Tablet Documentation

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Quick Links

GITHUB

BOM

CAD

USER GUIDE

Documentation Map

Challenge Overview

- Move 2 points around in a plane
- Provide force to user through magnet
- User can interact with various virtual objects through display
- Robot can track location of 1 or 2 fingers

Technical Requirements

- Continuous 6N at the end effector
- Moving speed up to 150 mm/s
- Wall stiffness of 1N/mm

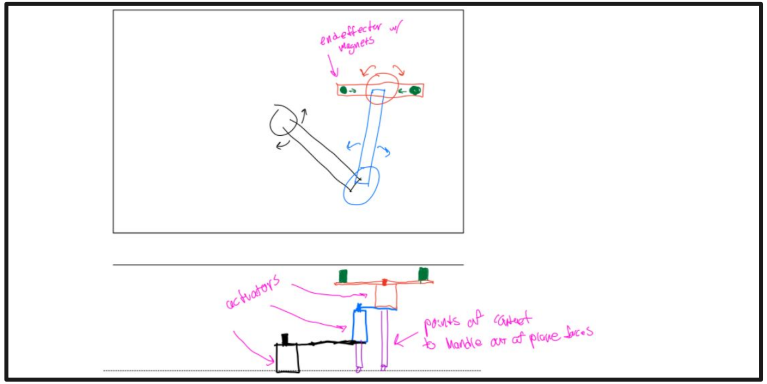
Documentation: Requirements & Architecture

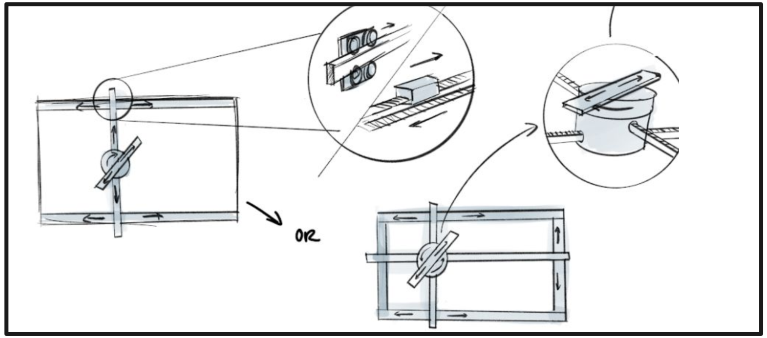
Concept Phase

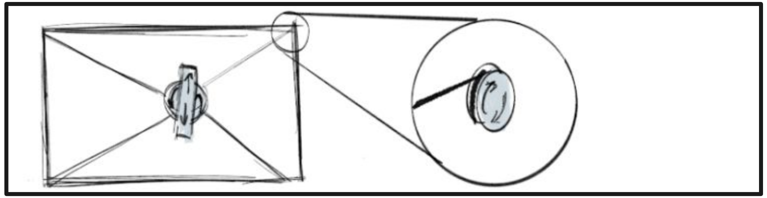
Brainstorm different ways to achieve all DOF:

- Gantry systems
- Cable systems
- Linkage systems

[Documentation: Requirements & Architecture]





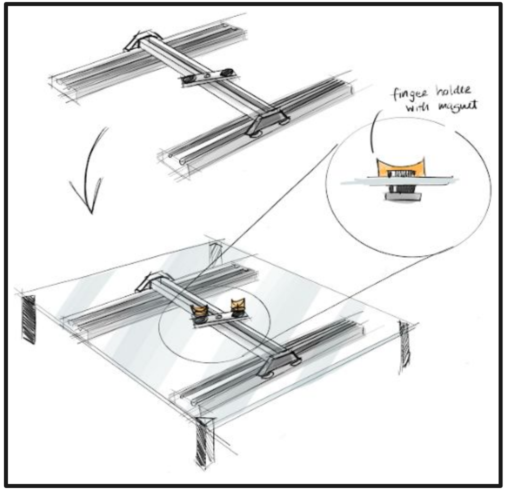


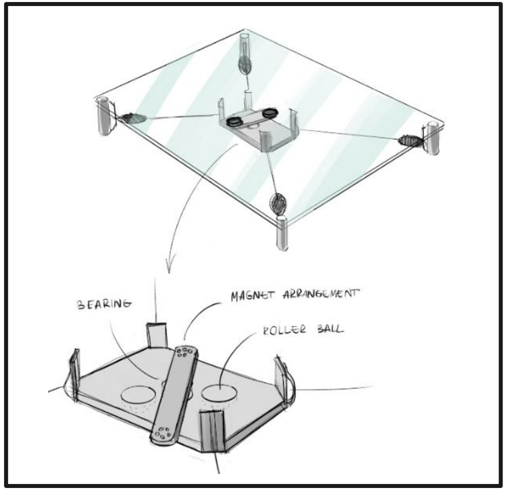
Concept Phase

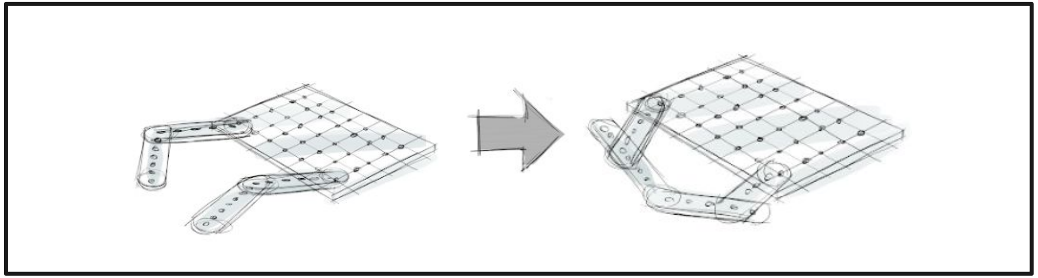
Ideation of prototypes:

- Gantry
- Cable Bot
- Open Linkage
- Closed Linkage

[Documentation: Refine Concepts]







Mechanism

Narrowed the ideation to two concepts:

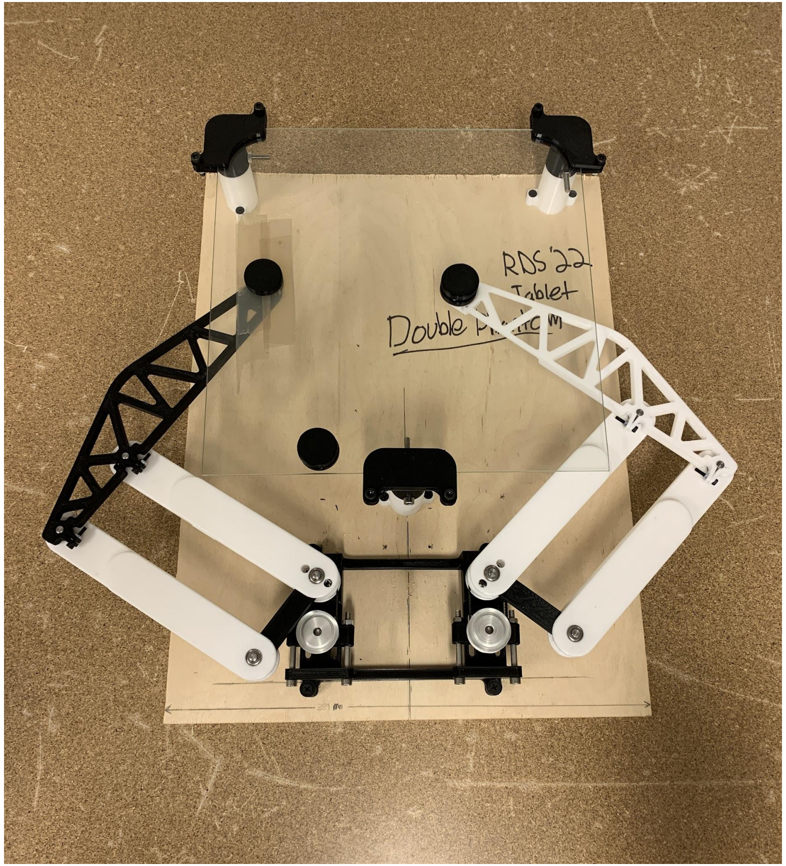
- Parallel Gantry
- Paralel Open Linkage

[Documentation: Prototype Subsystems]

GREEN: Still a possibility
RED: Idea was excluded

Concept	Gantry	Cable	Open Linkage	Closed Linkage
Parallel	Concerns with the amount of friction in the gantry system, especially with binding; A lot of mechanical adjustability that doesn't demonstrate clear benefits over other designs	Requires 6+ motors, 3+ for each magnet; no way for magnets to exist at similar heights due to interference of cables; stacking of magnets would be a significant issue	Low friction due to use of rotary joints over linear; can control each of the two arms using fixed motors at the base and belt systems;	Would require 8 links, 4 per system; difficult to justify using closed linkage system over open linkage system due to having larger mass and greater potential interference due to more links
Serial	Concerns with mass of system not allowing us to hit our free-motion inertia requirement, but it is likely the best option if actuator team finds that admittance control is preferred over impedance control	With end effector mass being equal, the cables have the least mass which makes them well-suited for impedance control; concerns with how to maintain proper tension in all cables while preserving backdrivability	Similar concerns as parallel with singularities and manipulability; can still anchor both joint actuators to ground using belts for less inertia and better impedance control	Limited workspace due to singularities; requires motors at the end effector to drive final two degrees of freedom, so there is increased inertia

Mechanism

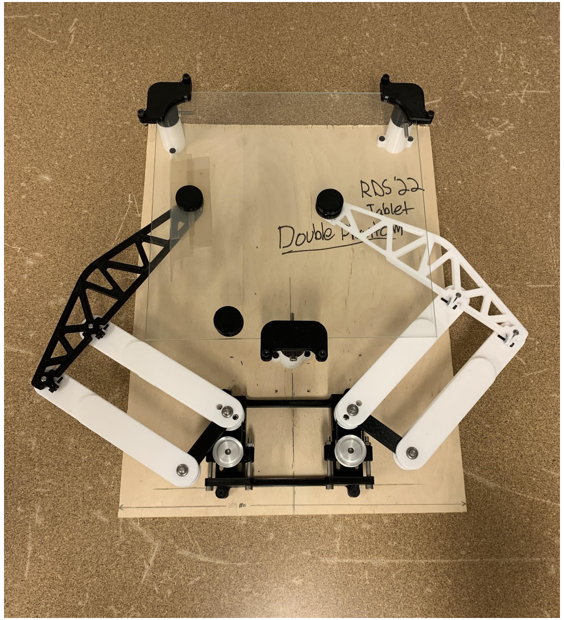


Mechanism

Ultimately decided on two, 2R arms with parallel linkages

- Easier to control friction at shafts w/ bearings than with rolling surfaces
- Low inertia - motors mounted at base rather than on frame
- Parallel design much more straightforward than in gantry system

[Documentation: Integrate Subsystems]



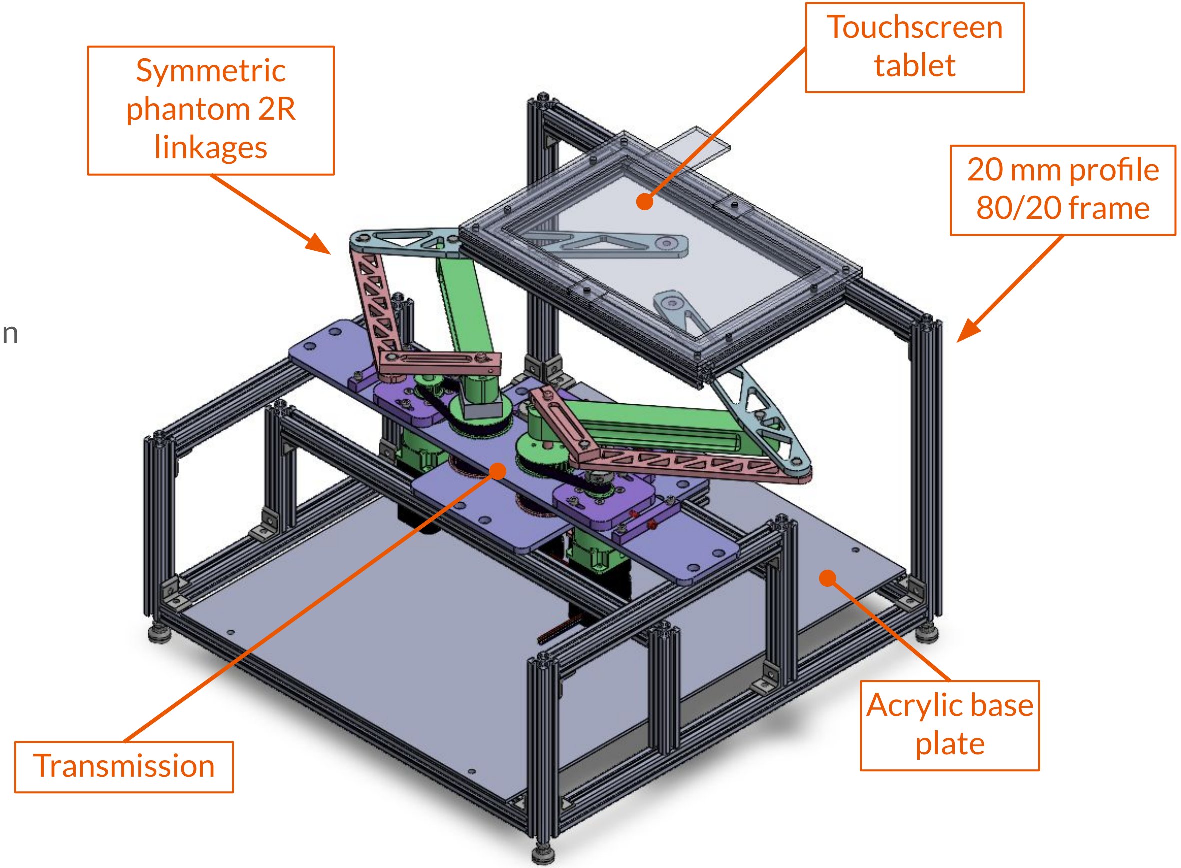
Documentation Map

Design Overview: Mechanical

Design: Top Level

Key Requirements

- Continuous 6N at each end effector
- Track fingers moving 150 mm/s
- 100 micron resolution of position at each end effector
- User experiences 100 grams or less of inertia in free motion



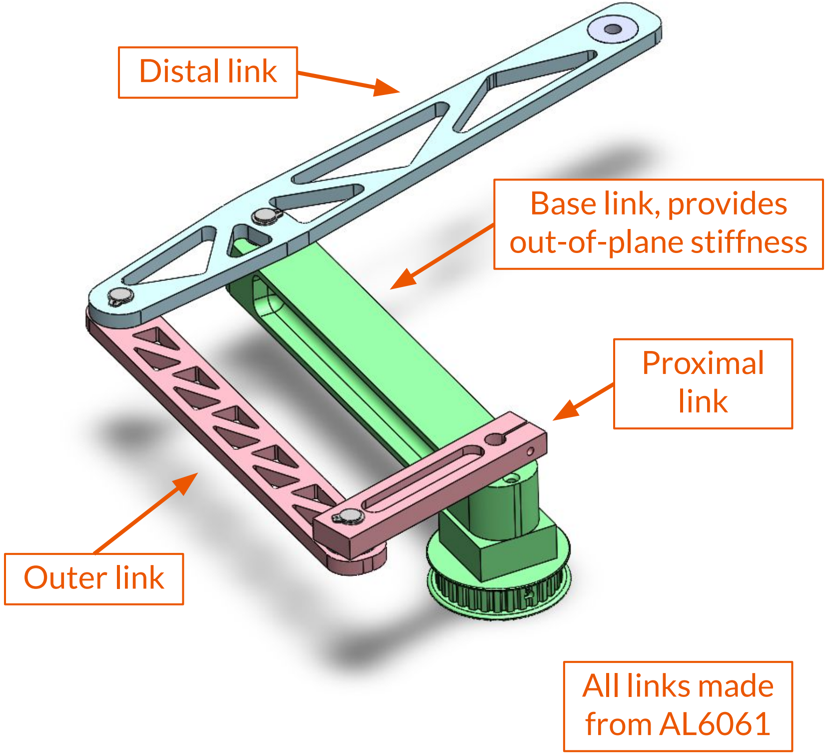
Design: Phantom Linkage

Pros

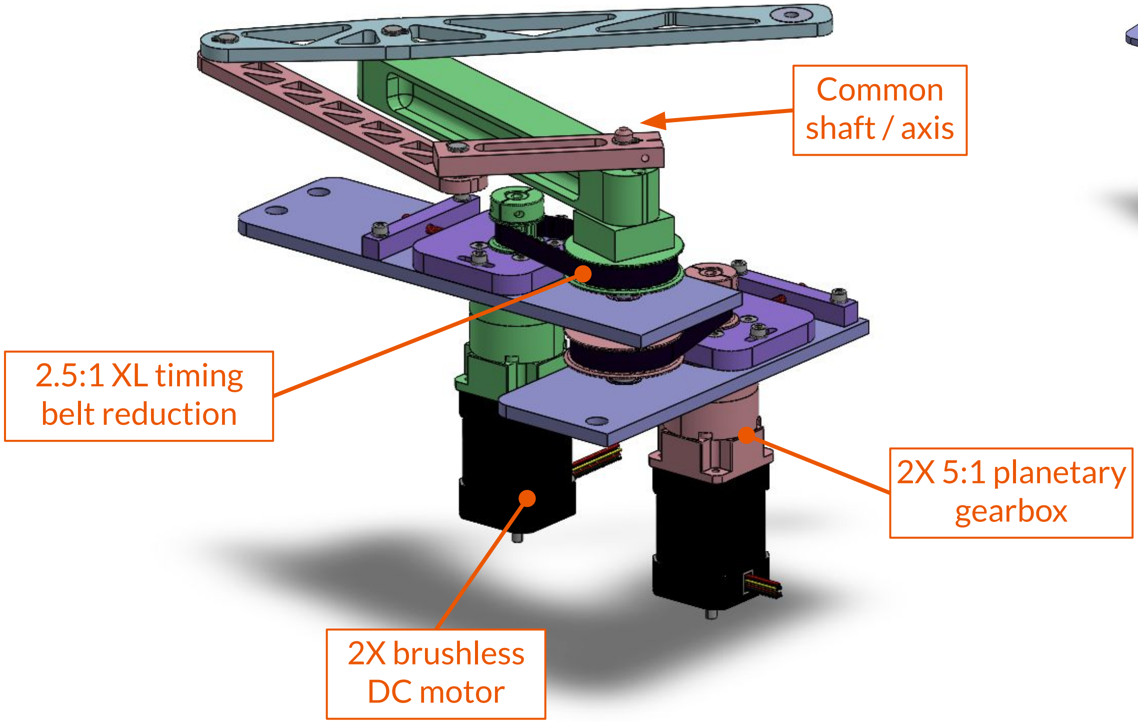
- Commonly solved kinematics
- Low inertia; all motors anchored to mechanical ground
- Uses only revolute joints; minimal friction and chance of binding

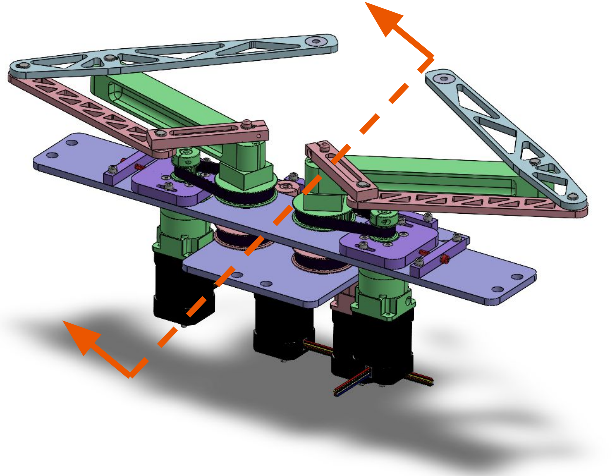
Cons

- Performs differently across workspace
- Extends beyond workspace; doesn't package cleanly
- Added inertia from proximal and outer links



Design: Transmission





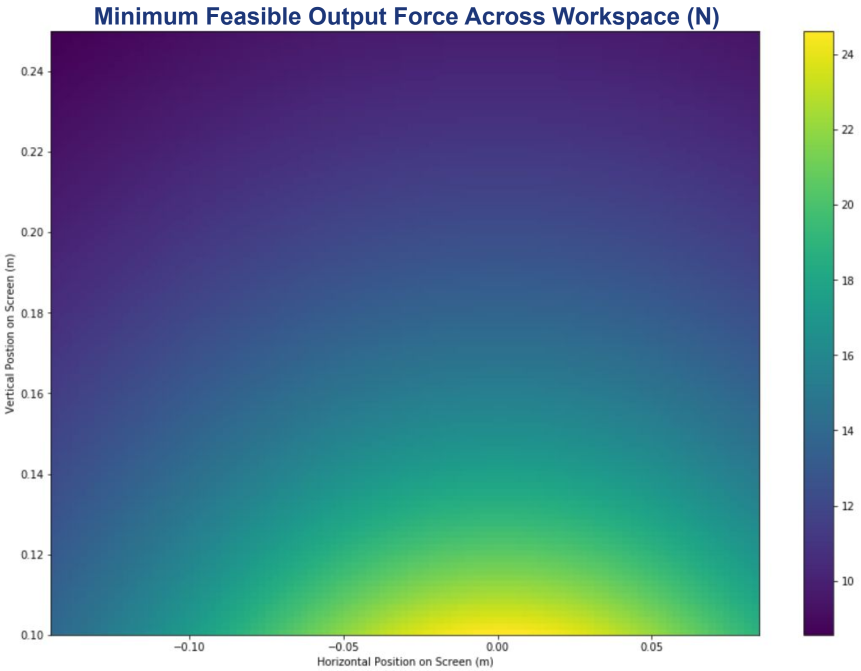
Transmission Component Selection

Rationale

1. 6N required continuously at end effectors
2. High torque motor with 12.5:1 overall transmission reduction meets force requirement
3. Gearbox has 0.1 degrees of backlash, which is too much when projected to end-effectors
4. Include pulley reduction between gearbox and output shafts to reduce backlash at the end effectors

Results

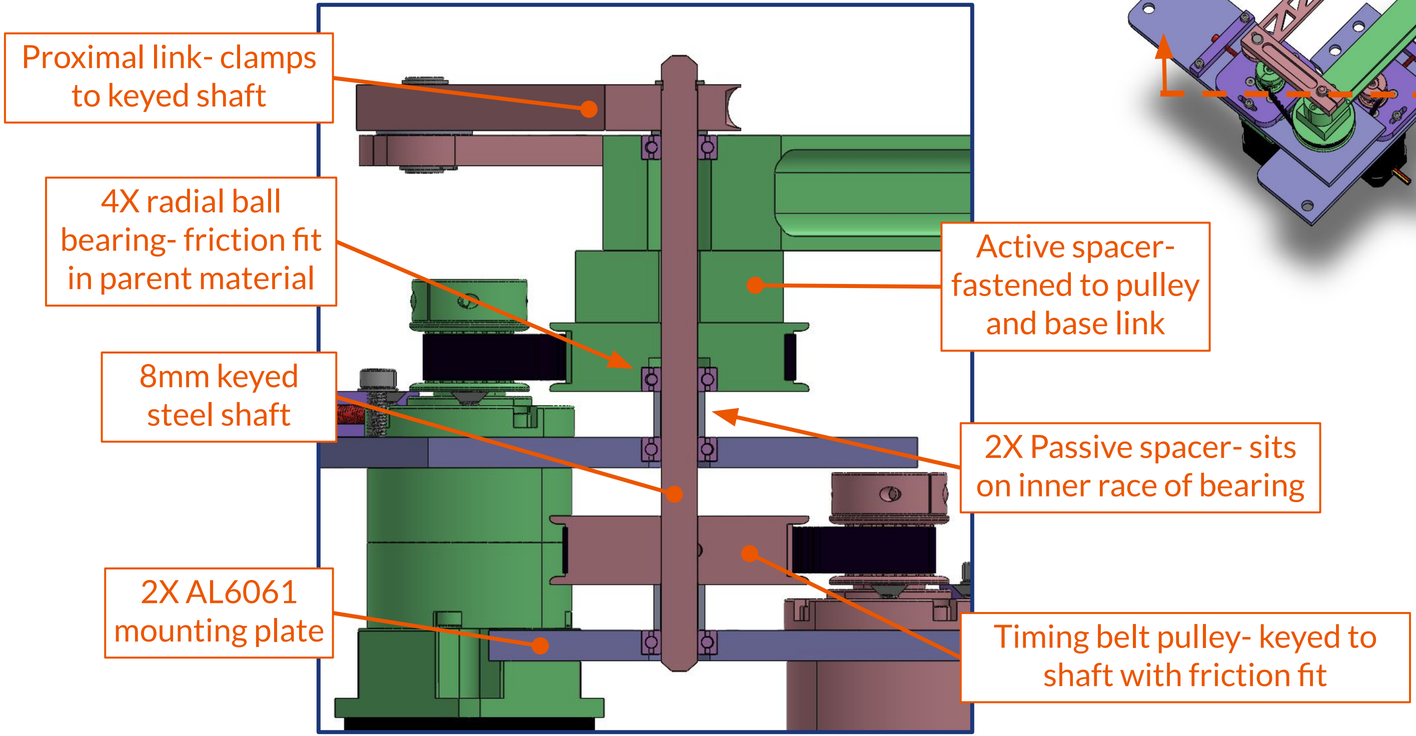
- Min. feasible output force: **8.5 N**
- Max. projected backlash: **0.31 mm**
- Max. reflected inertia: **32 g**



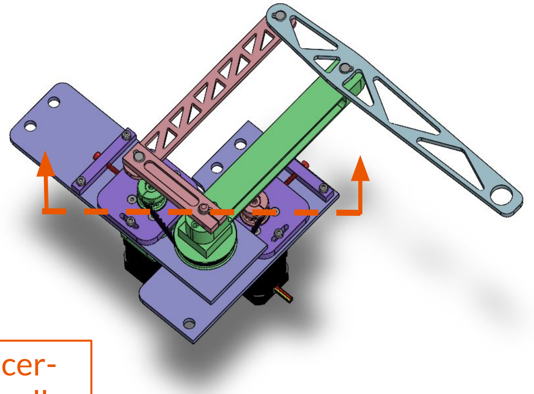
*For right-hand linkage

*Detailed motor specs, gearbox specs, and other workspace color plots in reference slides

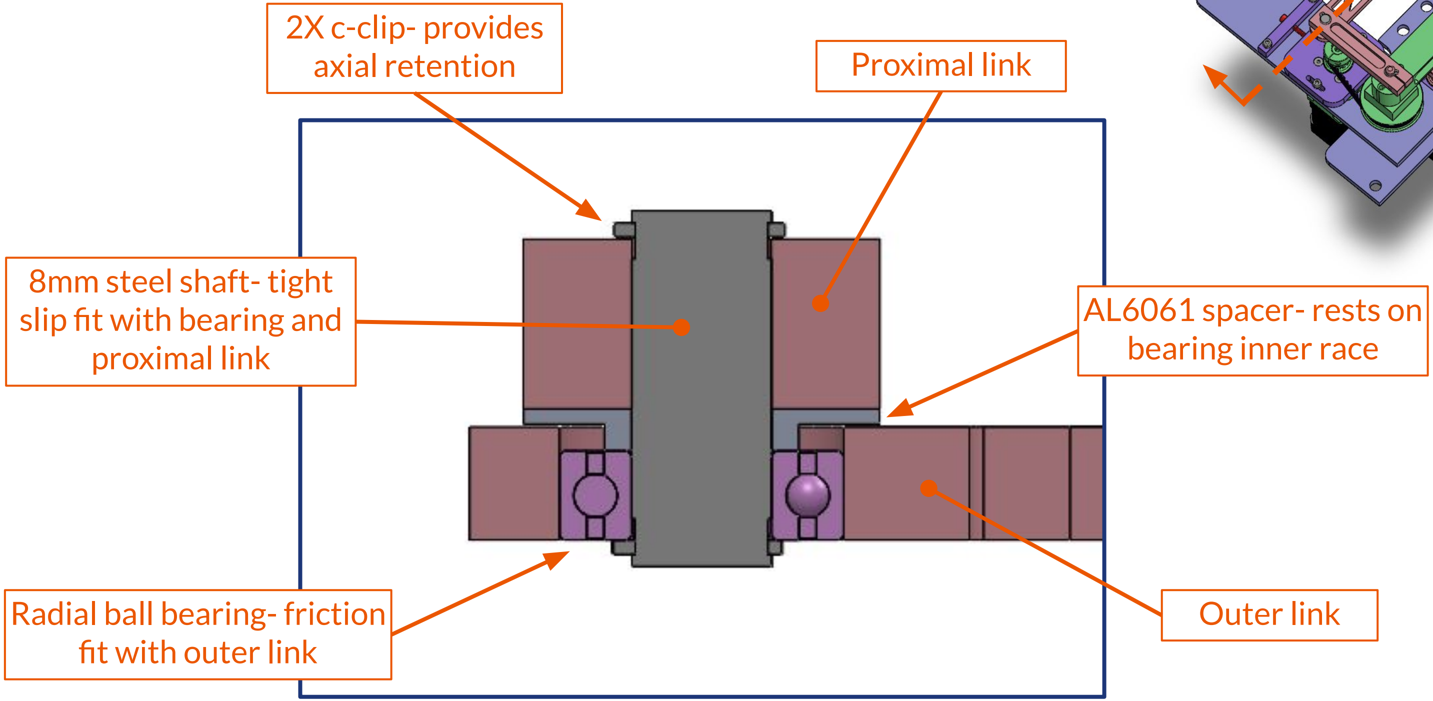
Shaft Stack: Common Axis

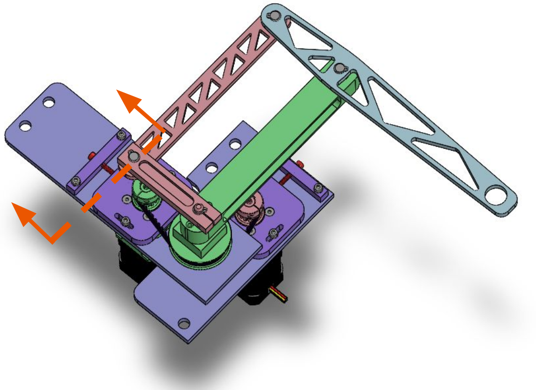


*Some components hidden for clarity

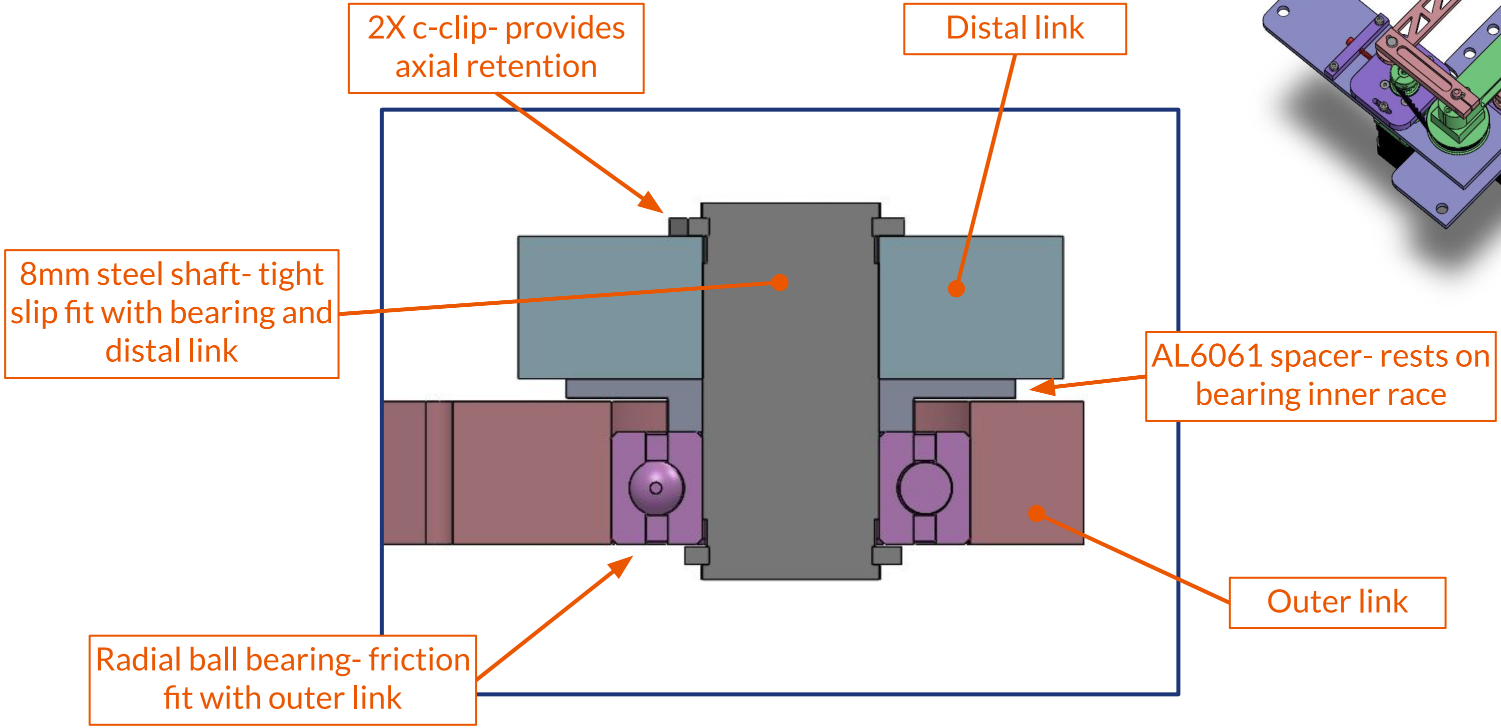


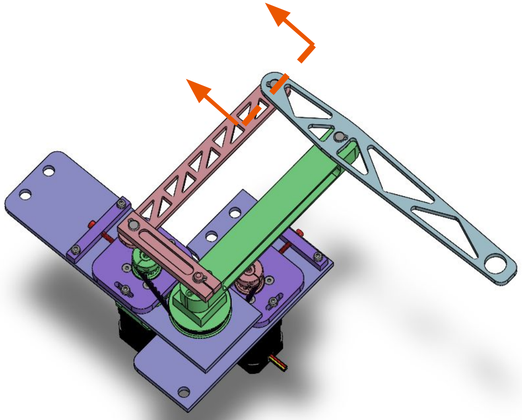
Shaft Stack: Proximal-Outer Axis



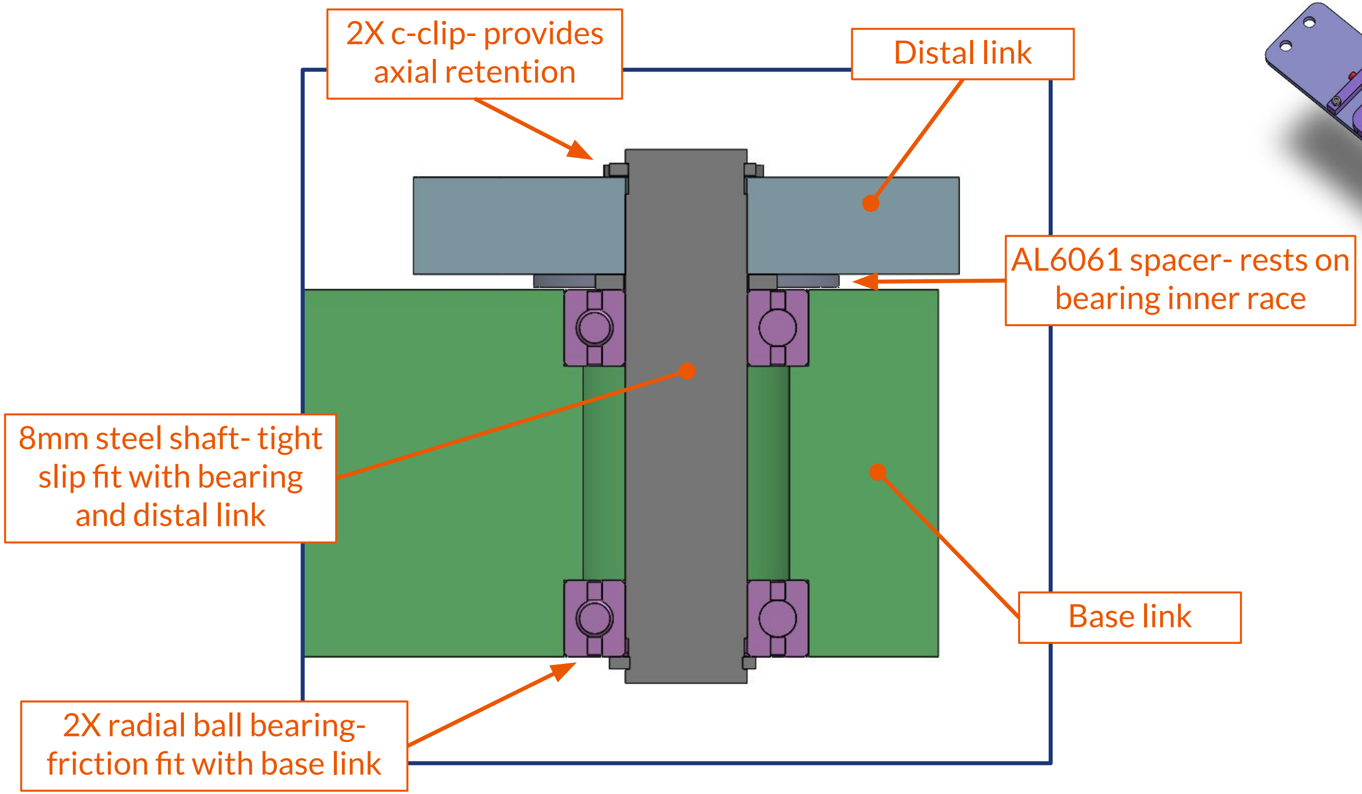


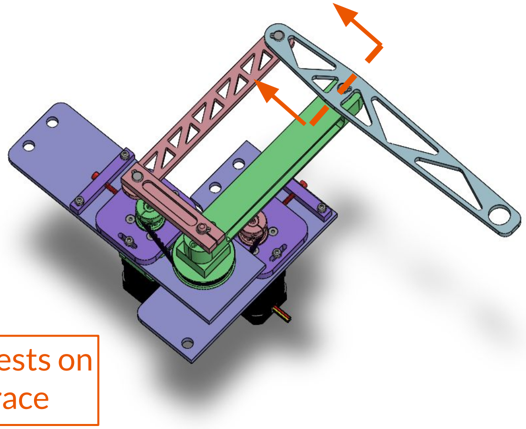
Shaft Stack: Distal-Outer Axis



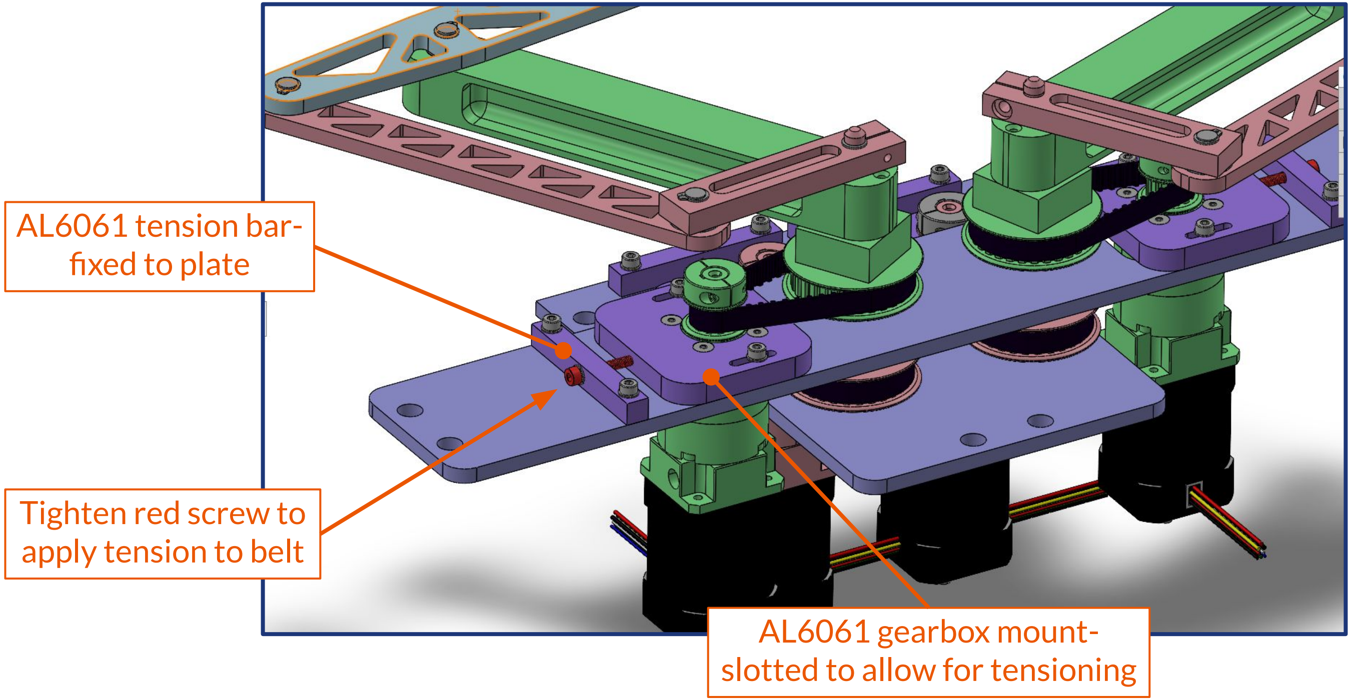


Shaft Stack: Base-Distal Axis

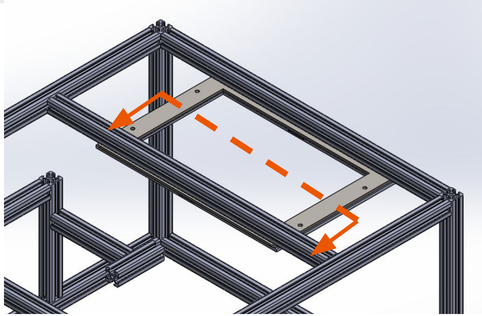


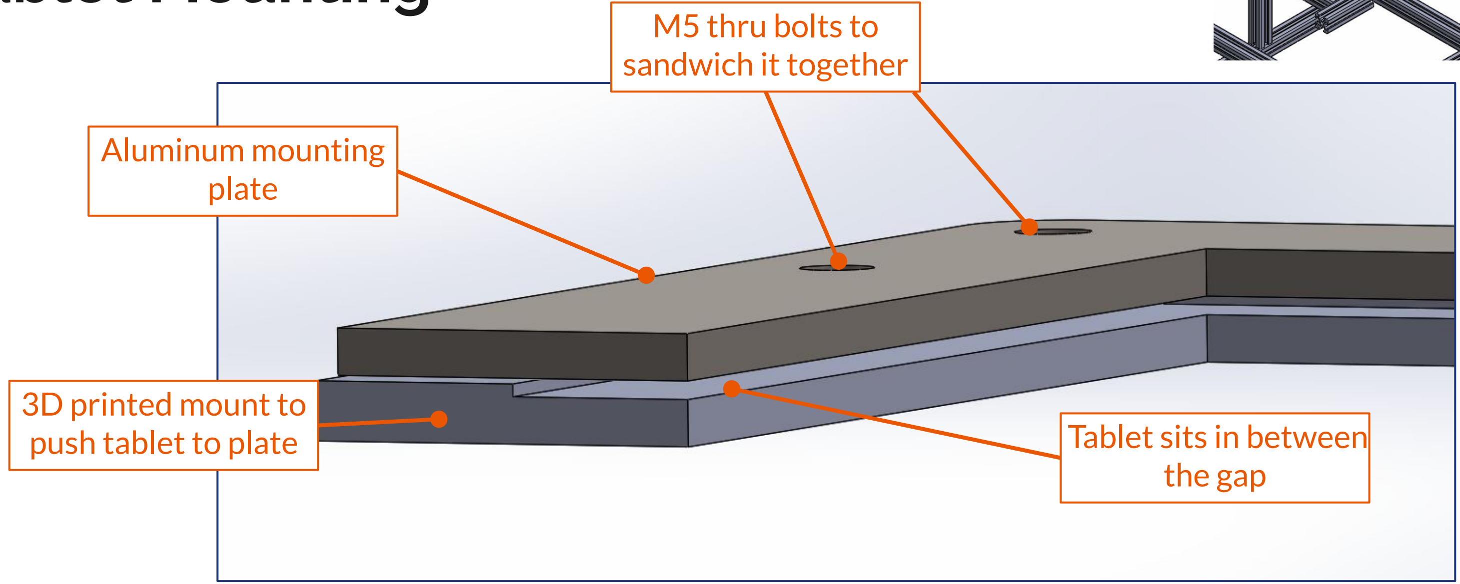


Design: Belt Tensioning



Tablet Mounting

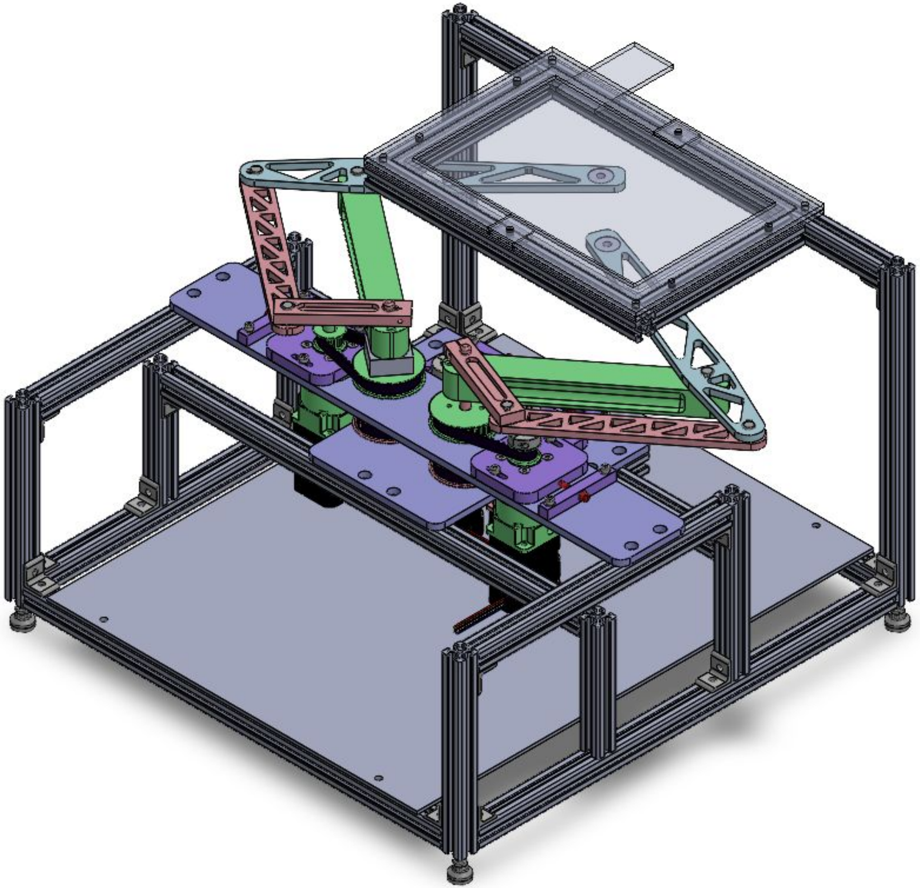




Design: Overview

Key Performance Specs

- Min. feasible output force: **8.5 N**
- Max. projected backlash: **0.31 mm**
- Max. reflected inertia: **32 g**
- Mass of one phantom linkage: **0.6 kg**



Design Overview: Magnets

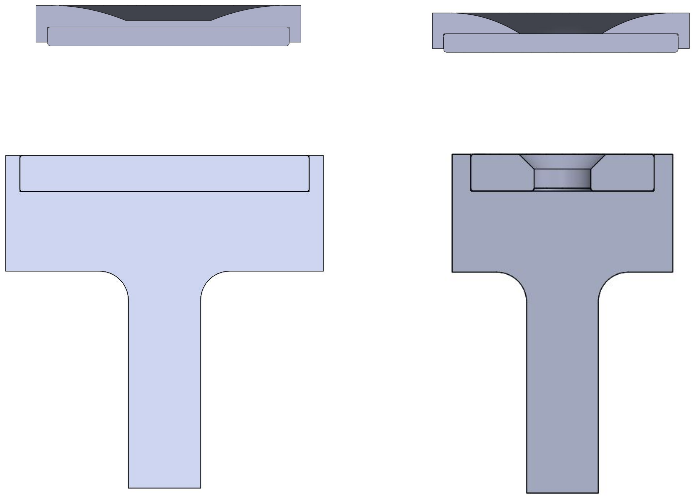
Design Requirements

LOW FRICTION:

- In free motion, the user should experience no more than 0.22 lbs or 100 g of inertia.
- Match finger speeds up to 150mm/s or 5.9 in/s

HIGH SHEAR STRENGTH:

- When the user is interacting with a virtual wall, the device will be able to respond with a stiffness of 1 N/mm or 5.71 lbs/in



Design Challenges

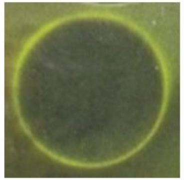
KEY ISSUE: Friction and shear strength coupled

Many attempts to mitigate friction:

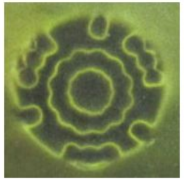
- Air bearing
- Teflon
- Lubricant
- Polymagnets
- Height variants
- Thrust bearings

Polymagnets

- Company that makes custom magnets to fit specific functions
    - Custom N/S patterns
- Reached out for a consultation
- Ordered a 20+ magnets

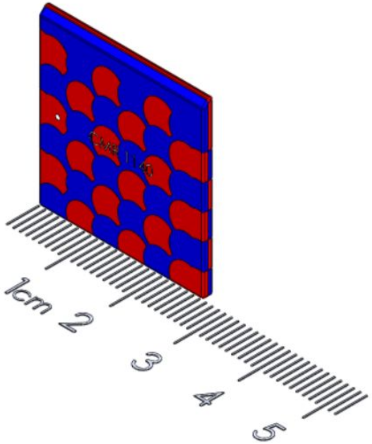


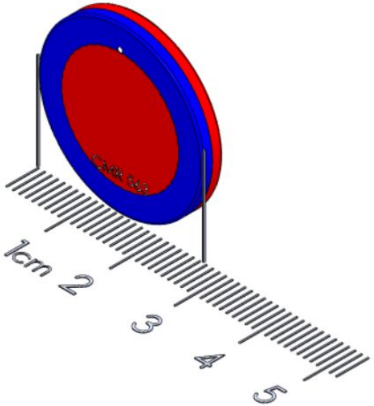
Standard magnet



Rotate-release with alignment feature

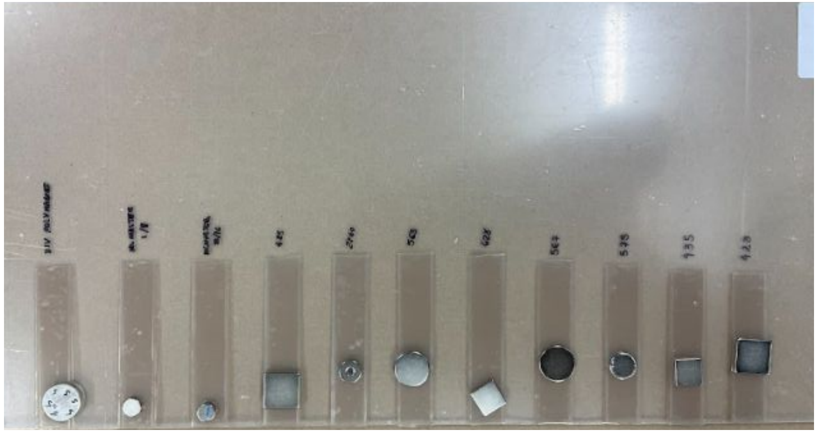
Magnet for Hall effect sensor application





Polymagnets: Testing

- Tried different magnet combinations with different friction mitigation techniques
  - Grease
  - Teflon tape
  - Teflon balls
- Qualitatively measured shear strength and friction
- Results changed once the actual screen was introduced - much larger distance + different materials

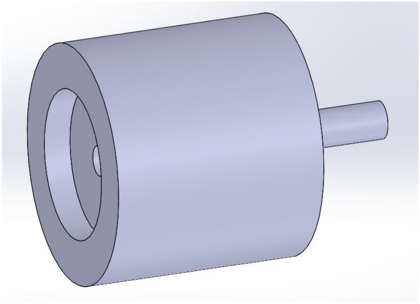


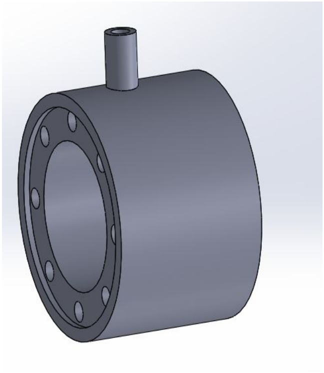
Air Bearings

- Ideal solution: Frictionless air bearings
- Prototyped several versions of ‘air pucks’ with different magnets
- Various compliant materials to seal air bearing to the tablet

Issues:

- Unable to develop an effective method of sealing/equally distributing the air
- Would need to include the infrastructure/package a pump
- Ultimately scrapped the idea

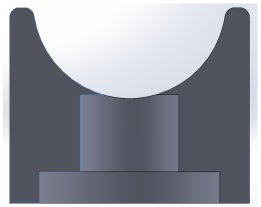


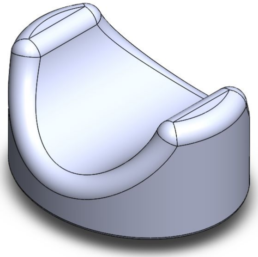


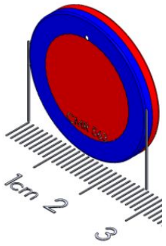
Alpha Design

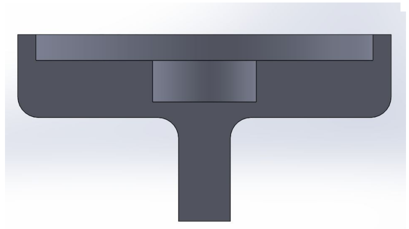
The Alpha design used two different magnets:

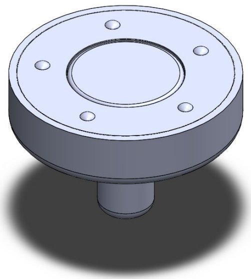
- Top magnet - ½ inch diameter neodymium magnet from McMaster - pulls 18lbs
- Bottom magnet - 1 inch, ⅛ inch polymagnet
- Together they give ~8N of shear strength with ~3N of friction
- Requirements: >6N of shear strength



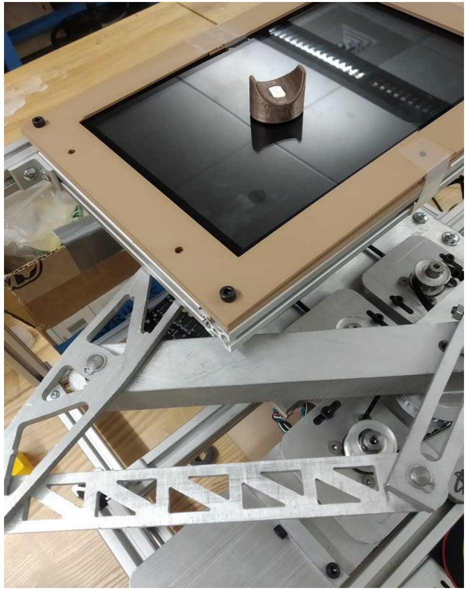


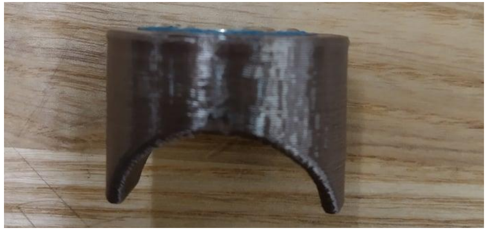






Alpha Design

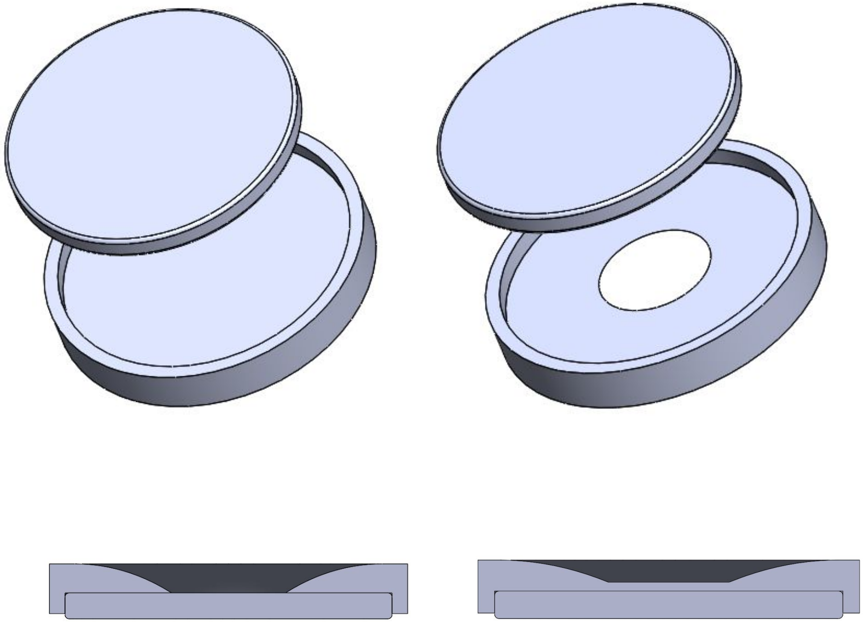




Beta Design: top magnet

For the final top magnet we are using a 0.75" polymagnet with a ring like user interface.

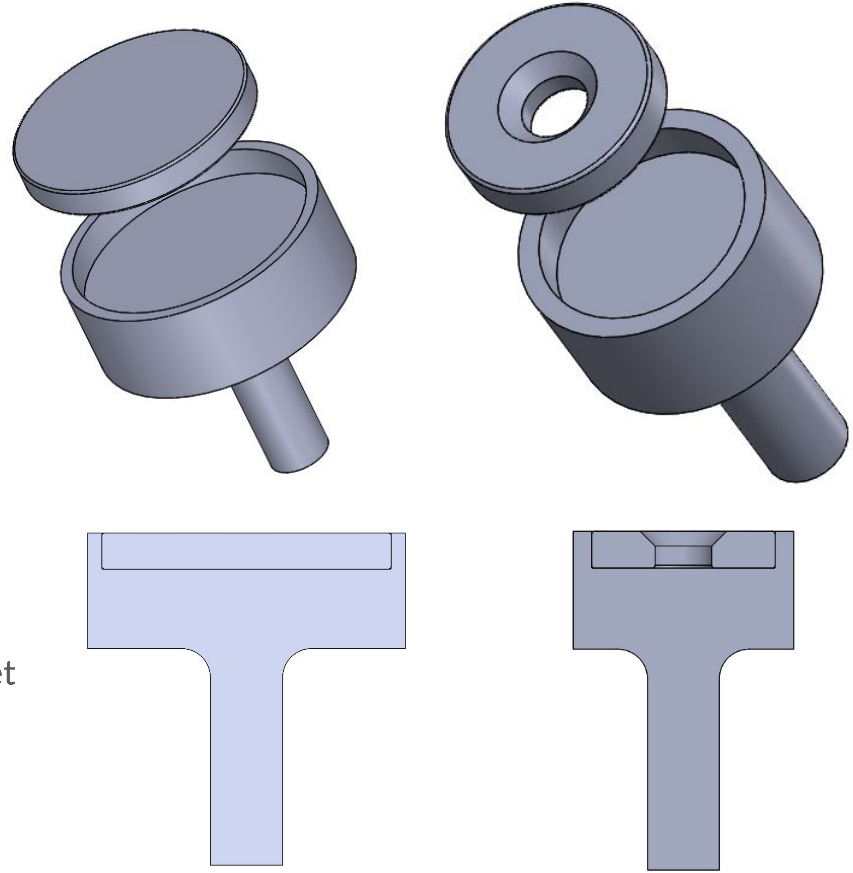
- The magnet of the left has no opening
- The magnet on the right has an opening to enable grounding through the user - this allows for determining the positioning of the user on the screen



Beta Design: bottom magnet

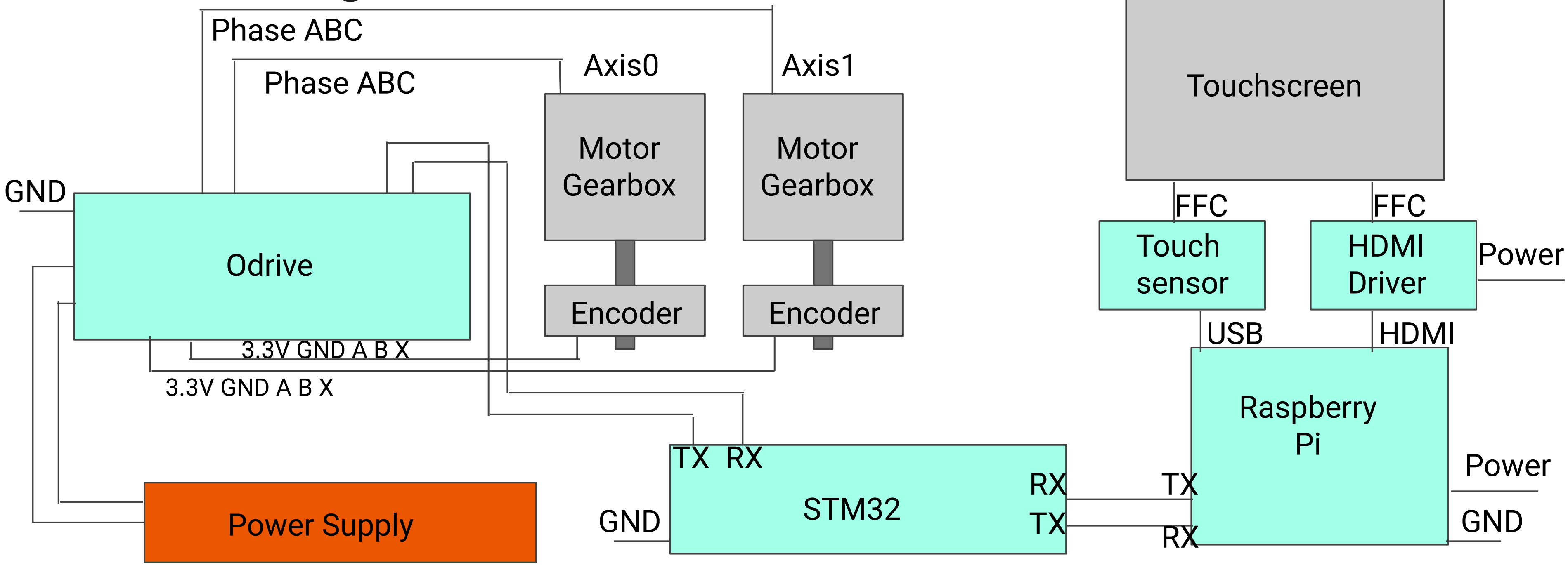
For the final bottom magnet we are using a 1”x0.125” a 0.625”x0.125” polymagnet with 3D printed holder.

- The weaker 0.625” magnet is to be used underneath the user directed top magnet
- The stronger 1” magnet is to be used underneath the robot controlled top magnet



Design Overview: Electronics

Wire Diagram



Communication

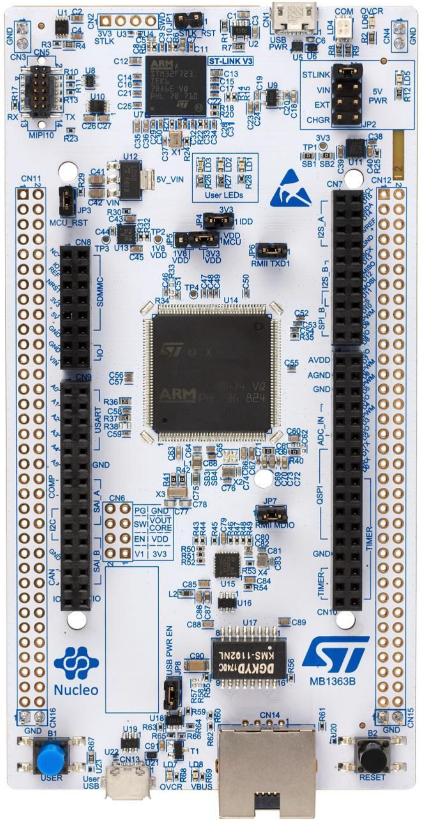
- STM32 and Odrive -> UART(ASCII)
- STM32 and Nvidia -> UART(ASCII)
- Odrive and encoder -> SPI(Serial Peripheral Interface)
- Nvidia and touch sensor -> I2C (Wire with USB)
- Share GND to obtain right value

Key Component - Raspberry Pi

- Job
    - Drive the touchscreen
    - Mouse tracking
    - Send data to STM32

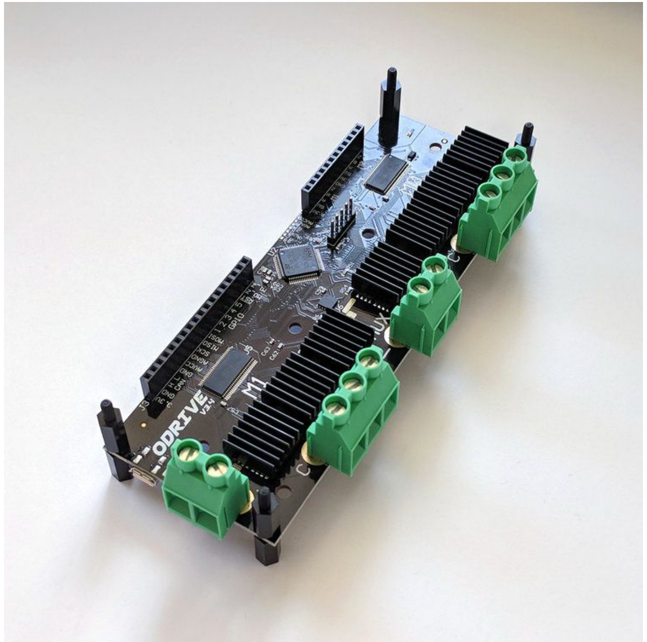
Key Component - STM32

- STM32 and Odrive -> UART(ASCII)
    - Baud rate: 115200
    - Request position and velocity(unit in revolution)
    - Receive data and preprocess(offset elimination and reduction ratio calculation) to get actual angle.
    - Calculate position in 2D tablet and Jacobian
    - Determine the force act on end-effect and trans to torque with Jacobian
    - Send cmd to Odrive
    - 500Hz
- STM32 and Nvidia -> UART(ASCII)
    - Baud rate: 11520
    - Request touchscreen position
    - 50Hz



Key Component - Odrive

- Python lib odrivetool
- DC power voltage input range 12-56V
- Peak current 120A per motor
- UART communication
- Position control and input torque

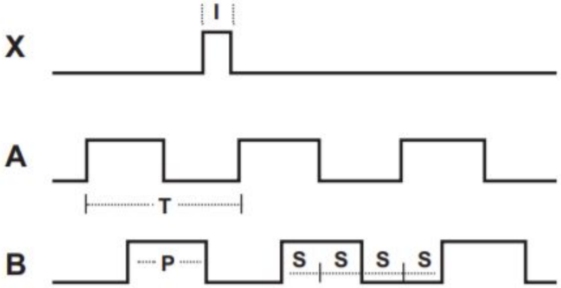


Key Component - Odrive

- Odrive calibration config
    - Odrv0.axis0.motor.config
    - Odrv0.axis0.controller.config
    - Odrv0.axis0.encoder.config
- Difference between axis0(green) and axis1(pink)
    - Odrv0.axis0.controller.config.pos_gain = 100
    - Odrv0.axis1.controller.config.pos_gain = 200

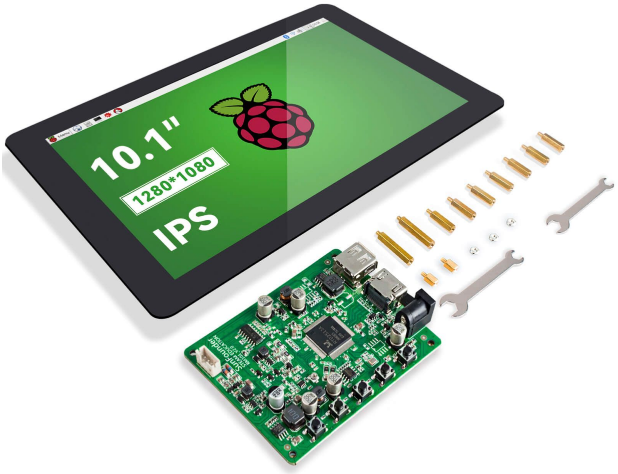
Key Component - Encoder

- AMT102-V from CUI Devices
- Quadrature resolutions 2048 PPR(Pulses Per Revolution)
- Counts Per Revolution 2048*4
- Creates linear resolution of 28 μm at end effector



Key Component - Touchscreen

- 10” x 7” Display (1280*800 pixel)
- Single point touchscreen
- Run tablet off of Nvidia Jetson Xavier NX
- Touch sensor with USB



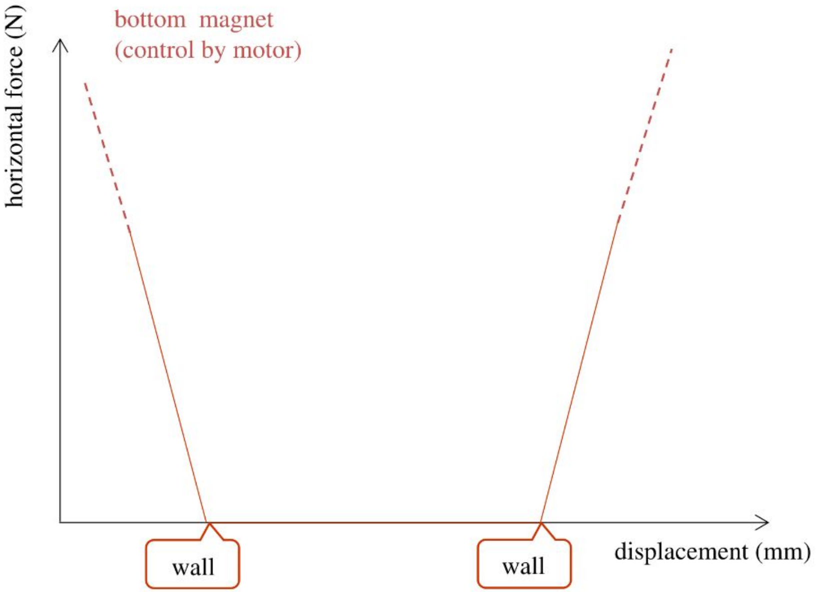
Key Component - Touchscreen

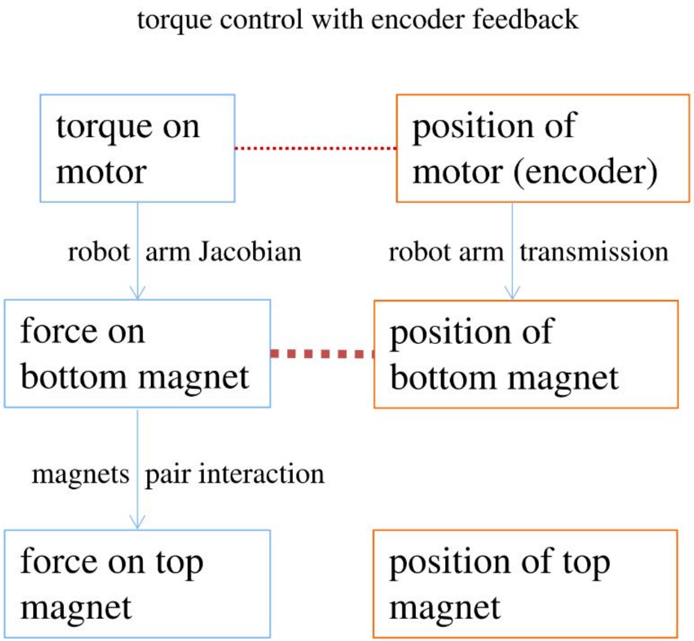
- Using python lib pyautogui
- Tracking mouse position
- Return position values in pixel
- CRITICAL: Touchscreen only supports single touch

```
import  os
import  time
import pyautogui as pag
try:
    while True:
        print("Press Ctrl-C to end")
        screenWidth, screenHeight = pag.size()
        print(screenWidth,screenHeight)
        x,y = pag.position()
        posStr = "Position:" + str(x).rjust(4)+','+str(y).rjust(4)
        print(posStr)
        time.sleep(0.01)
        os.system('cls')
except KeyboardInterrupt:
    print('end....')
```

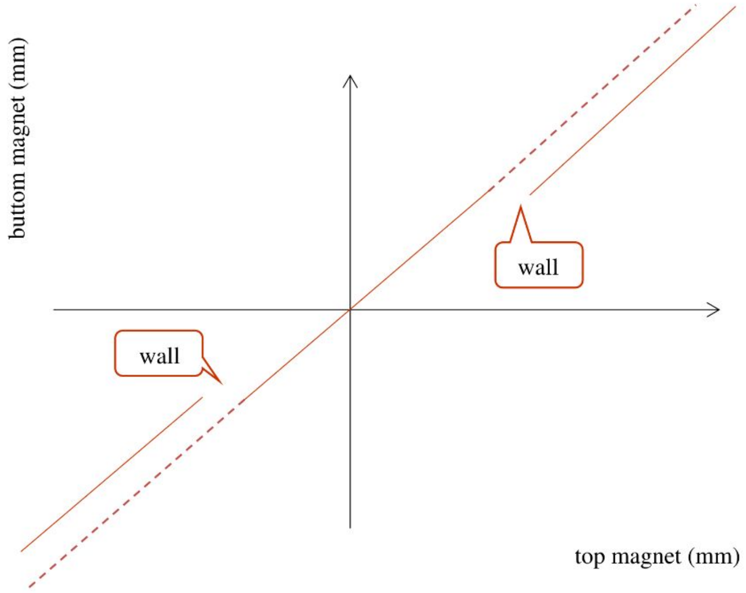
Design Overview: Software

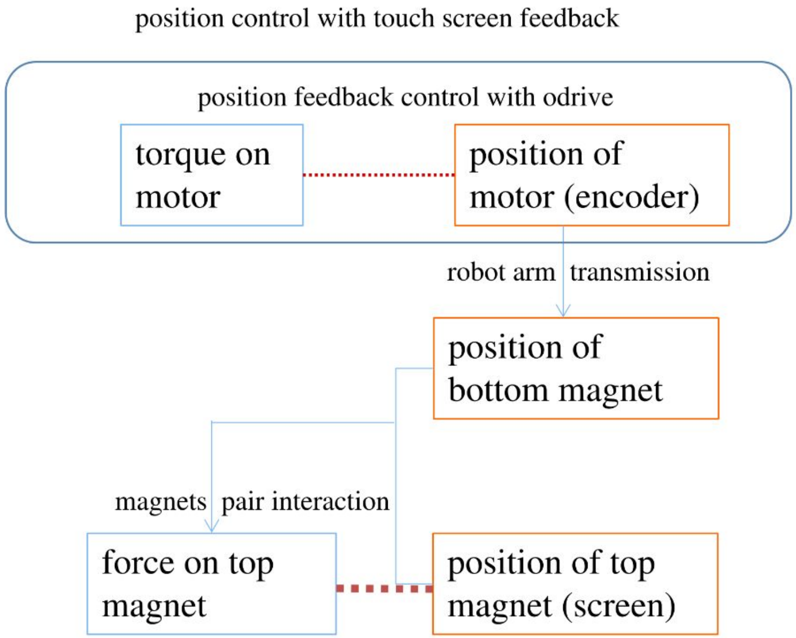
Control System: Control Theory – Passive





Control System: Control Theory – Active





Control System: Control Theory – Active

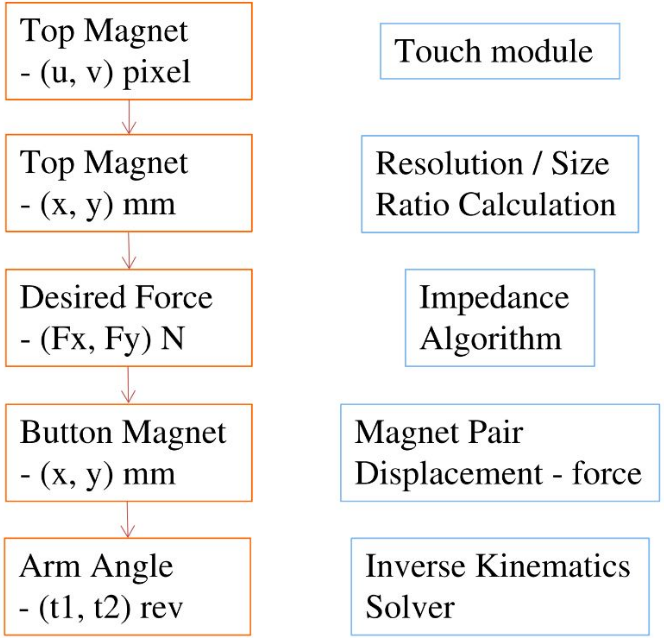
We run the close loop in frequency 500 Hz.

A small demo of circle wall impedance control is realized.

Limitations:

1. Friction !!!
   Big friction will lead user hard to move in free run area!

2. Need Precise calibration parameters!
   Small (either angle zero point or installation size) parameter error (several mm Een Effect displacement) will lead to huge force act on top megnet



Documentation Map

CAD Files & PDF Of Toleranced Drawings

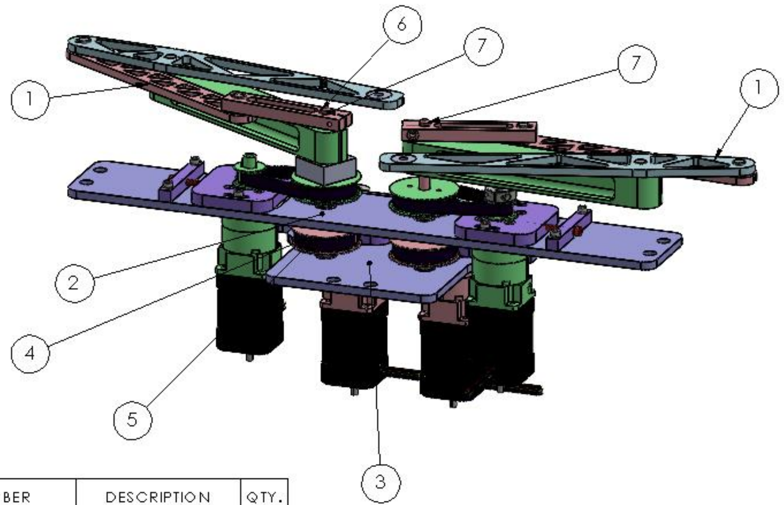
CAD files and drawings can be found at:

RDS 2022 Student Access Folder/Tablet/CAD

If you have a GrabCAD account they can also be found at:

Link to GrabCAD

Assembly Drawings



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	TB1-PHANTOM-LINKAGE		2
2	TB1-TOP-TRANSMISSION		1
3	TB1-TRANSMISSION-BOT		1
4	1277N787	Corrosion-Resistant Timing Belt Pulley	2
5	1679K197	Dust-Free Timing Belt	4
6	90154A137	External Retaining Ring	1
7	1439K221	1045 Carbon Steel Keyed Rotary Shaft	2

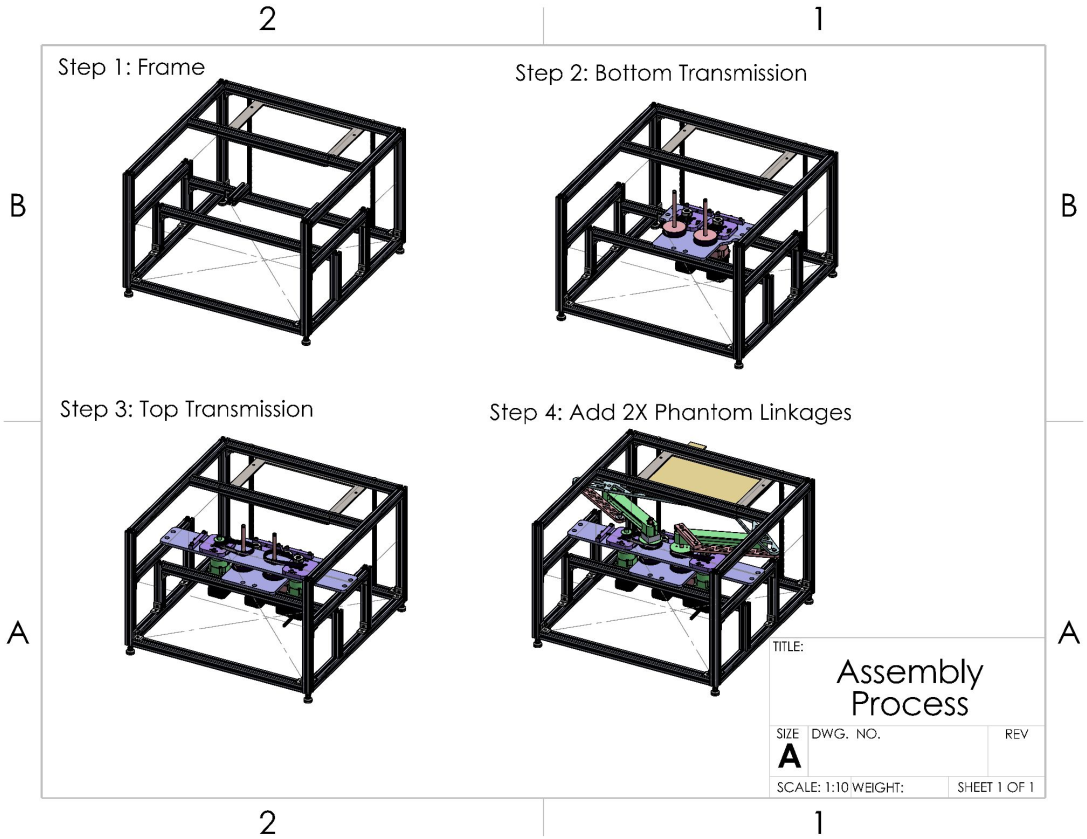
	NAME	DATE
DRAWN	C.M.	6/8/22
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

TITLE: Mechanism Overview

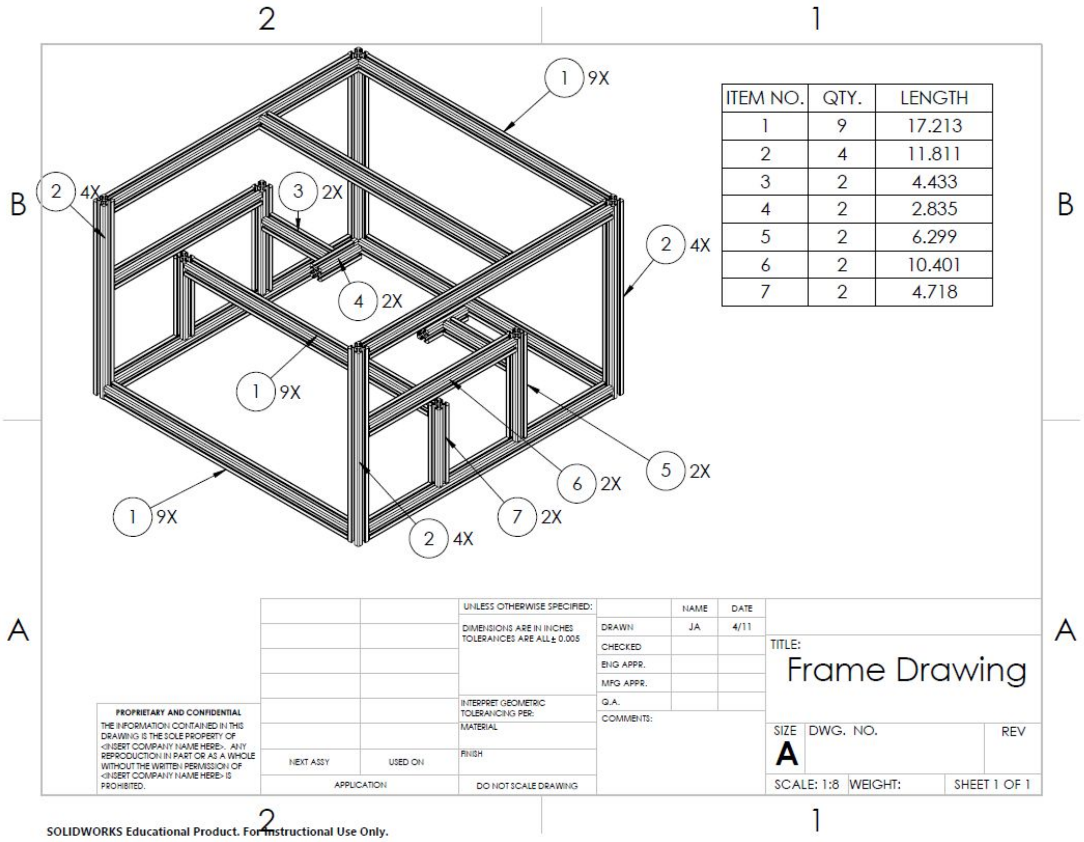
SIZE A | DWG. NO. | REV

SCALE: 1:10 | WEIGHT: | SHEET 1 OF 1

Assembly Drawings

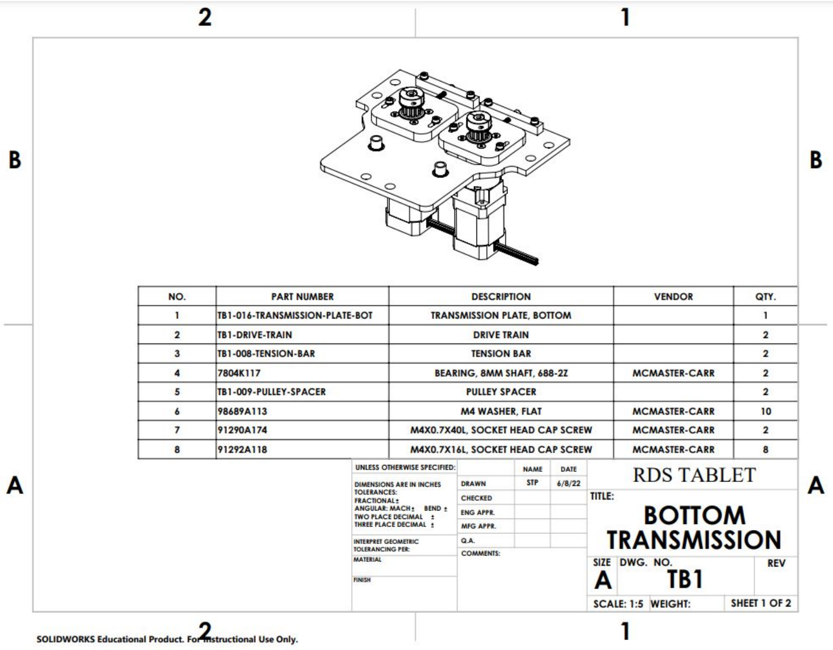


Assembly Drawings

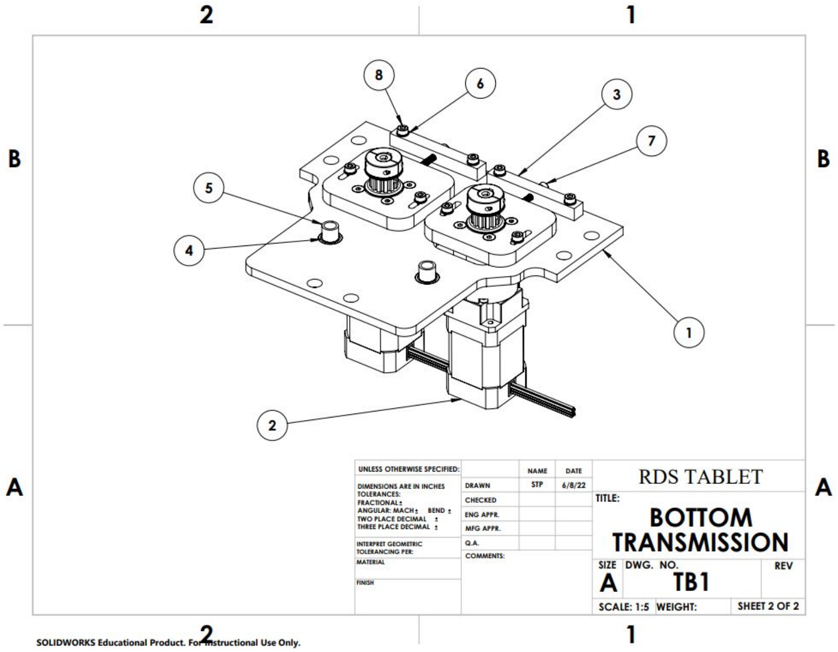


ITEM NO.	QTY.	LENGTH
1	9	17.213
2	4	11.811
3	2	4.433
4	2	2.835
5	2	6.299
6	2	10.401
7	2	4.718

Assembly Drawings

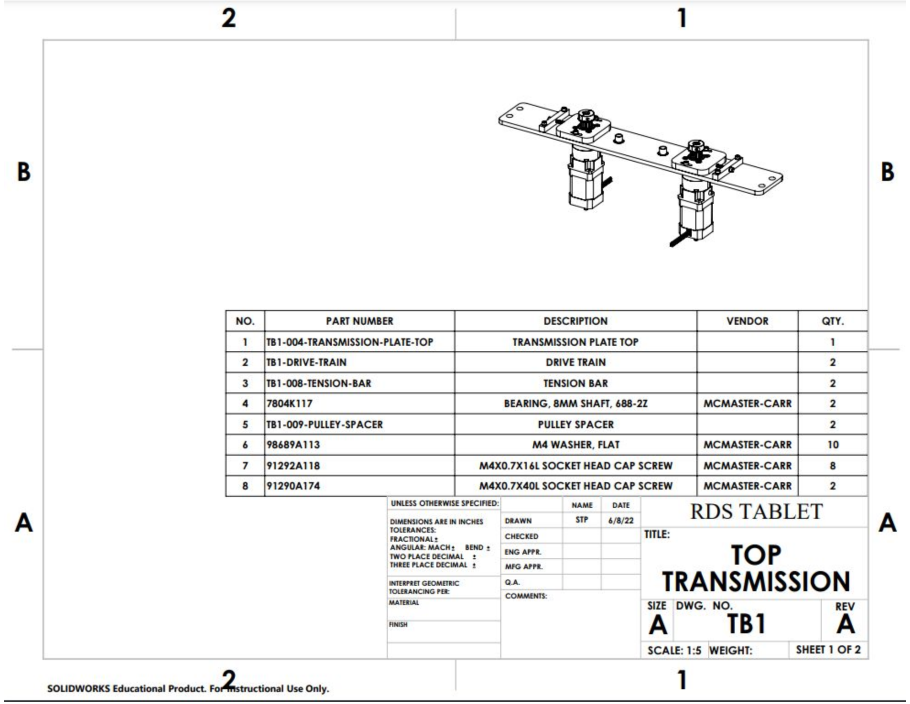


NO.	PART NUMBER	DESCRIPTION	VENDOR	QTY.
1	TB1-016-TRANSMISSION-PLATE-BOT	TRANSMISSION PLATE, BOTTOM		1
2	TB1-DRIVE-TRAIN	DRIVE TRAIN		2
3	TB1-008-TENSION-BAR	TENSION BAR		2
4	7804K117	BEARING, 8MM SHAFT, 688-2Z	MCMASTER-CARR	2
5	TB1-009-PULLEY-SPACER	PULLEY SPACER		2
6	98689A113	M4 WASHER, FLAT	MCMASTER-CARR	10
7	91290A174	M4X0.7X40L, SOCKET HEAD CAP SCREW	MCMASTER-CARR	2
8	91292A118	M4X0.7X16L, SOCKET HEAD CAP SCREW	MCMASTER-CARR	8

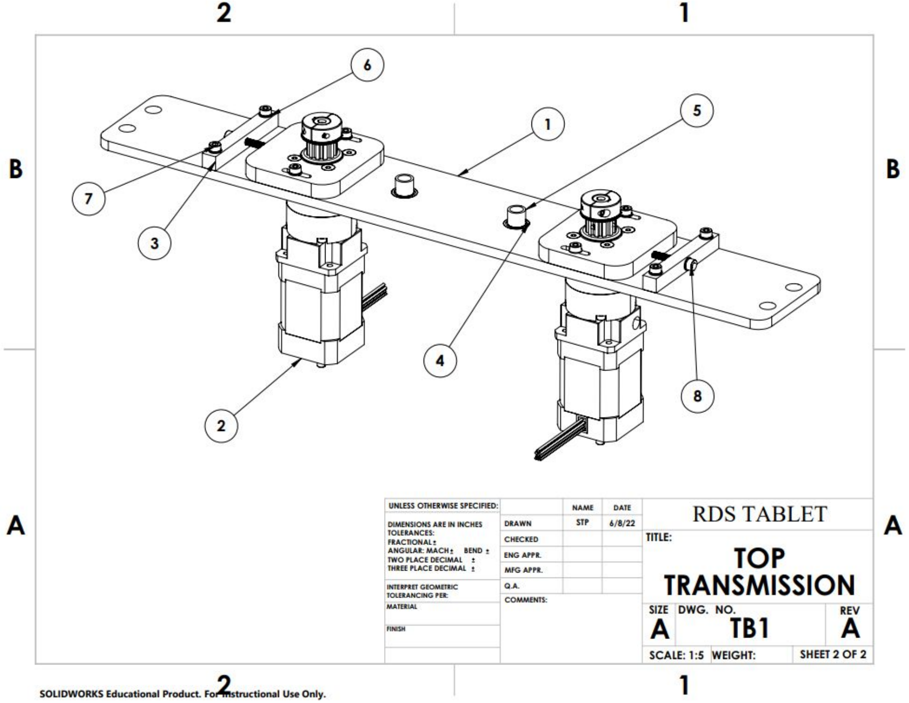


[PDF Drawings]

Assembly Drawings



NO.	PART NUMBER	DESCRIPTION	VENDOR	QTY.
1	TB1-004-TRANSMISSION-PLATE-TOP	TRANSMISSION PLATE TOP		1
2	TB1-DRIVE-TRAIN	DRIVE TRAIN		2
3	TB1-008-TENSION-BAR	TENSION BAR		2
4	7804K117	BEARING, 8MM SHAFT, 688-2Z	MCMASTER-CARR	2
5	TB1-009-PULLEY-SPACER	PULLEY SPACER		2
6	98689A113	M4 WASHER, FLAT	MCMASTER-CARR	10
7	91292A118	M4X0.7X16L SOCKET HEAD CAP SCREW	MCMASTER-CARR	8
8	91290A174	M4X0.7X40L SOCKET HEAD CAP SCREW	MCMASTER-CARR	2

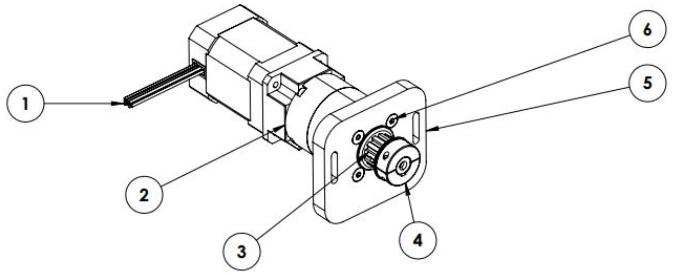


[PDF Drawings]

Assembly Drawings

2 1

B



B

NO.	PART NUMBER	DESCRIPTION	VENDOR	QTY.
1	BLY172D	BRUSHLESS MOTOR	ANAHEIM AUTOMATION	1
2	GBPS-0401-CS-AA171-197	5:1 PLANETARY GEARBOX	ANAHEIM AUTOMATION	1
3	TB1-005-DRIVE-PULLEY	DRIVE PULLEY		1
4	3444N12	CLAMPING SHAFT-COLLAR WITH KEYWAY	MCMASTER-CARR	1
5	TB1-006-MOTOR-MOUNT	MOTOR MOUNT		1
6	92125A188	FLAT-HEAD M4 SCREW	MCMASTER-CARR	4

A

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	STP	6/8/22
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

RDS: TABLET

TITLE:

DRIVE TRAIN

SIZE A DWG. NO. TB1-501 REV A

SCALE: 1:5 WEIGHT: SHEET 1 OF 1

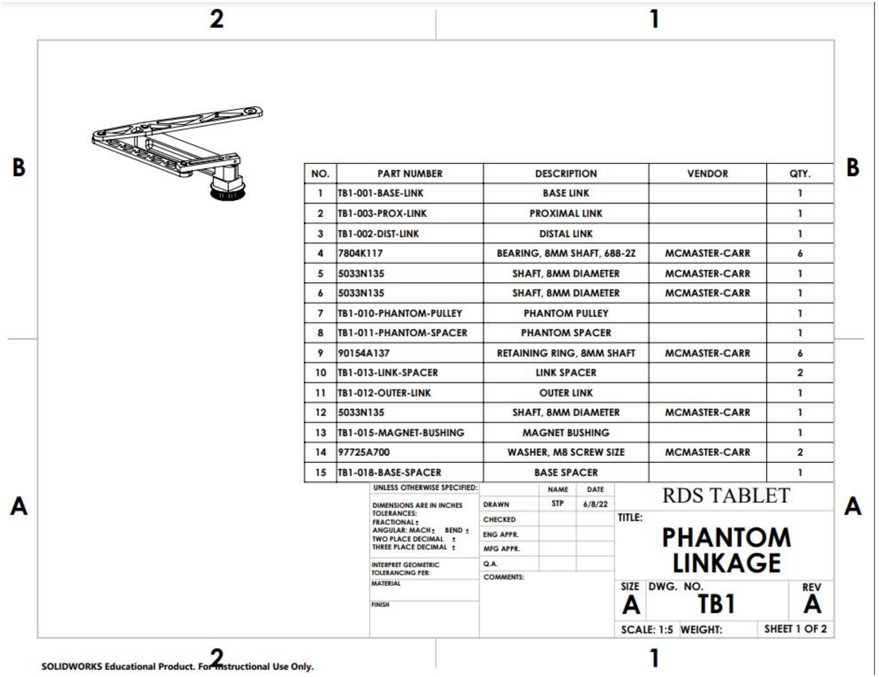
A

SOLIDWORKS Educational Product. For Instructional Use Only.

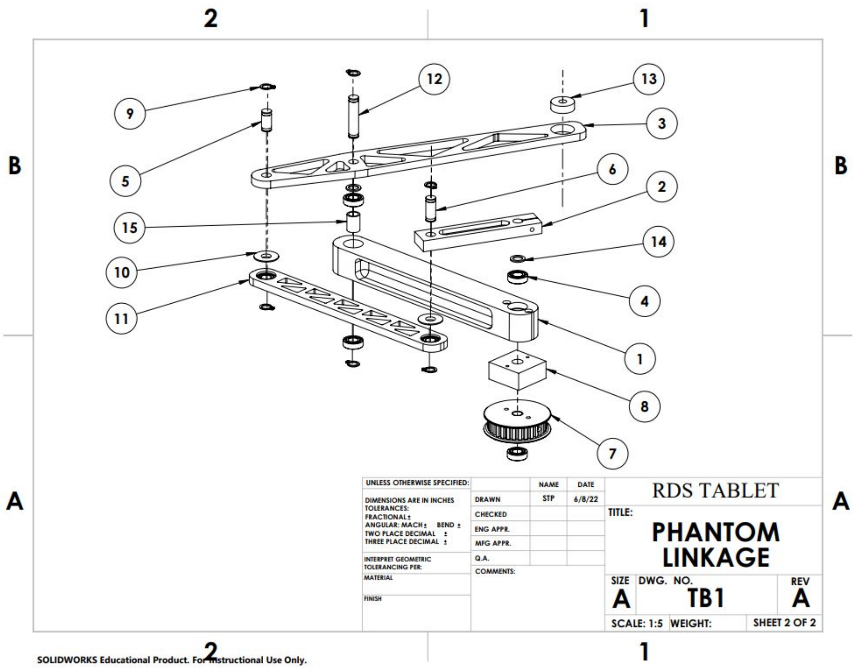
2 1

PDF Drawings

Assembly Drawings



NO.	PART NUMBER	DESCRIPTION	VENDOR	QTY.
1	TB1-001-BASE-LINK	BASE LINK		1
2	TB1-003-PROX-LINK	PROXIMAL LINK		1
3	TB1-002-DIST-LINK	DISTAL LINK		1
4	7804K117	BEARING, 8MM SHAFT, 688-2Z	MCMASTER-CARR	6
5	5033N135	SHAFT, 8MM DIAMETER	MCMASTER-CARR	1
6	5033N135	SHAFT, 8MM DIAMETER	MCMASTER-CARR	1
7	TB1-010-PHANTOM-PULLEY	PHANTOM PULLEY		1
8	TB1-011-PHANTOM-SPACER	PHANTOM SPACER		1
9	90154A137	RETAINING RING, 8MM SHAFT	MCMASTER-CARR	6
10	TB1-013-LINK-SPACER	LINK SPACER		2
11	TB1-012-OUTER-LINK	OUTER LINK		1
12	5033N135	SHAFT, 8MM DIAMETER	MCMASTER-CARR	1
13	TB1-015-MAGNET-BUSHING	MAGNET BUSHING		1
14	97725A700	WASHER, M8 SCREW SIZE	MCMASTER-CARR	2
15	TB1-018-BASE-SPACER	BASE SPACER		1



PDF Drawings

Documentation Map

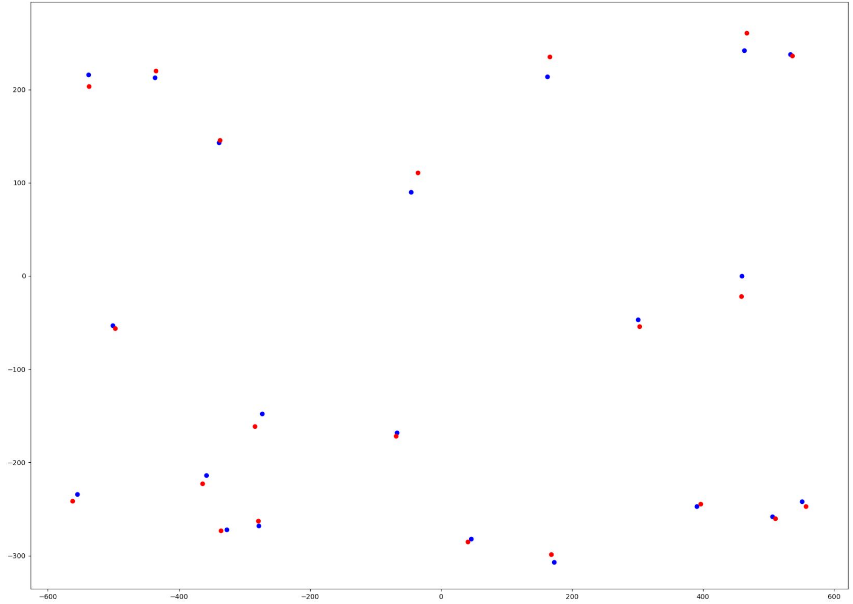
Calibration

Turn off motor let user to move freely
Record (u,v) screen (t1, t2) pairs - about 15-30 pairs
Using nonlinear optimization to solve overdetermined equations to get zero points of arm and installation transformation.

We use
R_ppi represent PPI of screen
R_sa represent rotation matrix 2d from arm to screen
t_sa represent translation 2d from arm to screen

$$\binom{u}{v} = R_{ppi}\left(R_{sa}\binom{l_1\cos\left(t_1 - t_{1(0)}\right) + l_2\cos\left(t_2 - t_{2(0)}\right)}{l_1\sin\left(t_1 - t_{1(0)}\right) + l_2\sin\left(t_2 - t_{2(0)}\right)} + t_{sa}\right)$$

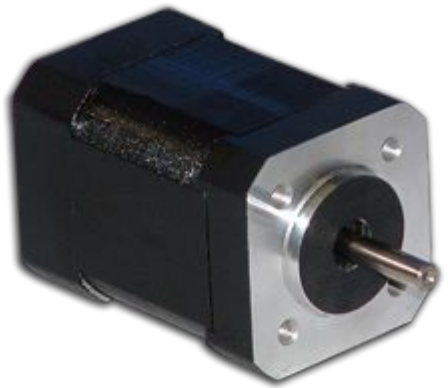
Calibration reprojection graph



Our calibration mean error is about 9 pixel (just 1.6mm) which is acceptable.

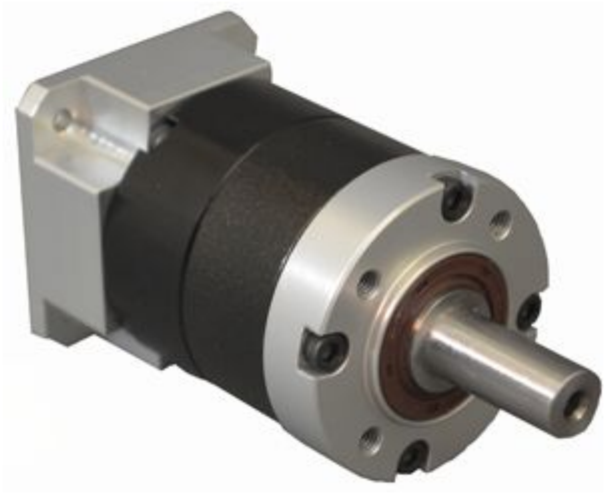
Motor Selection

- **BLY172D-24V-2000** from Anaheim Automation
- Continuous torque: **0.2N-m**
- Torque constant: **0.055 N-m/A**
- Continuous speed: **2000 rpm**
- Motor inertia: **48.0 g-cm2**



Gearbox Selection

- **GBPS-0401-CS-005** from Anaheim Automation
- Gear ratio: **5:1**
- Backlash: **0.1 degrees**
- Efficiency: **95%**



Gearboxes

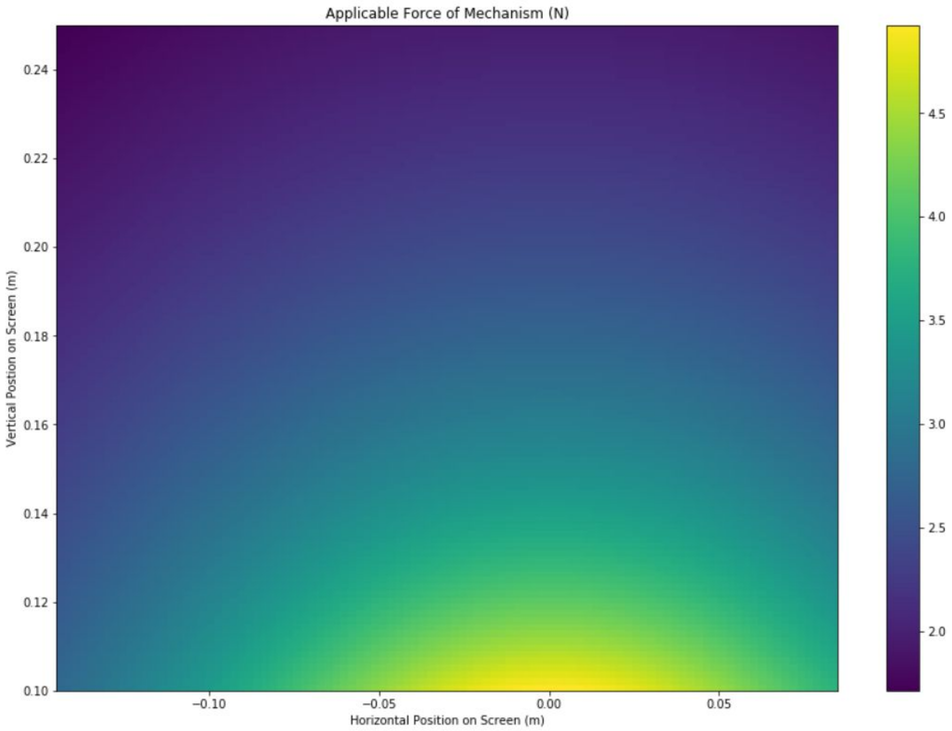
Weaker magnets allow for a weaker end effector and lesser torque required. Hence, gearboxes could be removed from the drive train.

Pros

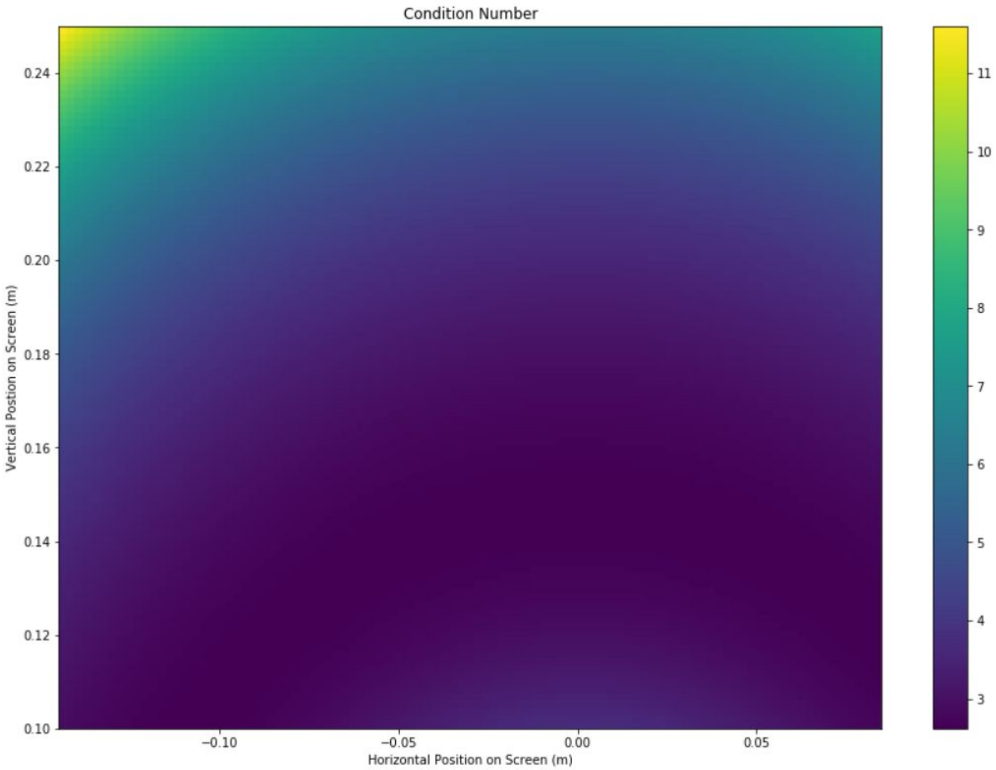
- No backlash
- Reduced reflected inertia & friction
- Re-gain budget

Cons

- Less force at end effector (1.7 N)
- Necessitates transmission changes

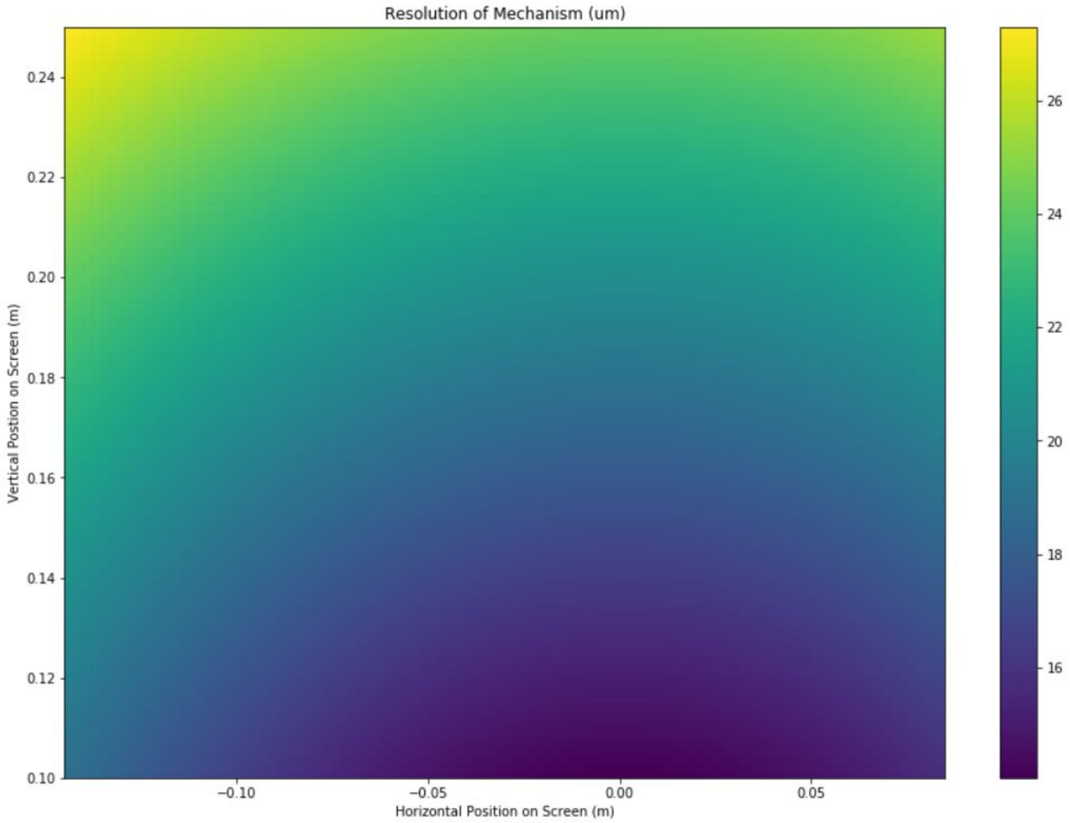


Condition Number Plot



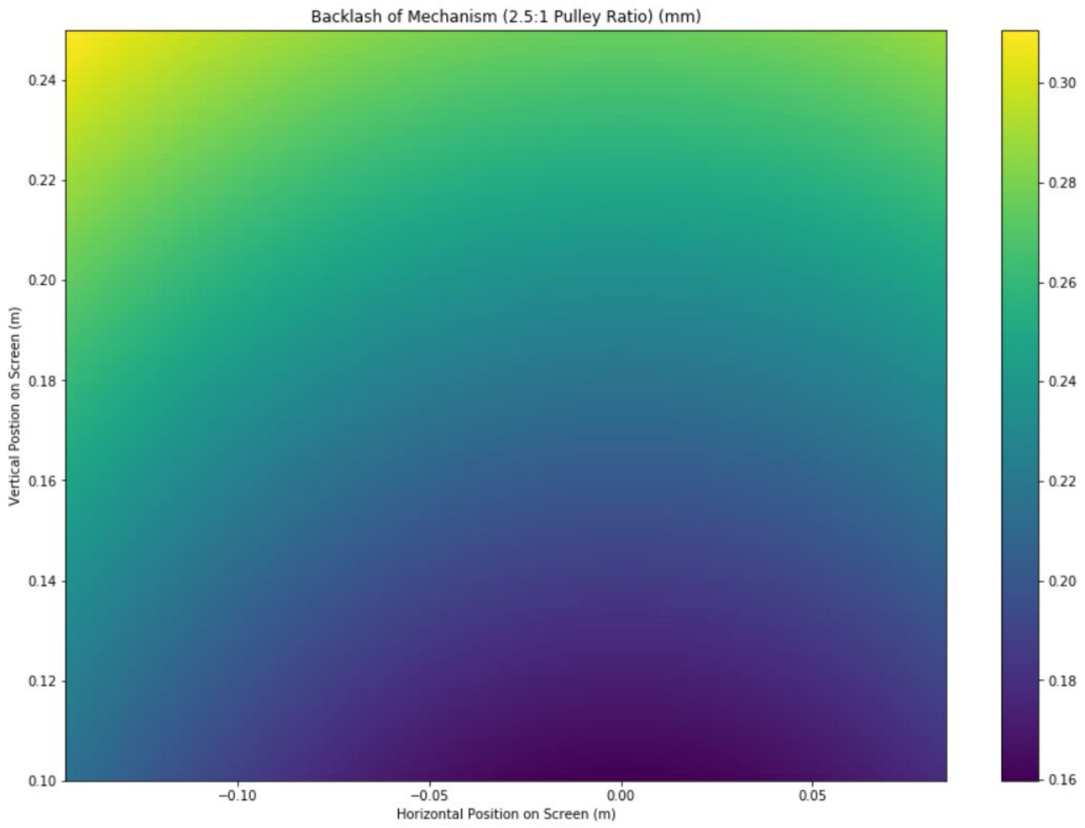
*For right linkage

Resolution Plot



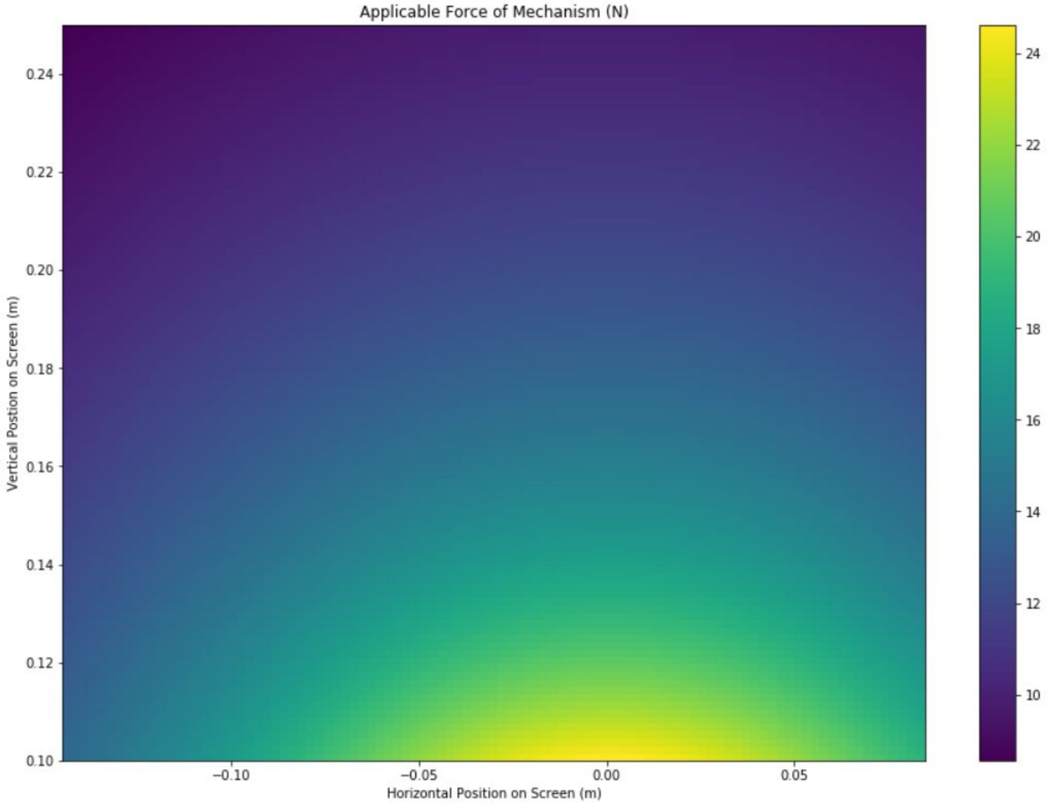
*For right linkage

Backlash Plot



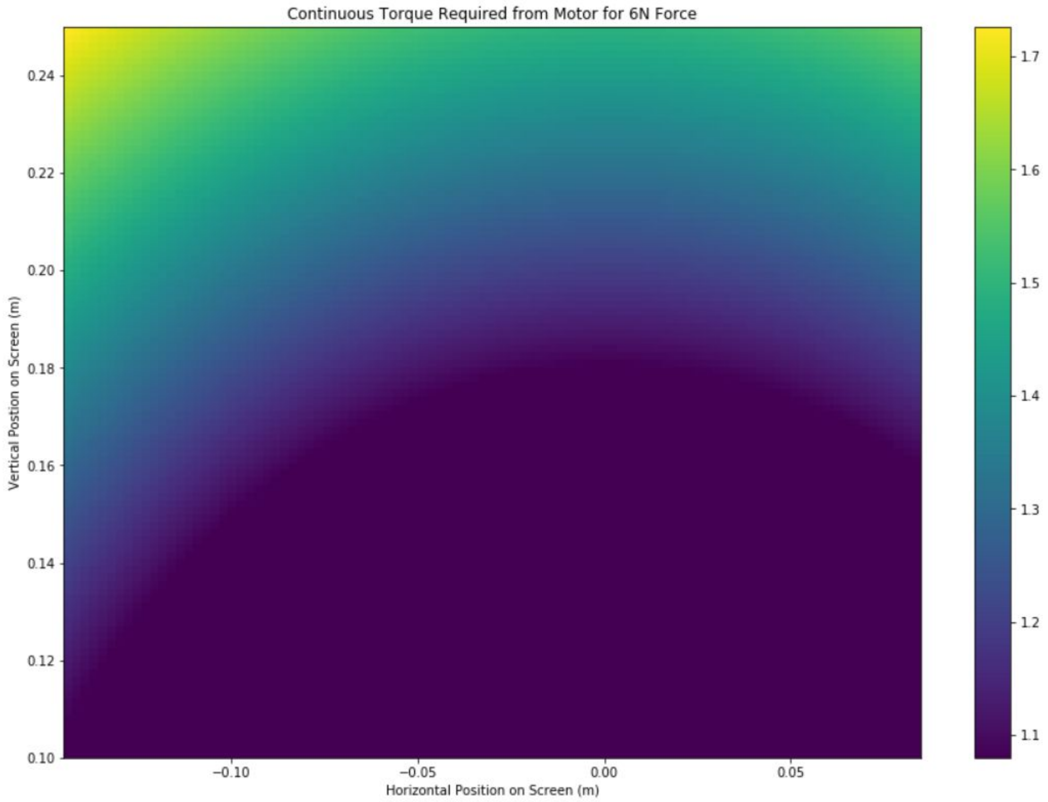
*For right linkage

Force Plot



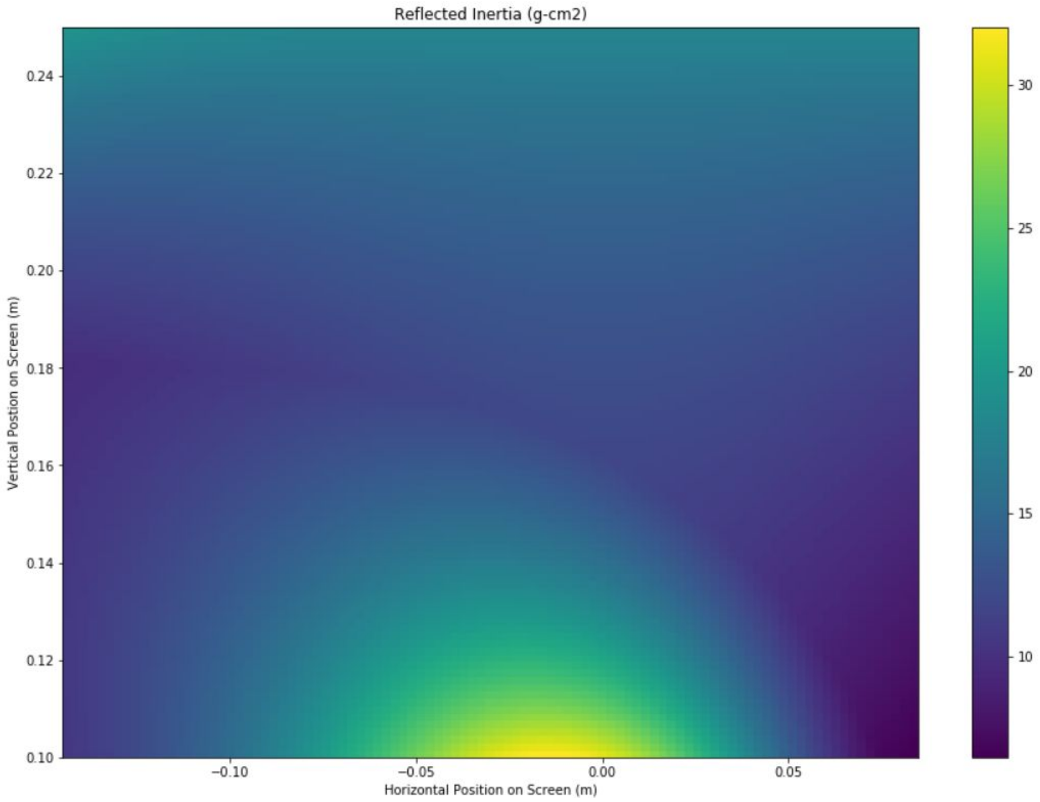
*For right linkage

Torque Plot



*For right linkage

Reflected Inertia Plot



*For right linkage

Documentation Map

1. Review of High-Level Goals

2. Design Overview

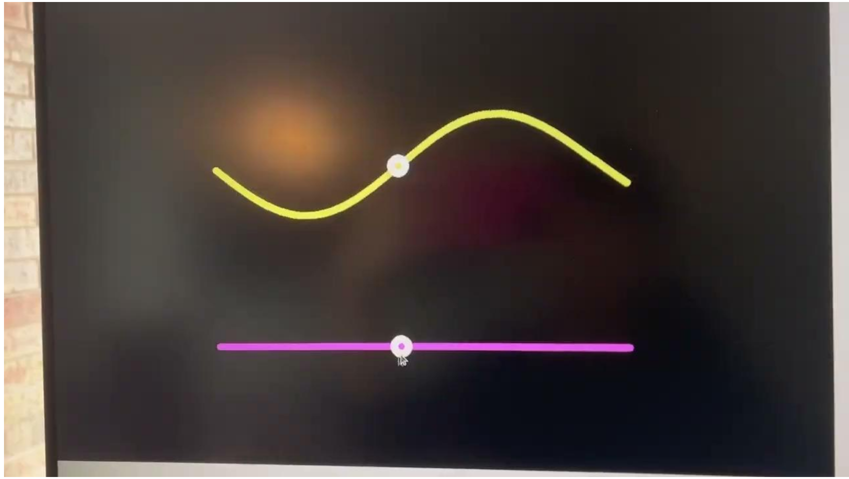
3. CAD

4. Key Supporting Analysis

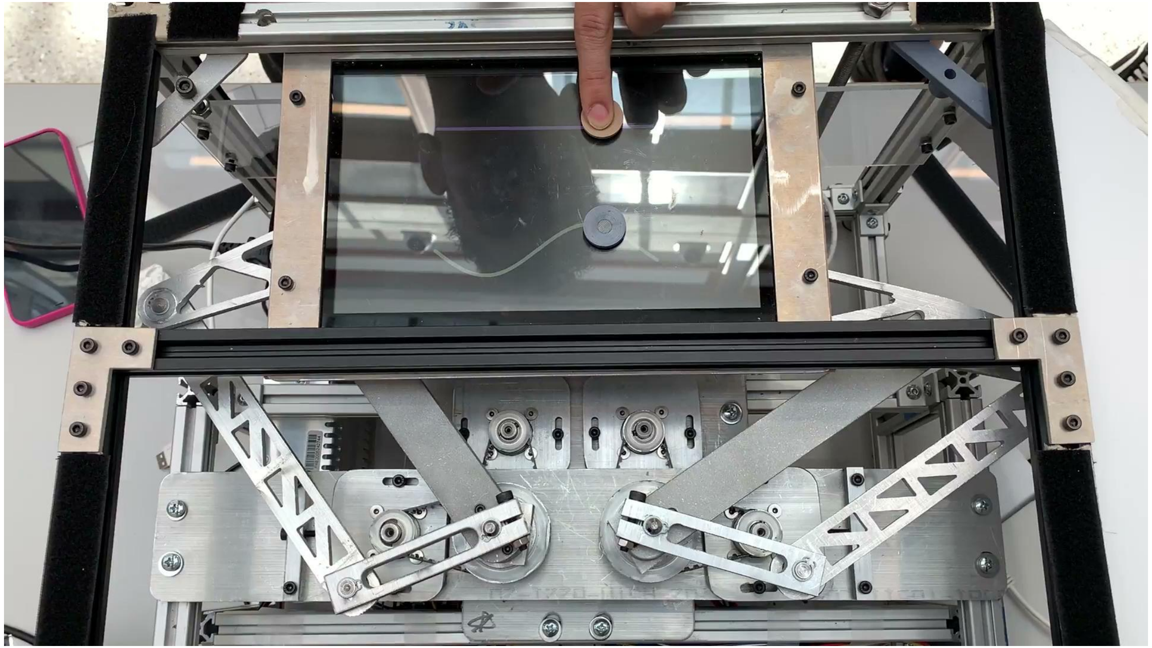
5. Demonstrations

Demo 1: Sensing Functions

Translating the concept of a function into an haptic experience for visual impaired individuals

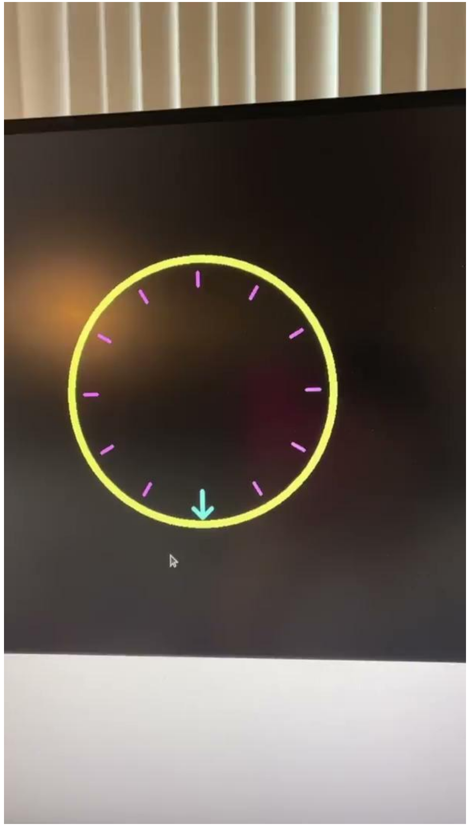


Demo 1: Sensing Functions



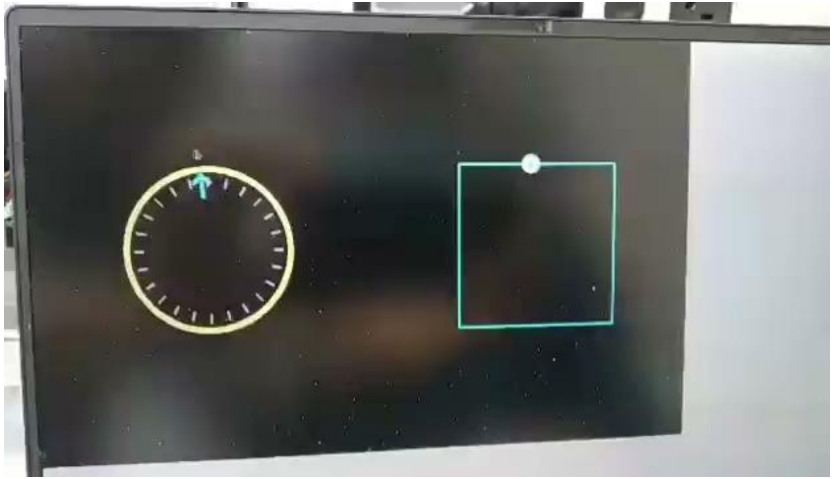
Demo 2: virtual knob

Creating the physical experience of knob on a digital screen



Demo 3: Knob + Shape sensing

Using a virtual knob to create the sensation of a shape



Other Demonstrations

Other demonstrations and videos can found in the google drive under:

RDS 2022 Student Access Folder/Tablet/Media

Link to GIT REPO

https://github.com/sjtuyuxuan/Tablet

Link to BOM

[RDS 2022 Student Access Folder/Tablet/Tablet BOM]

Link to User Guide

https://github.com/sjtuyuxuan/Tablet/tree/master/UserGuide

User Guide - Firmware

STM-32 Program (already flashed v2.0)

1. Install STM-32Cube IDE
2. From GItHub Link download project (v3.0)
3. Flash it into the Micro-controller

Raspberry Pi Gui

1. From GItHub Link download (gui.py for v2.0 STM-32 firmware, gui_v3.0.py for v3.0 STM-32 firmware)

Odrive

1. Firmware is already setup.

User Guide - Software

Raspberry Pi Gui code

1. Run python3 gui.py or python3 gui_v3.0.py in terminal.
2. Direct test with finger touch on the screen whether the code is working well.

STM-32

The user button is broken, so only the reset button is on the broad. We will use it for later calibration.

Odrive

Every time we restart the power of Odrive or one motor is out of control because of collision or other reasons, we need to redo the calibration sequence provide by odrive.

Note that the arm will move CCW for about 60-70 degree. PLEASE reserve enough space or the calibration sequence will not run successfully.

User Guide - Demos

Finish testing the Firmware and Software. Follow the guides below:

1. OPEN the Gui on Raspberry Pi with *Demo 1* scenario **AND touch the mouse(touch point) to the left up corner (from arm perspective).**
2. Connect the odrive with USB cable to PC and use python interface to do the calibration sequence for two motor. **Repeat for TWO arms (4 calibrate sequence)**

   i.
   ```
   import odrive
   from odrive.enums import *

   print("finding an odrive...")
   my_drive = odrive.find_any()
   ```

   ii.
   ```
   my_drive.axis0.requested_state = AXIS_STATE_FULL_CALIBRATION_SEQUENCE
   # wait for big-arm calibrate seq
   ```

   iii.
   ```
   my_drive.axis1.requested_state = AXIS_STATE_FULL_CALIBRATION_SEQUENCE
   # wait for fore-arm calibrate seq
   ```

User Guide - Demos cont

3. Let the left arm bottom magnet outside and right ram bottom magnet embedded.
4. Drag the arm to the calibrate anchor point.
    i. Left arm : Match the center point for the hole on the frame work and the hole used to insert the magnet. (We need more accurate for active arm so take off the magnet will help enhance the accuracy)
    ii. Right arm : Match the center point for the hole on the frame work and the center of button magnet.
5. Push the Reset button on STM-32. Wait for 10 second, until the arm move.
6. You will have 10 second to let left arm magnet into the hole
7. Demo is working!

User Guide - Demos cont

8. Using 'a'/'s'/'d' on keyboard to switch the demo

   i. ‘a' for Demo 1

   Ii. 's' for Demo 2

   Iii. 'd' for Demo 3 (only support on v3.0)

   Iv. 'esc' to quit the Demo

Note !!! switch from Demo 2 to Demo 1 need ensure the left arm is on the left or top (if on the buttom will lead to crash _ you may need calibrate it again!)