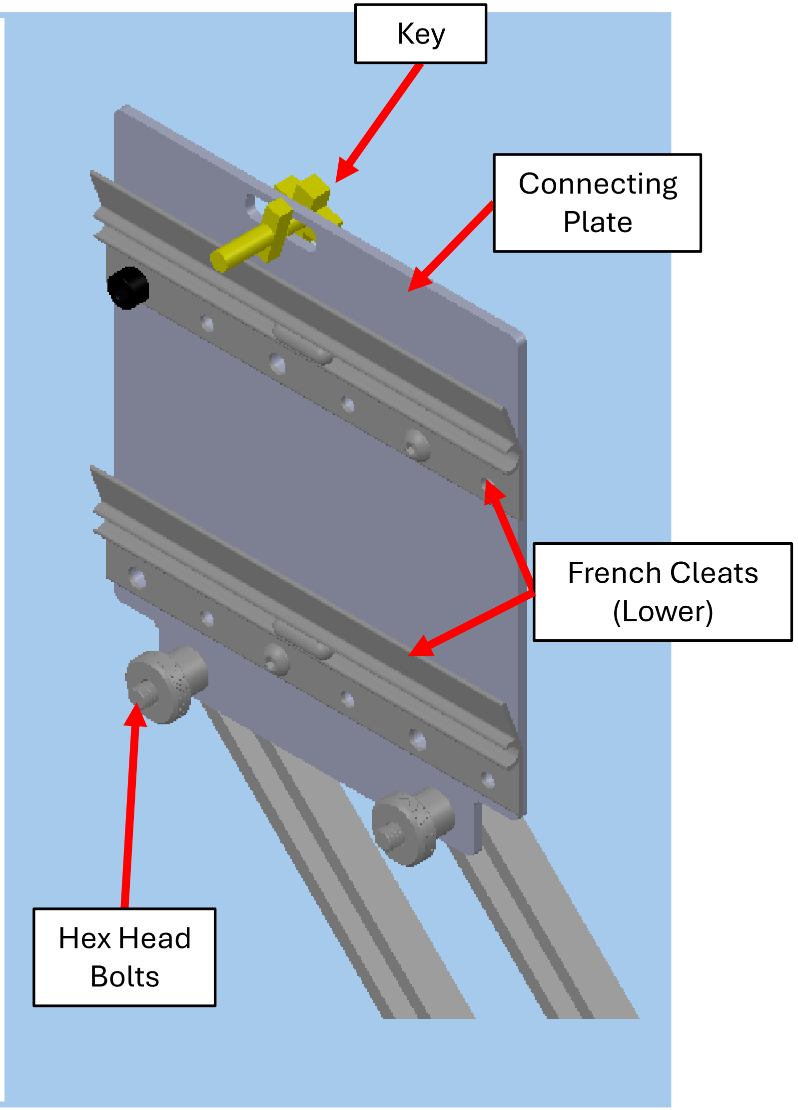
CAD Breakdown: Mounting System



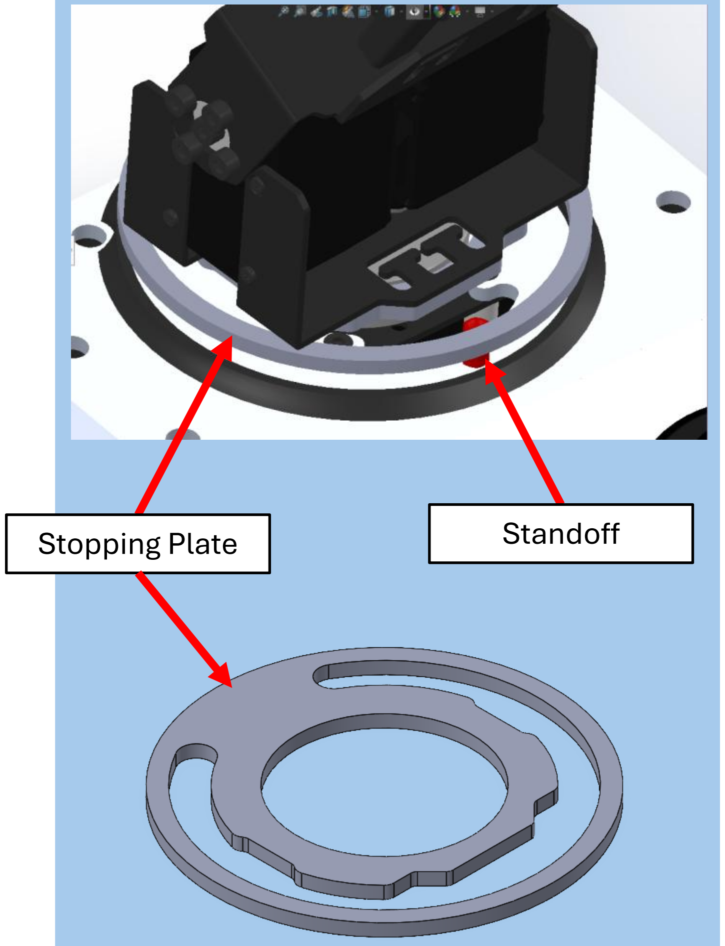
Key Components

Mounting Assembly:
- 1/4” Aluminum Mounting Plate
- 45° T-Slotted Rails
- Wing-Bolts
- Square Nuts

Connecting Assembly:
- 1/8” Aluminum Connecting Plate
- Hex Head Bolts
- Slot for 3D Printed Key
- Lower French Cleats



CAD Breakdown: Safety Features



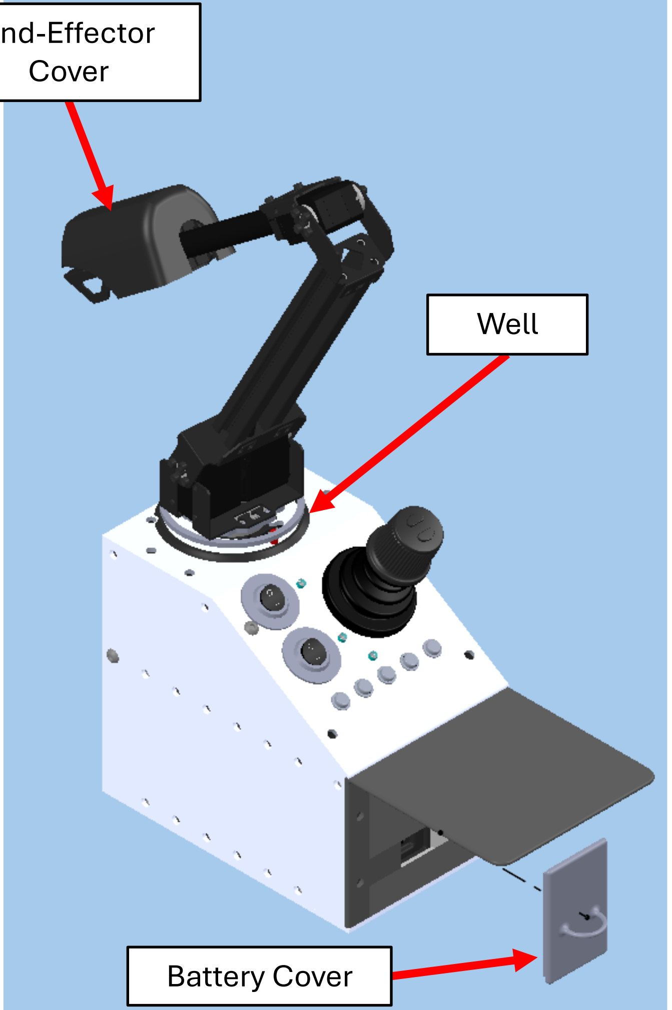
Key Components

Mechanical Stop:

- 1/8” 3D Printed Stopping Plate
- Standoff

Waterproofing:

- 1/8” 3D Printed Well
- 3D Printed Battery Cover
- 3D Printed End-Effector Cover

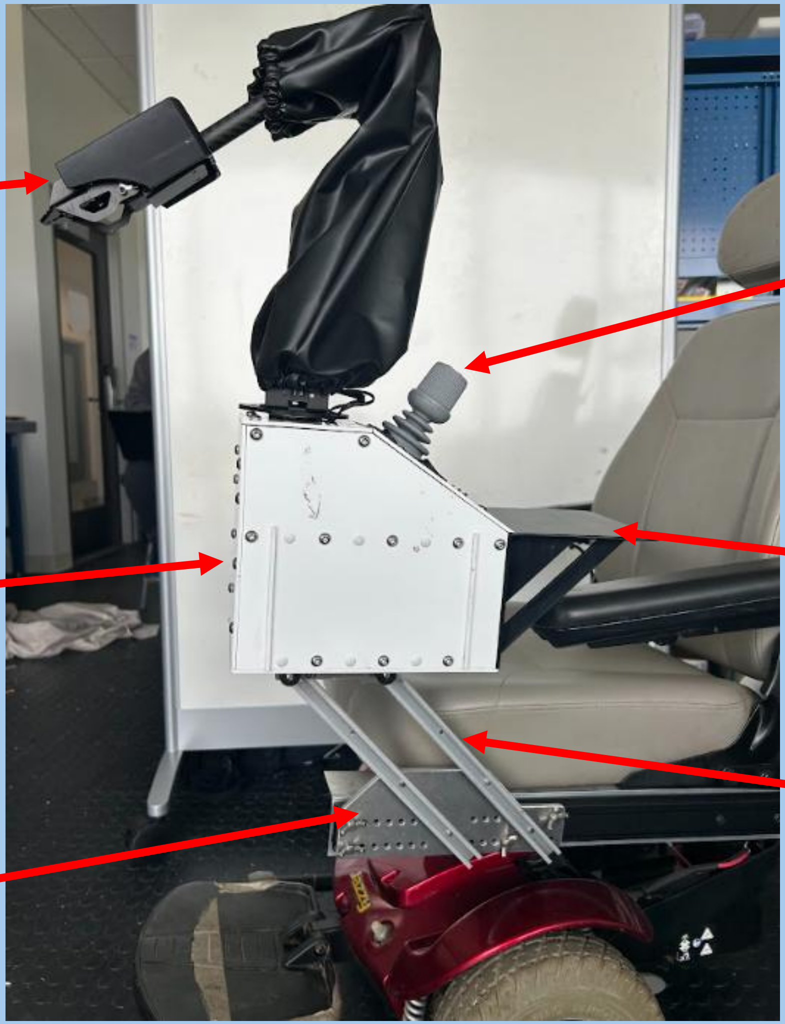


Build Progress: Physical Systems, Key Features

Waveshare Robotic Arm with Waterproofing Solutions

Case Containing Electronics and User Interface

Mounting Structure



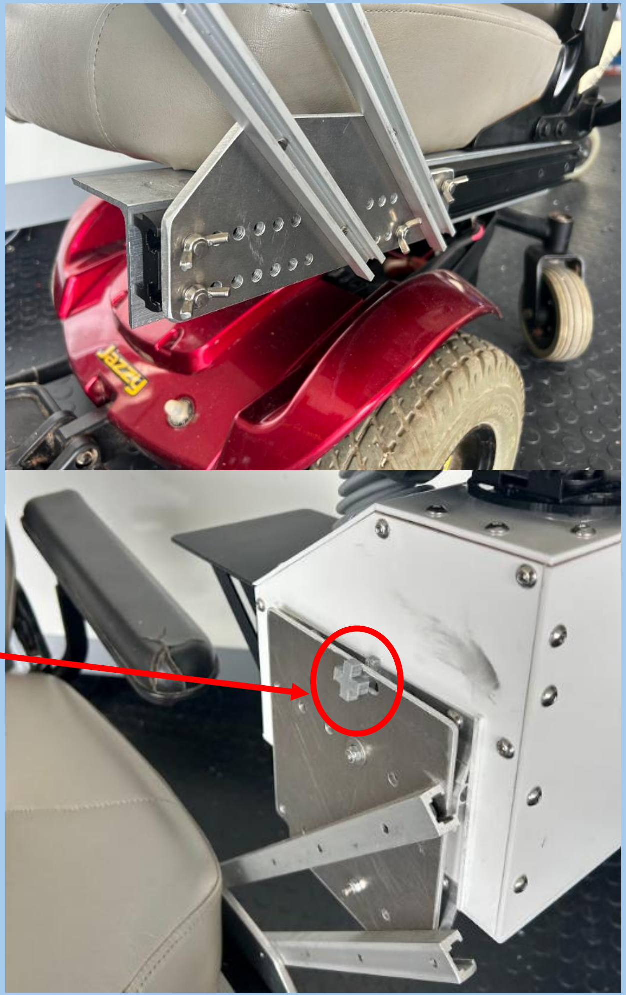
User Interface (Joystick, Buttons, Switches, LED)

Armrest

Vertical Adjustments Rails

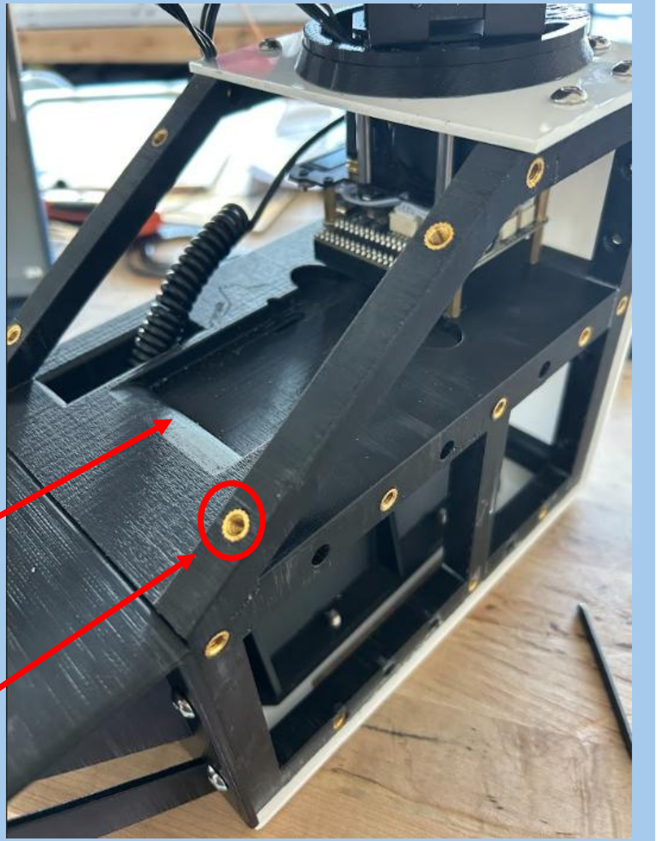
Build Progress: Physical Systems - Mounting

- The lower diagonal rail was cut to remedy safety concerns
- There was concern for the stability of the mounting schematic on the Jazzy wheelchair (vibrations) but proved to be stable on the Permobil through sponsor testing
- There is current concern for the reliability of the 3D-printed French cleat key - broken multiple times despite solid infill

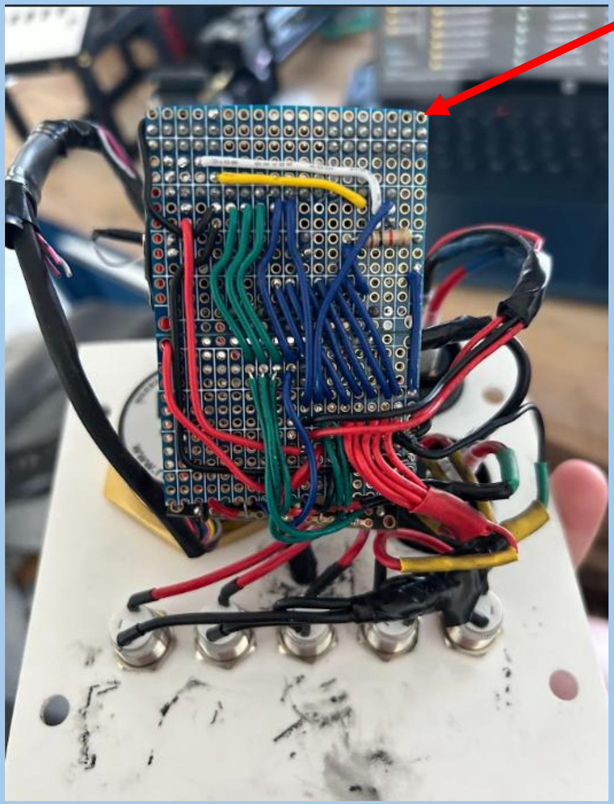


Build Progress: Physical Systems - Case

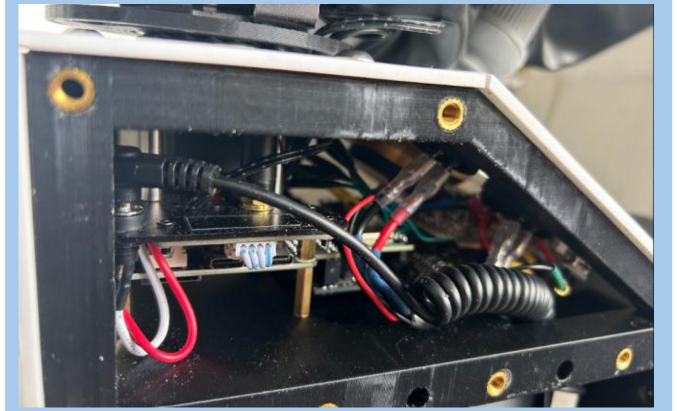
- Updated user interface with joystick shifted right
- 2 LEDs removed from user interface due to electronics complications
- Added armrest for additional support while in use
- Mounting frame with cutout for feather to slide into place under the ESP 32 headers on the robotic arm
- Nut inserts in frame for mounting acrylic plates and French cleats

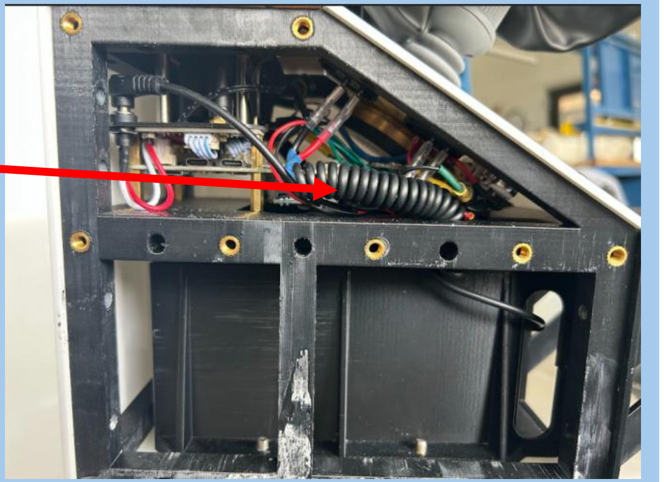


Build Progress: Electronics Systems



- The protoboard is the main connection point between the feather, control systems, and ESP32 on robot
- All control systems are soldered directly to the protoboard. Using separate connectors posed issues for long term robustness
- Pigtail cable that powers the robotic arm from the battery. Robotic arm powers the feather and all control systems





Build Progress: Waterproofing Systems

- Added a “cap” to the end effector to shield from rain (clips into the LED mount)
- Sleeve to cover the “elbow” and shoulder joint, attaches to the carbon fiber tube that goes from the elbow to the end effector
- “Well” used under the stopping plate to keep water from falling onto the ESP 32 board under the robot

Test Results

Test 1: End Effector Max Length Accuracy

Addresses TR 1.3.2: The system shall have an accuracy of +-10mm

Test Equipment:

- Calipers, Tape measure, Whiteboard, Whiteboard marker, Tape, Wheelchair

Summary of Test Procedure:

- Assemble test system onto wheelchair and attached marker onto end-effector with tape
- Mark 35" and 48" lines on whiteboard to replicate ADA standard button height dimensions
- Navigate wheelchair to the whiteboard so the user is perpendicular to the surface
- Navigate arm with marker and mark three points at 35" and 48" mark
    - This will be done at the lowest increment by slightly shifting the joystick past its dead zone
- Measure horizontal (X,Y) and vertical (Z) distances and compare to expected value

Expected Value: <10 mm (0.39")	Outcome Value: ~5-14 mm (0.19-0.55")

Outcomes/Conclusions/Recommendations:

- Measured values fell below and above expected value
- The cause of fluctuation was the rate at which the joystick function is looped
- Meets the button standard of 0.75" set by ADA, code revision is still required

Test Results

Test 2: End Effector Max Load Capacity

Addresses TR 1.1.4: The arm should be able to bring a drink weighing 470g to the user

Test Equipment:

- Drink (liquid, container, and portable cupholder), Scale, and User interface (drinking function)

Summarized Test Procedure:

- Program drinking function (min. and max. range)
- Measure/record weight of drink: liquid, container, and portable cupholder
- Position drink at the initial position of the drink function, then initiate the drink function
- Observe/record the system behavior; determine if the system is stable or unstable
- Repeat steps and increase weight by 0.1kg until system is determined to be unstable

Expected Value: Min. and Max. (500g)	Actual Value: Min. (600g) and Max. (500g)

Outcomes/Conclusions/Recommendations:

- This test was performed with clamp and table; recommend re-running test mounted to wheelchair. Similarly, test was performed without end effector cover
- The robotic arm is capable of fulfilling TR.1.1.4

Introduction | Design | Manufacturing | Test Results | Project Closure

Test Results

Test 3: Restricted Motion Compliance

Addresses TR 5.2.0: The robot shall have physical and program safeguard to prevent it from reaching undesired locations

Test Equipment:

- Robotic arm system, Monitoring laptop

Summarized Test Procedure:

- Power on the system
- Initiate arm motion
- Test positive and negative arm limits (min. and max. range along arc)
- Test edge case use
- Repeat steps 3-6 at medium and maximum speed

Expected Value: Remained within +/- 30 degrees	Actual Value: Remained within +/- 30 degrees

Outcomes/Conclusions/Recommendations:

- System passes test by not entering safe zone
- Physical motion restrictor was not utilized, digital motion restrictor sufficient for test

Test Results

Test 4: Installation Time

Addresses TR 3.0.0: The arm shall be installed in less than one hour and be operational within 30 minutes

Test Equipment:

- Phone stopwatch, mounting system, electronics box

Summarized Test Procedure:

- Start stopwatch
- Attach mounting system to Unitrack
- Mount electronics box to French cleats of mounting system
- Place key in slot
- Stop stopwatch

Expected Value:	Actual Value:
30 min	58.52 sec

Outcomes/Conclusions/Recommendations:

- System passes the test
- Significant overprediction due to many design simplifications

Test Results

Test 5: Maintenance Time

Addresses TR 3.1.0: The system shall have maintenance work completed in less than three hours

Test Equipment:

- Phone stopwatch

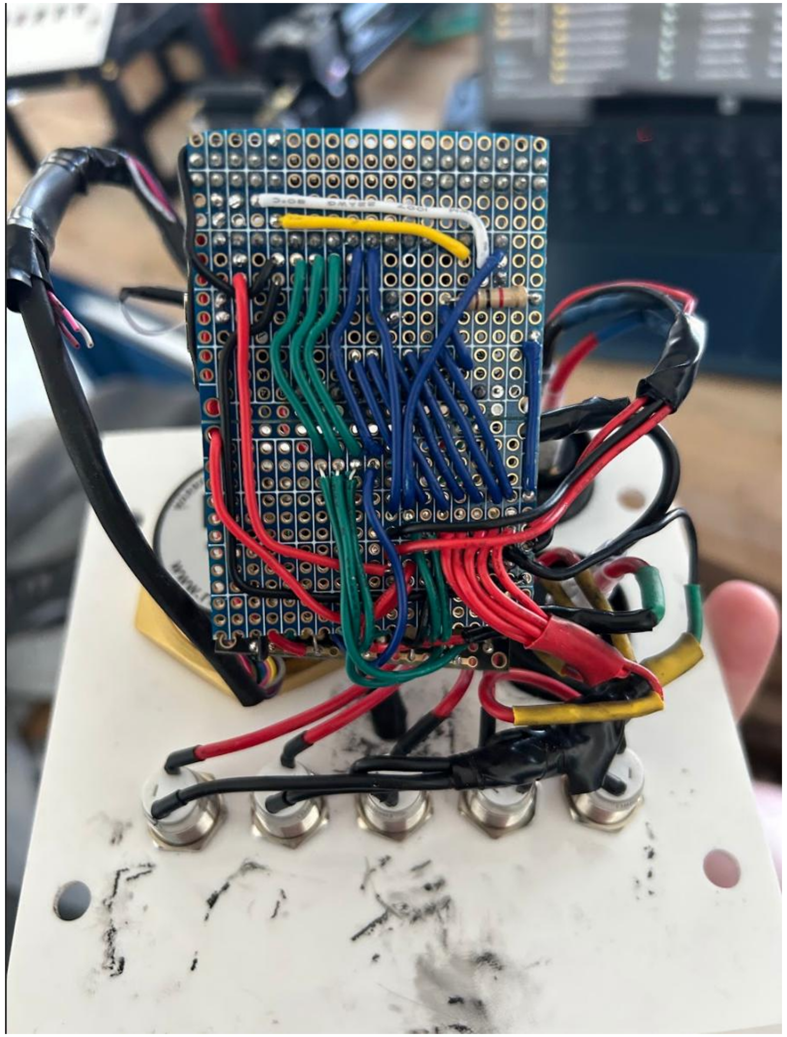
Summarized Test Procedure:

- Begin timer, remove both side panels and the diagonal panel that contains the control interface
- Inspect the 3D printed frame and all fasteners. Inspect the wires of the control interface, and all solder joints/heat shrink/possible loose connection points
- Inspect the mounting structure visibly and by touch
- Reassemble the system
- Power on the system to ensure normal operation
- End timer, record time

Expected Value: 1 hr	Actual Value: 22 min 05 sec

Conclusions/Recommendations:

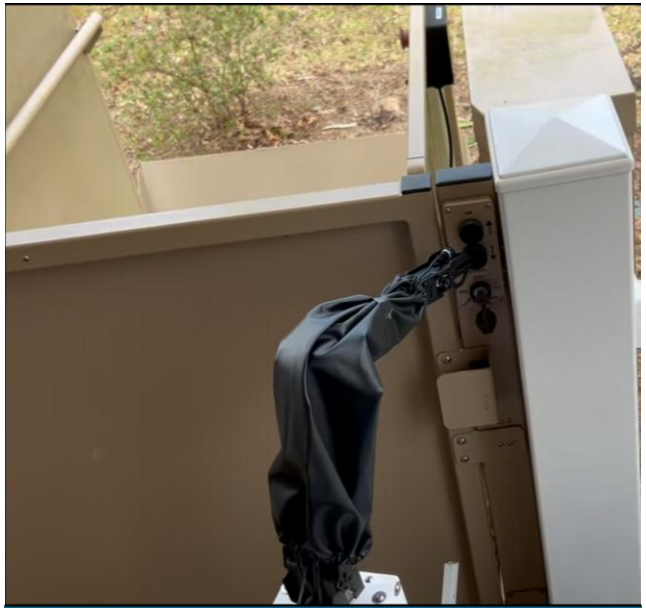
- This maintenance inspection did not require any fixing of parts
- Recommend re-running this test after significant use or next maintenance period ~ 6 months



Test Results – Meeting with Colin

Colin using the joystick to get a drink (Note this is not the automatic drink function – we were unable to test due to mounting interferences)

Colin going through door (door is larger than standard, but is ADA compliant)



Colin testing pushing buttons on lift outside – end effector sometimes slipped off the button


PAAC
PPMD ADULT
ADVISORY COMMITTEE

Test Results –Colins Feedback

TRR:	Now:

Joystick Position:
- The initial design in TRR was developed under assumed dimensions of the chair, since each person's chair is different
- Fitment testing on Colins chair showed some initial assumptions were incorrect
- Joystick was moved right to align closer with the armrest on Colins chair

Joystick Selection:
- Toggling the end effector between open and close was not ideal
- New joystick has two buttons on top to pitch the end effector to specific angles, other controls remained the same

Case Changes:
- In addition to moving the joystick over, added an armrest for additional support
- Added padding on armrest for comfort
- Battery remains accessible through cutout underneath

Status of Requirements – Updates since TRR

Technical Requirement ID	Requirement	Verification Method	Status
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	Test	Completed
TR 1.2.0	The robot shall have no more than six degrees of freedom to reduce the complexity of controls	Inspection	Met with robot arm choice
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	Met with robot arm choice
TR 1.4.1	The battery that powers the robot arm shall last 24 hours between charges	Analysis	Completed

Status of Requirements – Updates since TRR

Technical Requirement ID	Requirement	Verification Method	Status
TR 1.3.1	The device should be able to depress elevator buttons and the handicap door button between 35" and 48" as specified by ADA standards	Analysis	Completed
TR 1.3.2	The system shall have an accuracy of +-10mm while at full extension	Analysis and test	Analysis Completed – Testing Completed – Revision/Retest Needed
TR 3.0.0	The robot shall be installed in less than one hour and should be operational within thirty minutes of installation	Test	Completed
TR 5.3.0	The robot shall have safeguards against unexpected de-energization	Inspection	Completed

Conclusions

Meeting User Requirements:

- The team believes we have met most of the user requirements
- Need additional user testing and feedback to verify this assertion
- Colins feedback suggest the project is on the correct path: new user requirements can be added for project continuation

Marketability:

Team 205
~$2,000
4 DoF
Detachable System
Open Source
Market
~$60,000
6 DoF
Fixed System
Built in Software

Overall System Performance:

- Team is satisfied with performance and proud of the effort that went into developing a functional system
- Though satisfied, refinements can be made that would improve multiple facets of the system

Lessons Learned

What Went Well:

Design Process:
- Constant feedback through many meetings
- Continuously evolving design
- End user's needs met

Team Improvement:
- Significant refinement since PDR
- More information-quicker progress, more productivity

Teamwork:
- Equal division of tasks
- Gain new skills

Where We Fell Behind:

After PDR:
- CAD Lacking Detail
- Missing Context
- Misunderstandings

After CDR:
- Lacking electronics design
- Lacking a plan for interacting with the robot (microcontroller)
- Minimal code

After TRR:
- Waterproofing

Important Realizations:

Design Process:
- No standard configuration – difficult design process
- Trying to overaccommodate leads to delays and confusion

Constant Feedback:
- Helpful during design process
- Allowed for continuous refinement
- Led to user satisfaction

Current State:
- Room for improvement
- Time constraints limit optimizations

Future Work

Future Work for our Team:

- Work on the report
- Finalize any last aspects of the project we feel need a little more work (very small tasks)
- Working on the final deliverables for Mr. Keith from PPMD
- GitHub – giving as much as we can so this can continue as an open-source project

Things We Would Change Given More Time:

Robotic arm choice:
- Initial analysis showed the Waveshare was a fair option for our project
- After working with the Waveshare, other options may be better, more research needs to be done

Coding:
- Coding could use refinement and optimization
- None of the members have any formal education in robotics coding

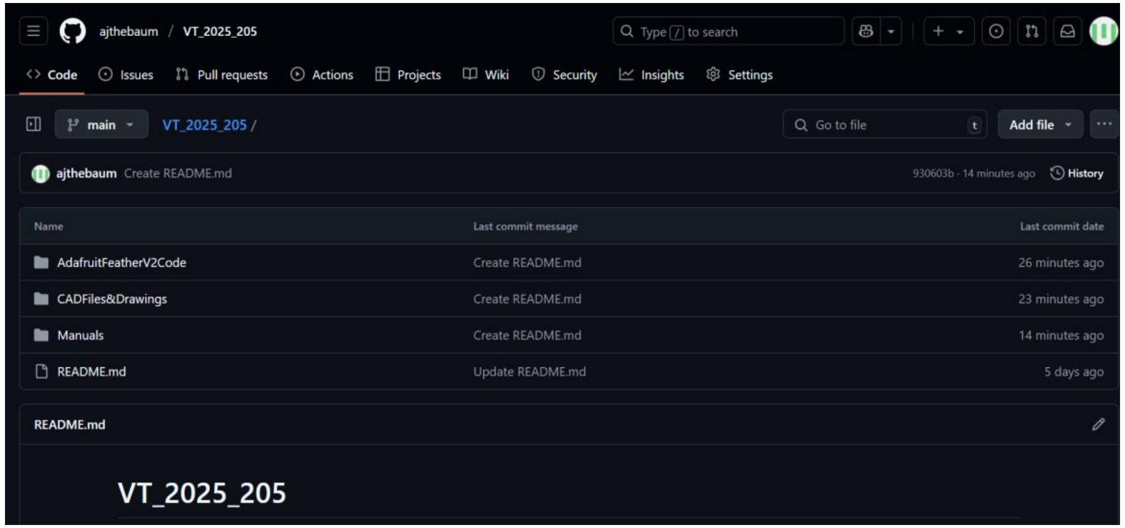
Recommendations for a Future Team:

- Maybe try a new arm – learn from our choice of arm and its capabilities to influence their own decisions
- Continue frequent discussion with the PPMD team – it was a huge help with the design process
- The case can be reworked, as well as the mounting mechanism, which can likely be strengthened and motorized for ease of positioning
- Theres different, likely better ways to meet the customer needs that should be explored

One Last Project Goal We Want to Cover

Open Source:

- We are populating a GitHub with our CAD, code, and manuals files
- Updating a google drive with our tutorial videos, and other images from the duration of the project
- Developing a BOM (GitHub) for all materials in the final design, and estimates for manufacturing from third party companies
- QR codes for GitHub and images on expo poster



GitHub

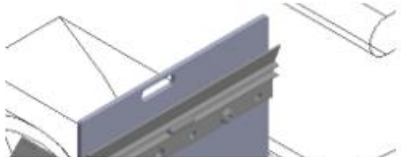
Photos

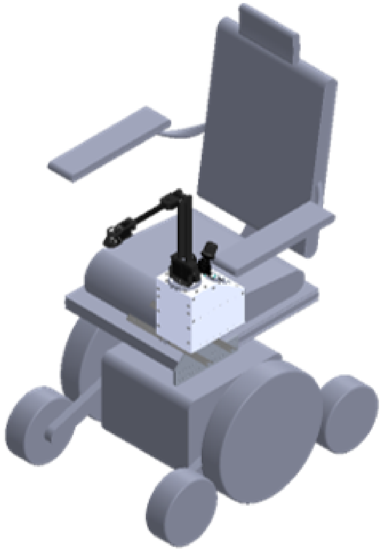
Introduction | Design | Manufacturing | Test Results | Project Closure

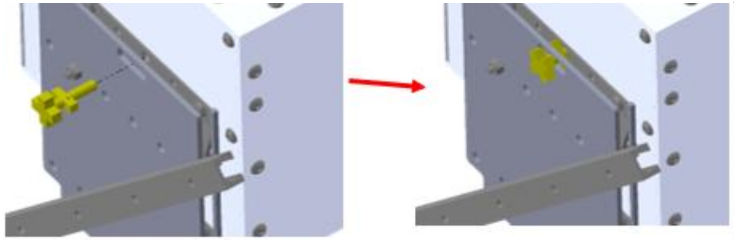
THANK YOU FOR LISTENING!

Before questions, the team would like to open the presentation to Mr. Keith or Colin via zoom to discuss more on DMD, PPMD and the long-term goals of this project

Step 33: Replace the button head and locknut that fits into the rails with an M6 x 0.75, 12mm long bolt and square nut.

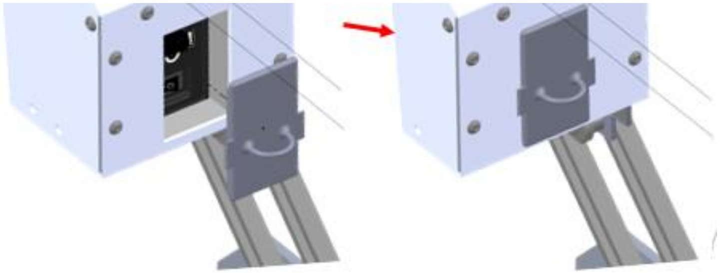






Step 34: Slide the case's French Cleats onto the mounting assembly's French Cleats.

Enjoy!



Blooper Slide

Bill of Materials

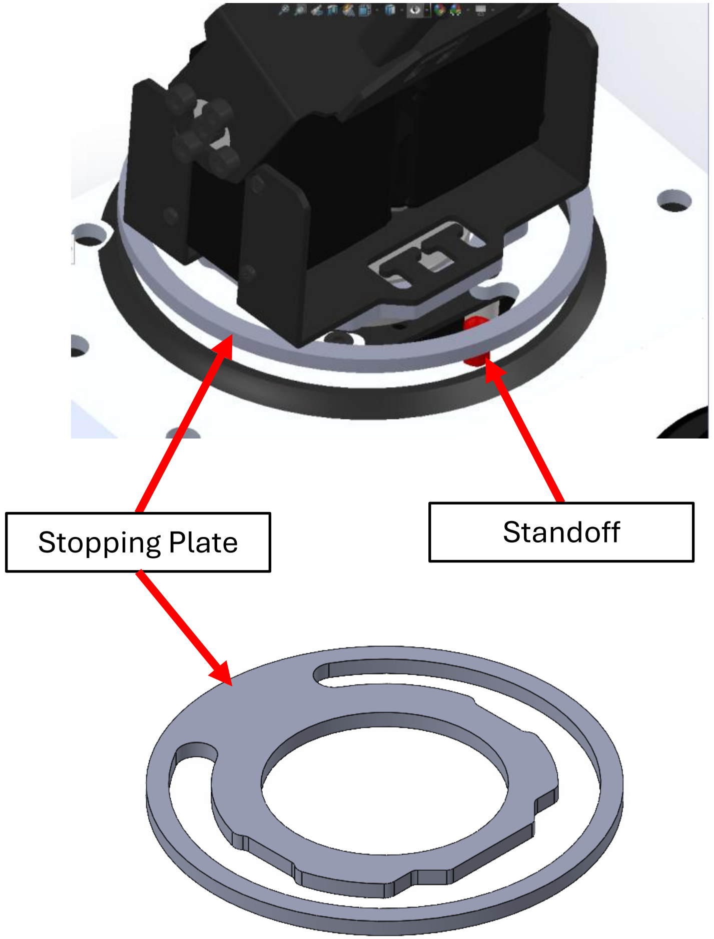
Team Number	205
Team Name	Robotic Arm to Assist Motorized Chair Users
Total Cost	$ 1,068.92

Bill of Materials

Taxes and Shipping NOT included

Level-1: Electronics
Level-2: Waterproofing
Level-3: Mounting
Level-4: 3D Printed
Level-5: Hardware
Level-6: Other

BOM Level	Part Name	Part Number	Part Details	Unit Cost	Quantity (Ea./Pkg.)		Total Cost	Procurement Details	Additional Notes
Level-1	Waveshare Roarm	RoArm-M2-S		$ 223.99	1	Ea.	$ 223.99	Amazon	Direct Order
Level-1	Joystick	HE2 SERIES 3 AXIS	Handle(two buttons), Limiter(square), Outout((	$ 290.07	1	Ea.	$ 290.07	Ruffy Controls	Direct Order
Level-1	Buttons	B0C2G4RC4Q	Size(momentary) and Color(silver)	$ 12.49	5	Pkg.	$ 62.45	Amazon	Direct Order
Level-1	Switches	B0CKXRHJPF	Type(5pcs switch + switch holder)	$ 8.09	2	Pkg.	$ 16.18	Amazon	Direct Order
Level-1	Wires	1311	22AWG Solid Core	$ 15.95	1	Ea.	$ 15.95	Adafruit	Direct Order
Level-1	Heat Shrink Tubing	asd-123	Heat Shrink Tube Kit with Box(5 colors/12 Sizes)	$ 6.99	1	Pkg.	$ 6.99	Amazon	Direct Order
Level-1	Male-Male Plug Cable	B0BN2YX895	Voltage(12V) and Input Current(1.5A)	$ 8.99	1	Pkg.	$ 8.99	Amazon	Direct Order
Level-1	Battery	PB120B1	12V Lithium ion	$ 8.99	1	Pkg.	$ 8.99	Amazon	Direct Order
Level-2	Sleeve Cover	B0D6Y2R9LZ	Color(black+blue) and Material(PU leather)	$ 9.56	1	Pkg.	$ 9.56	Amazon	Direct Order
Level-2	Hole Plugs	suiwotin - 220105 - 7	Color(white) and Size(1/4")	$ 6.99	1	Pkg.	$ 6.99	Amazon	Direct Order
Level-2	Silicon Gasket Maker	B0CXPXLCCH	Size(3 Fl. Oz.) and Style (Ultra Black)	$ 14.96	1	Pkgs.	$ 14.96	Amazon	Direct Order
Level-3	Sliding Plate		Thickness(1/4") and Size(1x1ft)	$ 52.42	1	Ea.	$ 52.42		Additional Manufacturing
Level-3	Connecting Plate		Thickness(1/8") and Size(1x1\2ft)	$ 26.47	1	Ea.	$ 26.47		Additional Manufacturing
Level-3	Fixturing T-Track	1850A11	Length(18")	$ 9.83	2	Ea.	$ 19.66	McMaster	Direct Order
Level-3	French Cleats	2152A11	Material(Al.)	$ 8.24	1	Pkg.	$ 8.24	McMaster	Direct Order
Level-4	3D-Prints		Material(ABS)	$ 95.56	1	Pkg.	$ 95.56		Additional Manufacturing
Level-5	Heat-Set Inserts for Plastic	94459A340	Brass, 10-32 Thread Size, 1/4" Installed Length	$ 12.36	1	Pkg.	$ 12.36	McMaster	Direct Order
Level-5	316 Stainless Steel Button Head Hex Drive Screw	98164A178	er-Corrosion-Resistant, 10-32 Thread Size, 1/2"	$ 9.82	1	Pkg.	$ 9.82	McMaster	Direct Order
Level-5	Male-Female Threaded Hex Standoff	91075A467	inless Steel, 3/16" Hex, 5/16" Long, 6-32 to 6-32	$ 3.79	1	Ea.	$ 3.79	McMaster	Direct Order
Level-5	18-8 Stainless Steel Pan Head Slotted Screws	91792A144	6-32 Thread Size, 1/4" Long	$ 5.51	1	Pkg.	$ 5.51	McMaster	Direct Order
Level-5	Lock Nut for T-Track	1850A26	Steel, 3/4"	$ 3.38	2	Ea.	$ 6.76	McMaster	Direct Order
Level-5	Low-Strength Steel Square Nut	96887A319	Class 5, Zinc-Plated, M6 x 1 mm Thread	$ 14.40	1	Pkg.	$ 14.40	McMaster	Direct Order
Level-5	Alloy Steel Socket Head Screw	91290A017	Black-Oxide, M2 x 0.4 mm Thread, 10 mm Long	$ 15.56	1	Pkg.	$ 15.56	McMaster	Direct Order
Level-5	High-Strength Steel Nylon-Insert Locknut	94645A102	ss 10, Zinc Plated, M5 x 0.8 mm Thread, 5 mm H	$ 16.62	1	Pkg.	$ 16.62	McMaster	Direct Order
Level-5	Low-Strength Steel Nylon-Insert Locknut	90633A007	Thin-Profile, Zinc-Plated, 6-32 Thread Size	$ 10.20	1	Pkg.	$ 10.20	McMaster	Direct Order
Level-5	Stainless Steel Wing-Head Thumb Screw	92625A413	M6 x 1mm Thread Size, 12mm Long	$ 4.44	4	Ea.	$ 17.76	McMaster	Direct Order
Level-6	Acrylic Panel		hite Opaque), Dimension(12"x12"), and Thickne	$ 76.68	1	Pkg.	$ 76.68		Additional Manufacturing
Level-6	Portable Cupholder	B0CKGM1G9M	Color(Black Reflective)	$ 11.99	1	Ea.	$ 11.99	Amazon	Direct Order
					Total		$ 1,068.92		


Stopping Plate
Standoff