ELEVATE

The Retrofittable Standing Desk Converter

MEAM Senior Design Day Presentation April 24, 2023

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standing desk

noun

a desk that can be used to work comfortably while sitting or standing

$9.5 billion market size by 2028
50% expected growth[1]

Improves posture
Reduces neck and shoulder pain
Improves vitality
Reduces stress[2,3]

Increases productivity[3]

[1] - Credence Research | [2] - Autonomous | [3] - Ma, Ma, Li, and Kim (2021)

The Problem

The Full Standing Desk

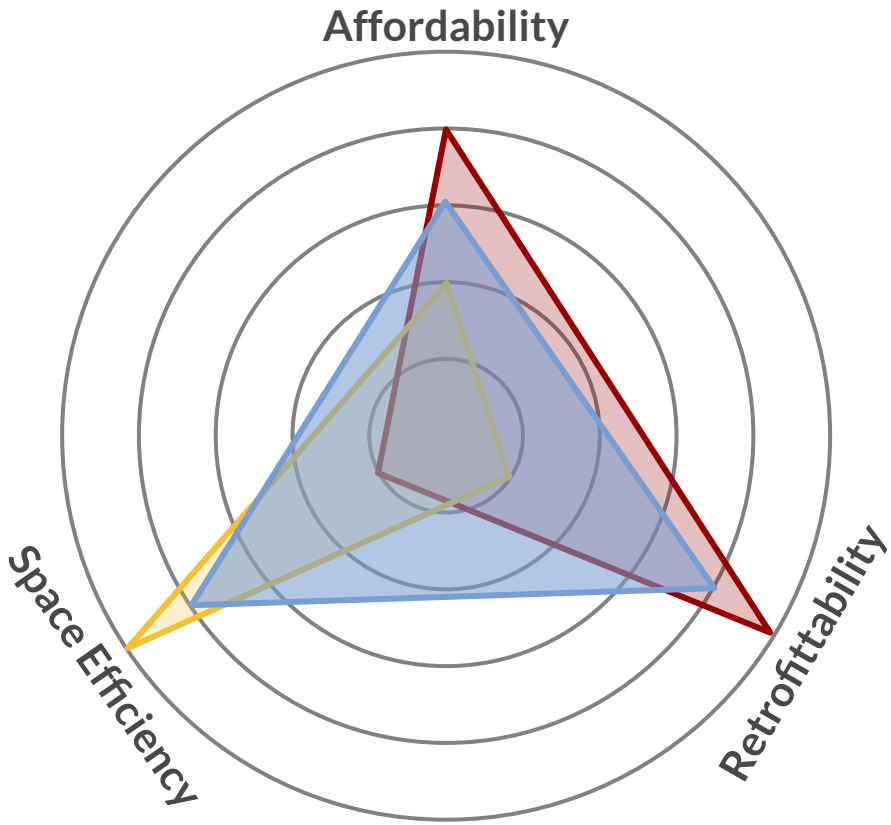
The Standing Desk Converter

Expensive

Lack of Portability

Space Inefficient

Competition Comparison



ELEVATE

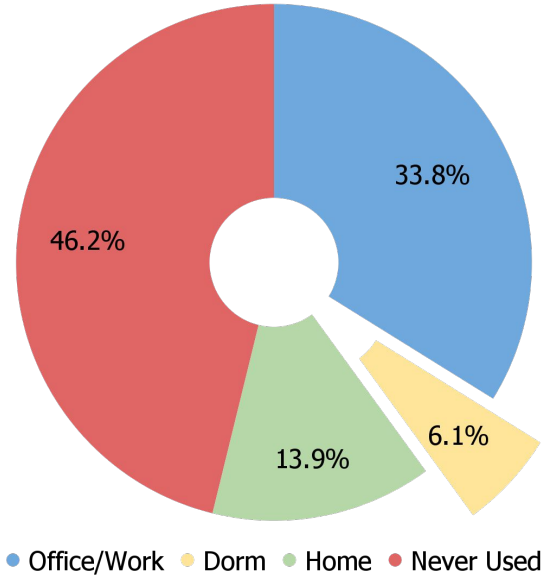
Our Advantage

	ELEVATE		
Volume (in^3)	20” x 22” x 10” *	36.6” x 23.1” x 6.25”[5]	72” x 30” x 25.5”[4]
Weight (lb)	30	43.5[5]	50[4]
Space Efficient	Yes	No	Yes
Retrofittable	Yes	Yes	No
Easy to Install	Yes	Yes	No
Cost ($)	250	300[5]	889[4]

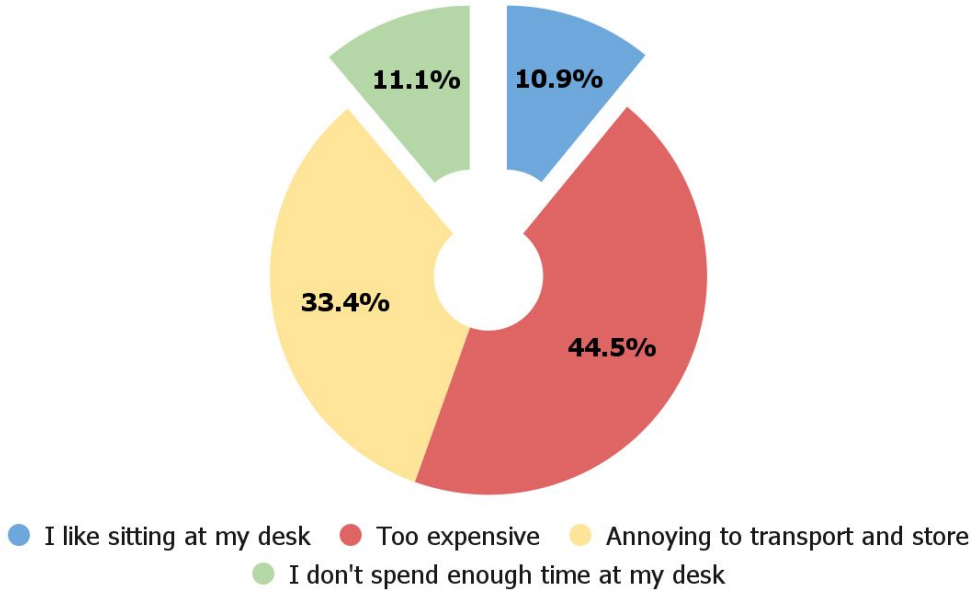
[4] - Herman Miller | [5] - WorkWhileWalking.com | * Dimensions of four units side by side

Potential Markets

Where College Students Have Used Standing Desks



Reasons College Students Don't Have Standing Desks



System Characteristics

FUNCTIONAL
300lb at ½” / sec
1.5’ adjustability

AFFORDABLE
< $300

RELIABLE
Load cycling
IP62 rating
UL consumer product ratings

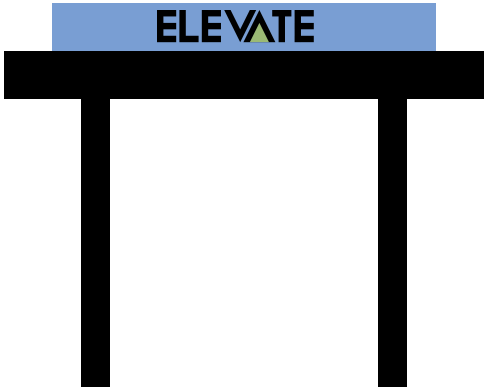
USER-FRIENDLY
< 40 lbs
Space efficient
Intuitive to install

UNIVERSAL
Works for majority of desks

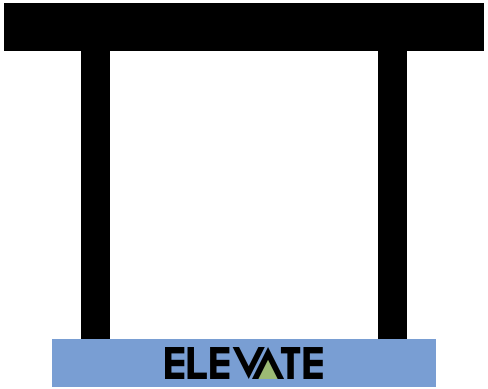
SAFE
No backdriving
Rigid
Stable

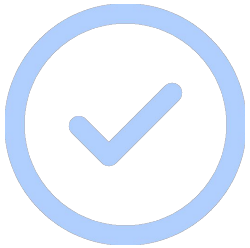
Concept Selection

On Desk

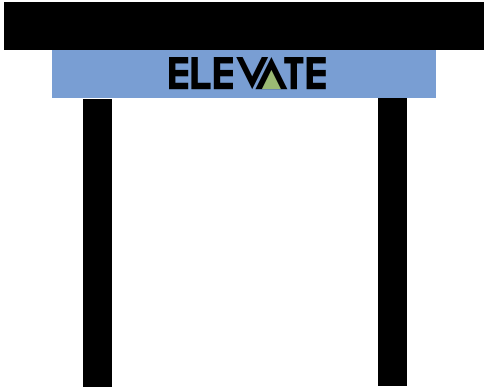


Under Legs



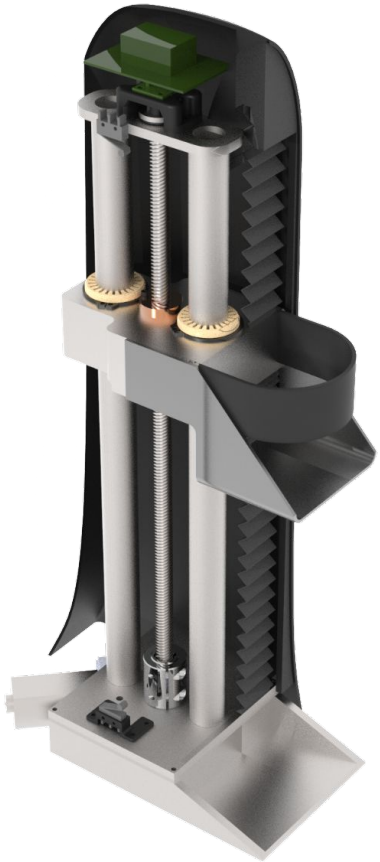


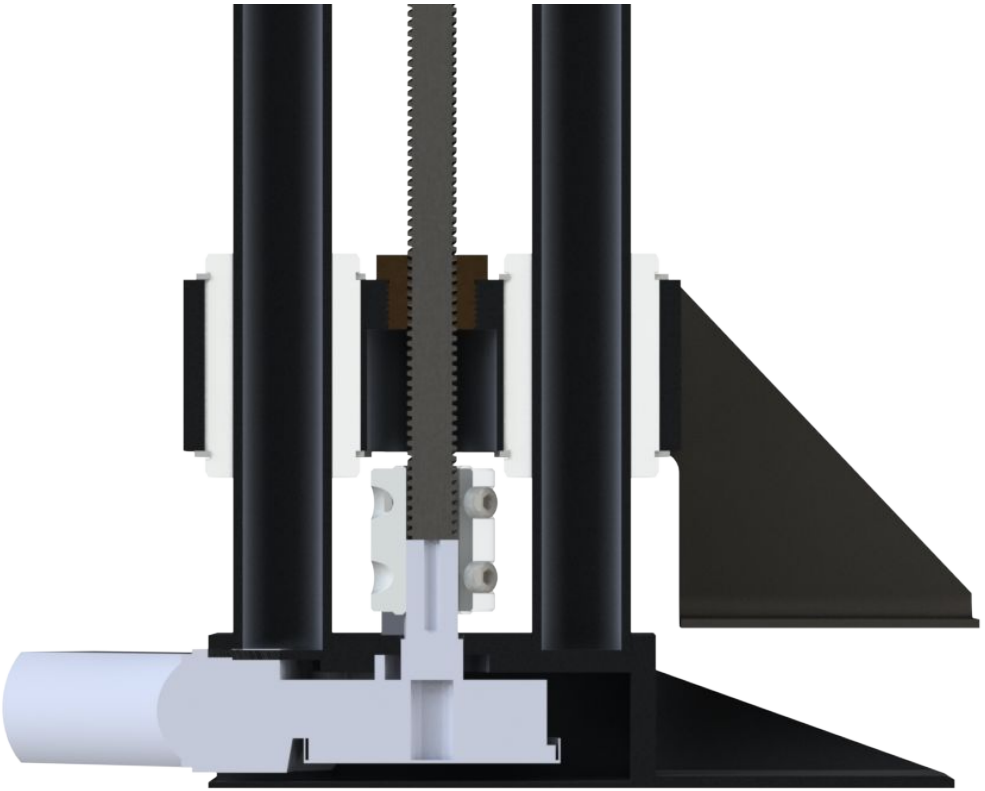
Under Desk



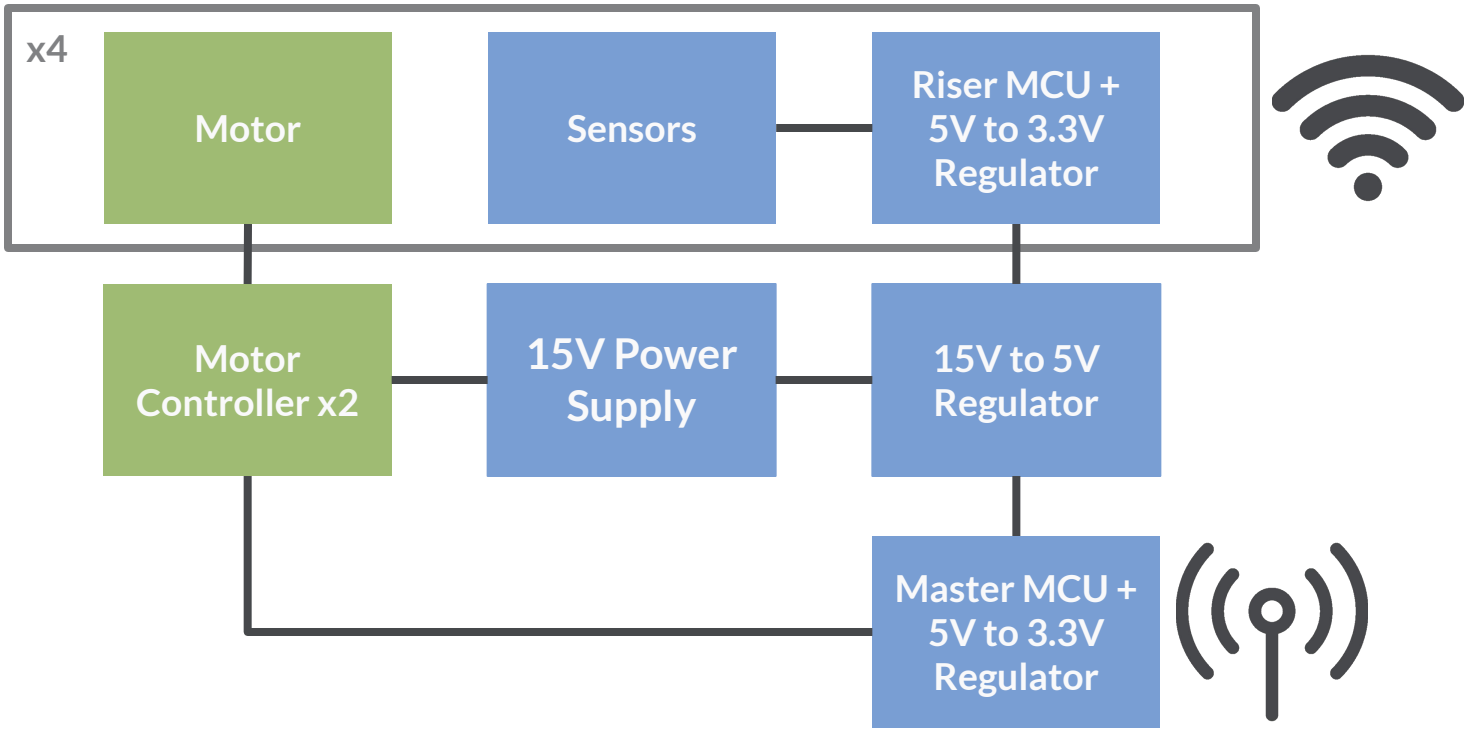
Final System Form

Riser Cross-Sections

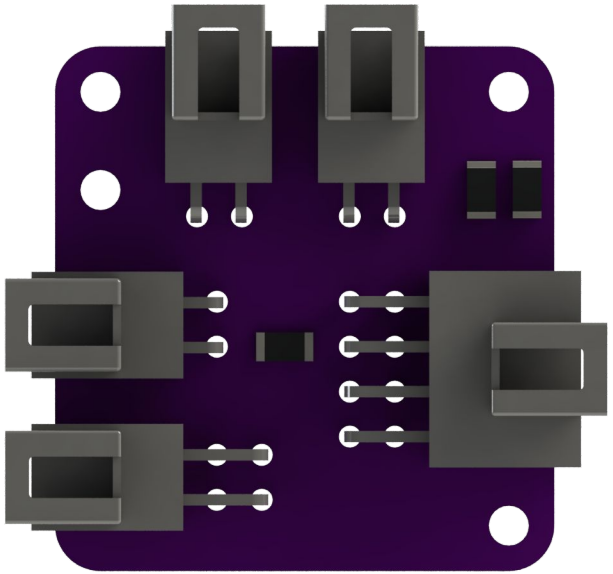




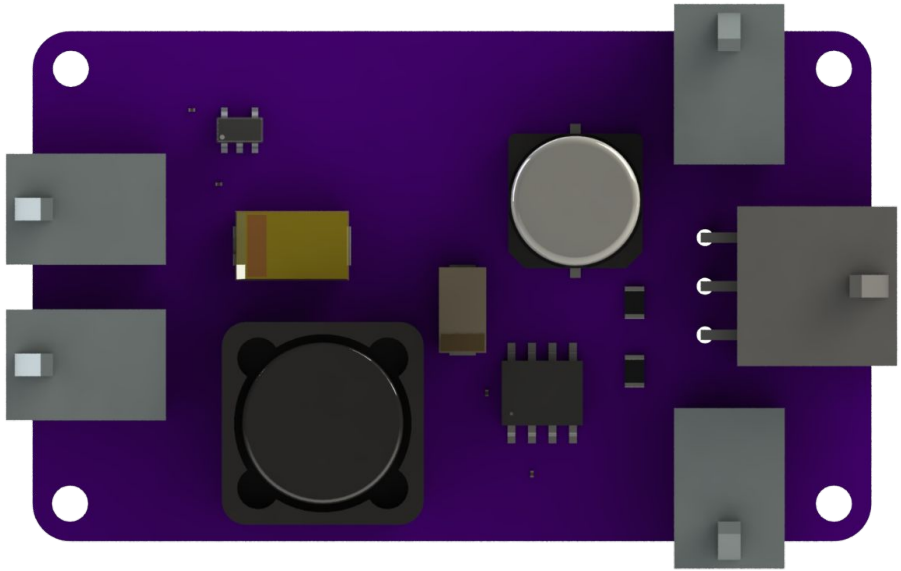
Electrical Architecture



Custom Boards

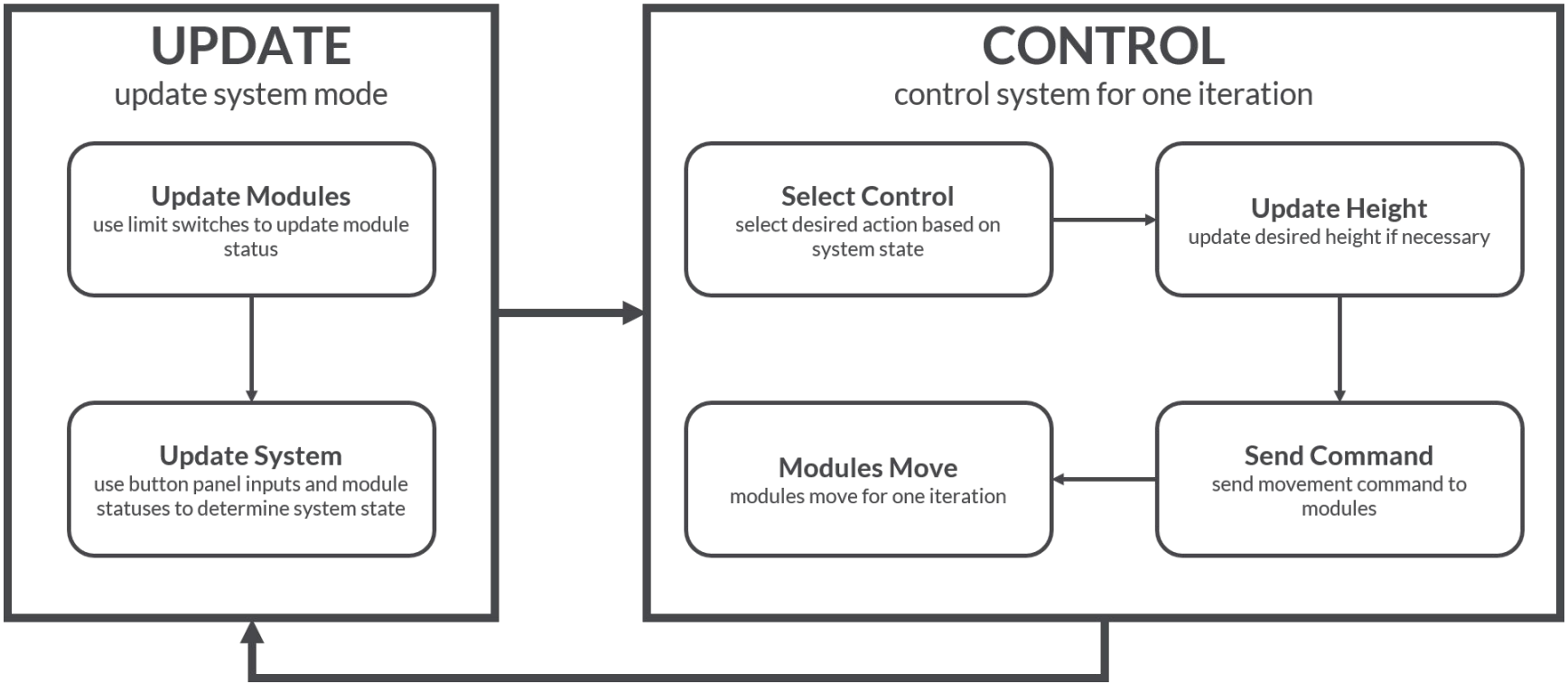


Module Board

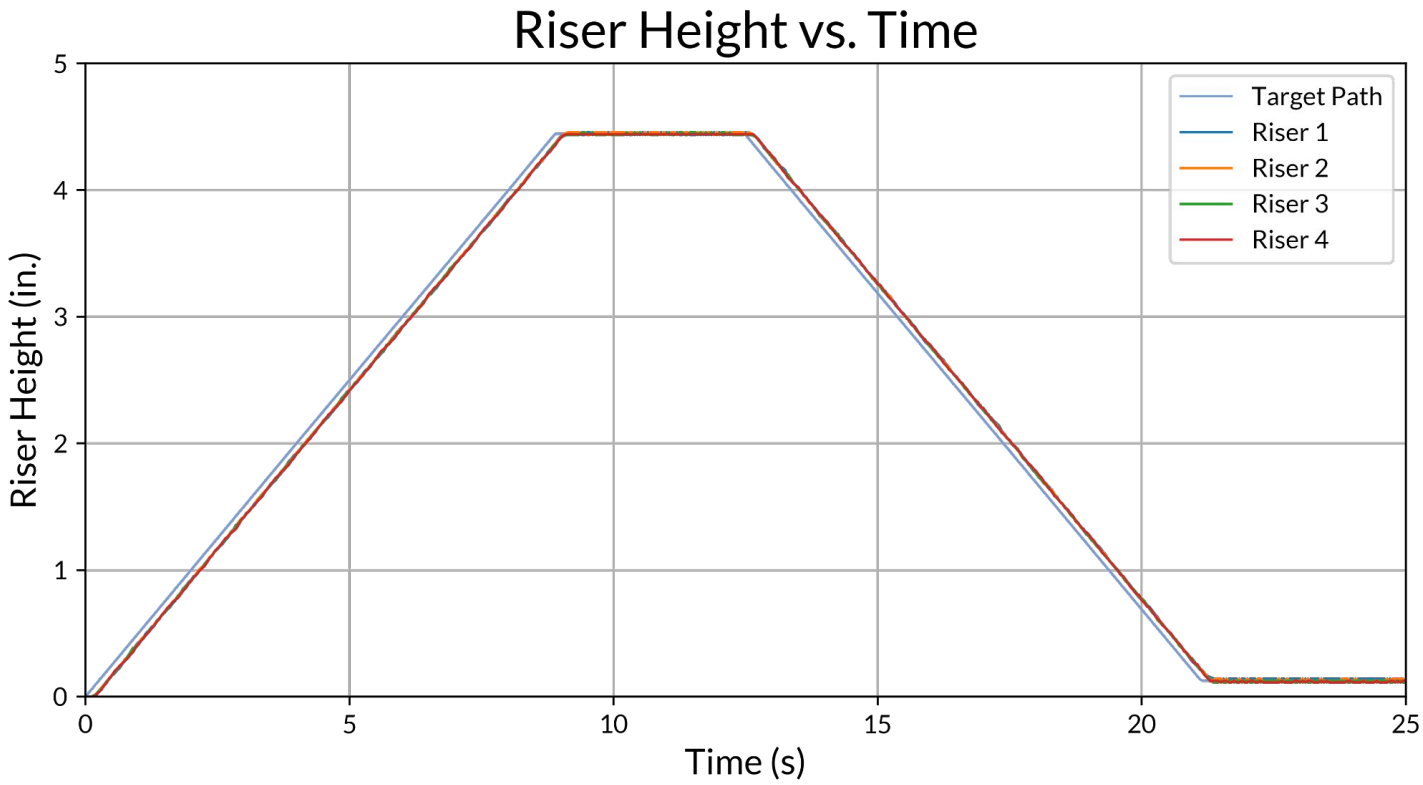


Power Distribution Board

Software Control Scheme



Control Validation



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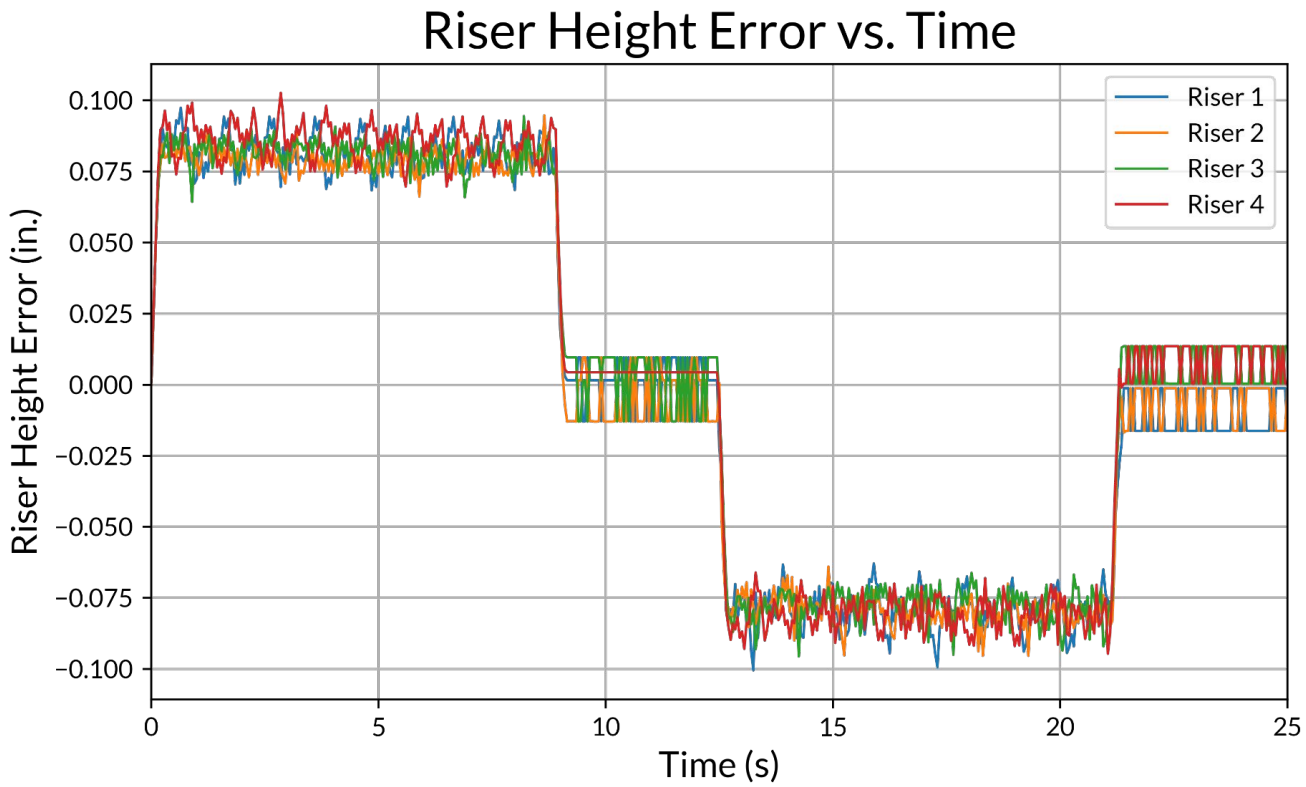

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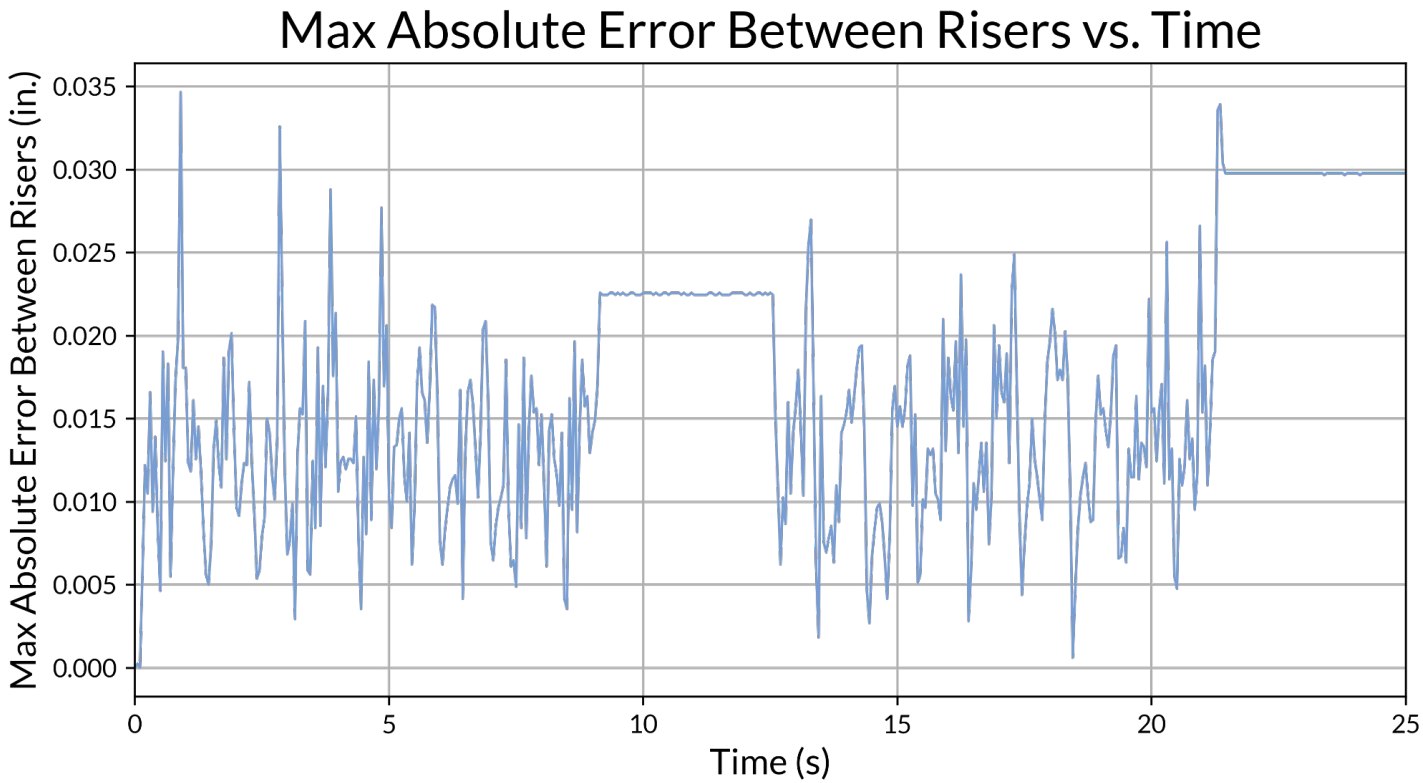

Testing and Validation

Founders

Darrion Chen

Design & Manufacturing

MEAM

Jonathan Lee

Electrical & Software

MEAM & ROBO

Griffin Addison

Design & Prototyping

MEAM & ROBO

Advisors

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Electrical Engineering Consultant

Thank you all for your support!

References

Slide 2

1. Credence Research, “Standing desks market by product type (fixed standing desk, mechanically adjusted desk, electrically adjusted desk, converter standing desk) by end use (household, commercial) by distribution channel (Online by type (standard (fixed) standing desks, mechanical adjustable standing desks, electrically adjustable standing desk, converter standing desk), by application (corporate office, education, residential, healthcare, manufacturing) - growth, future prospects and competitive analysis 2016 – 2028,” *Market Research Reports*. [Online]. Available: https://www.credenceresearch.com/report/standing-desks-market. [Accessed: 25-Feb-2023].
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Slide 5

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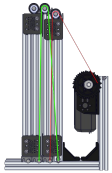
Cost Breakdown

Component(s)	Prototype Cost [$]	Mass Production Cost [$]
Motors	76	45
Encoders	15	12
Custom PCBs	150	20
Lead Screw Components	50	25
Metal stock	0	5[1]
Machining	0	10[2]
PCB assembly	0	30
Total Price	**291**	147

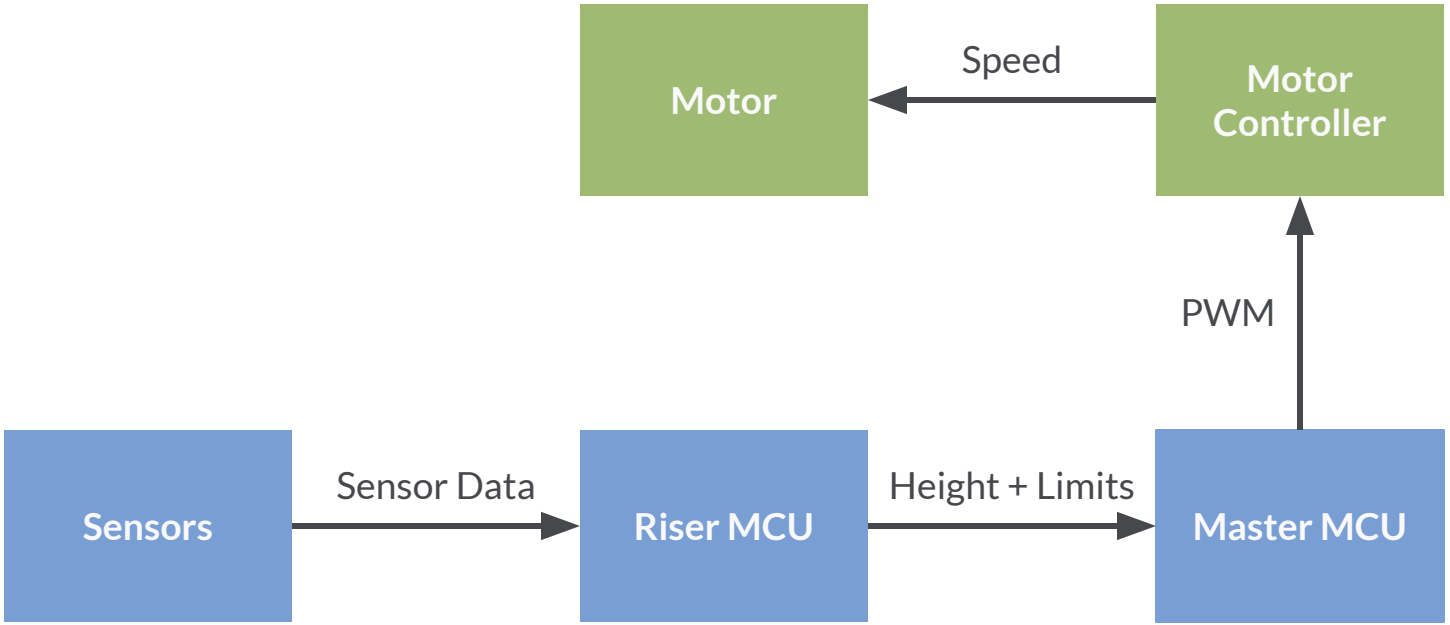
[1] - Business Insider | [2] - WARDJet | [5] - Fully

Linear Actuator Selection

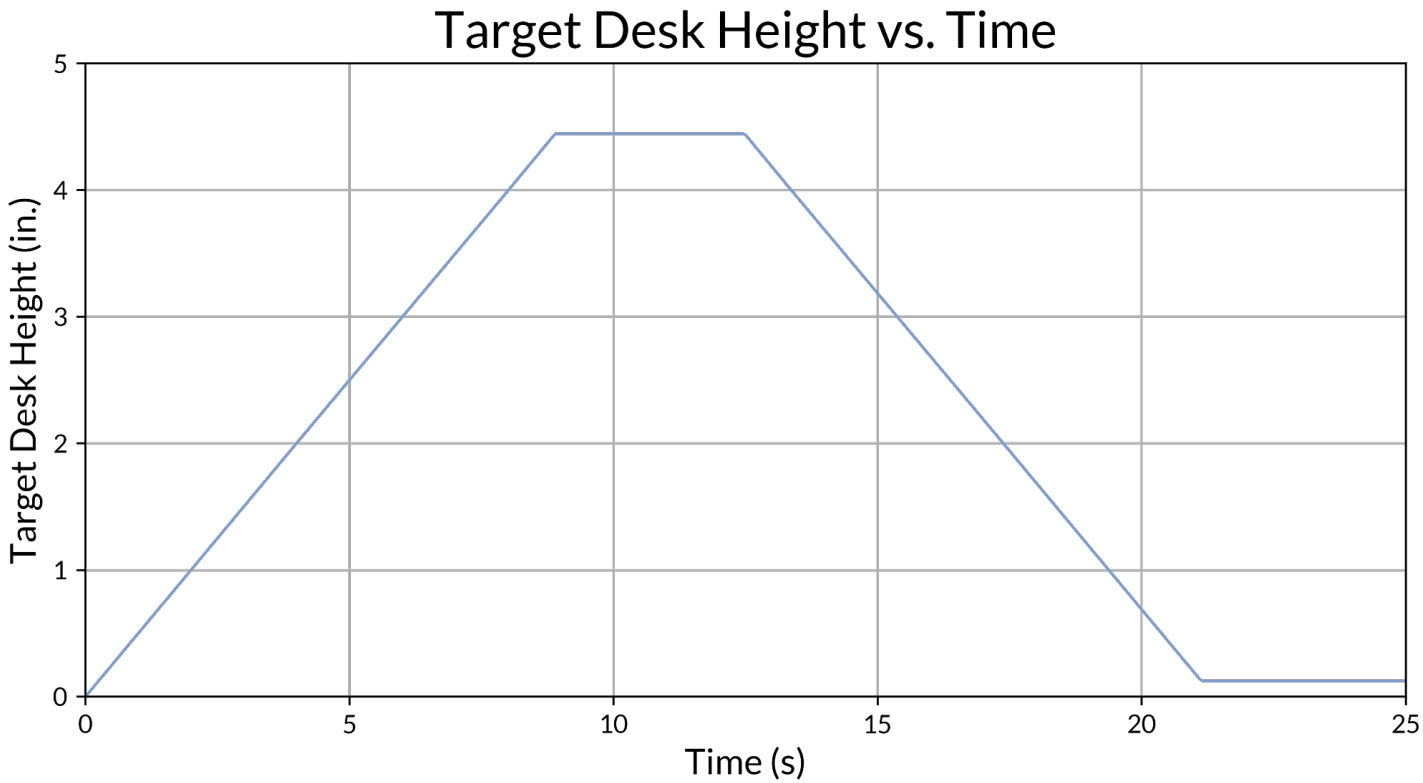
	Hydraulics / Pneumatics	Cascade Lift	Rack and Pinion	Scissor Lift	Lead Screw
					
Simple	High component count[6]	Low component count	Moving motor	High component count	Least component count
Reliable	Leaks	Cable tangles	Load on teeth	Low torsional stiffness	Minimal maintenance
Safe	Pressurized	Backlash	Not backdrivable	Not backdrivable	Not backdrivable
Affordable	High cost of components	$260[7]	$60[8]	Uses a lead screw	$15[9]

[6] - Satyendra | [7] - WestCoast Products | [8] - McMaster | [9] - McMaster

Data Flow


Motor
Speed
Motor Controller
PWM
Sensors
Sensor Data
Riser MCU
Height + Limits
Master MCU

Control Validation



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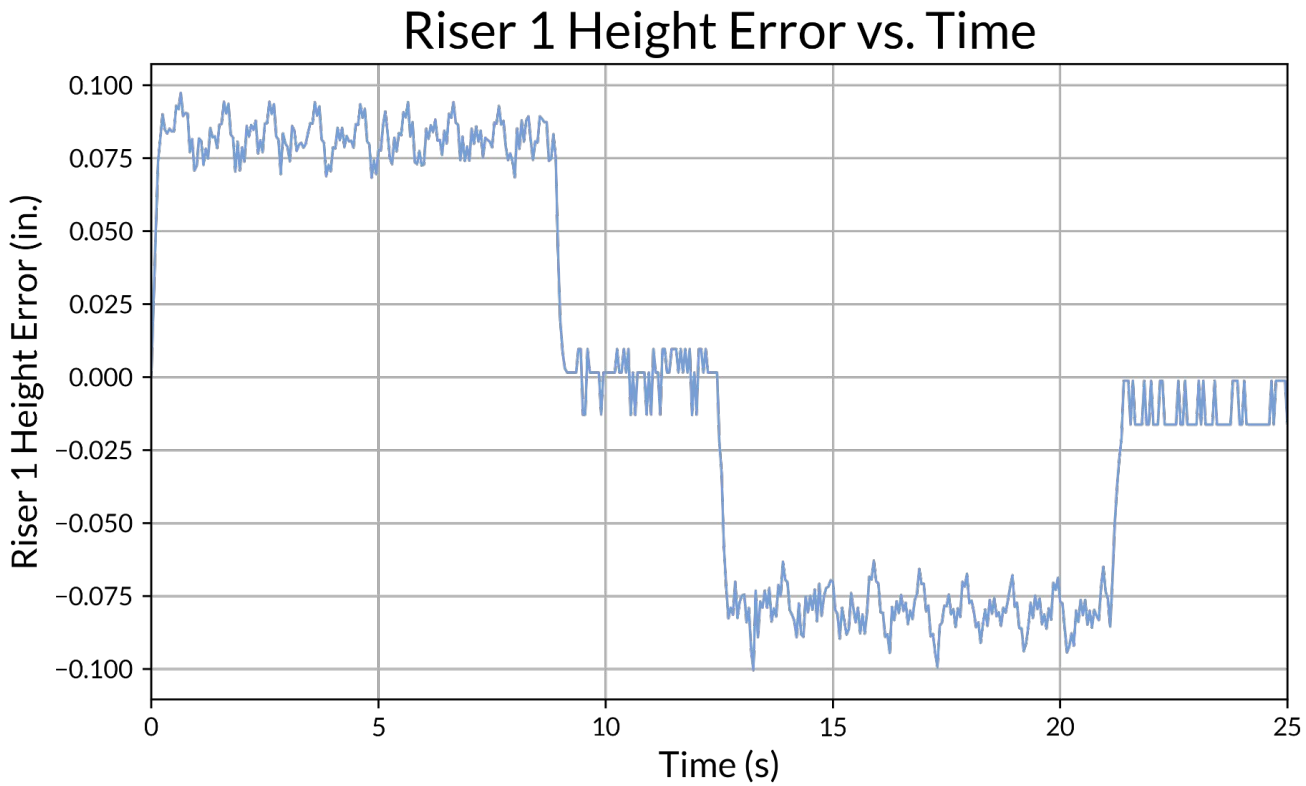

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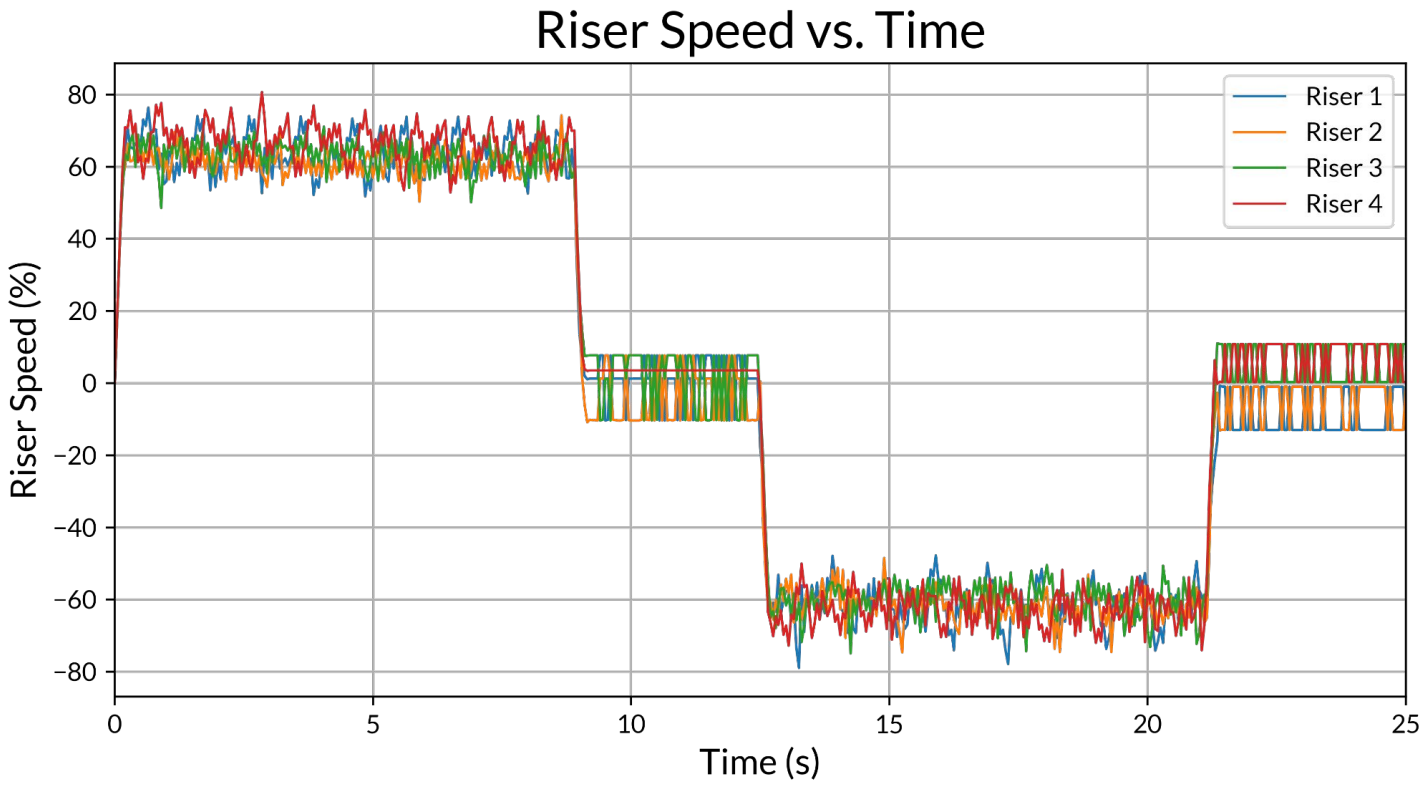
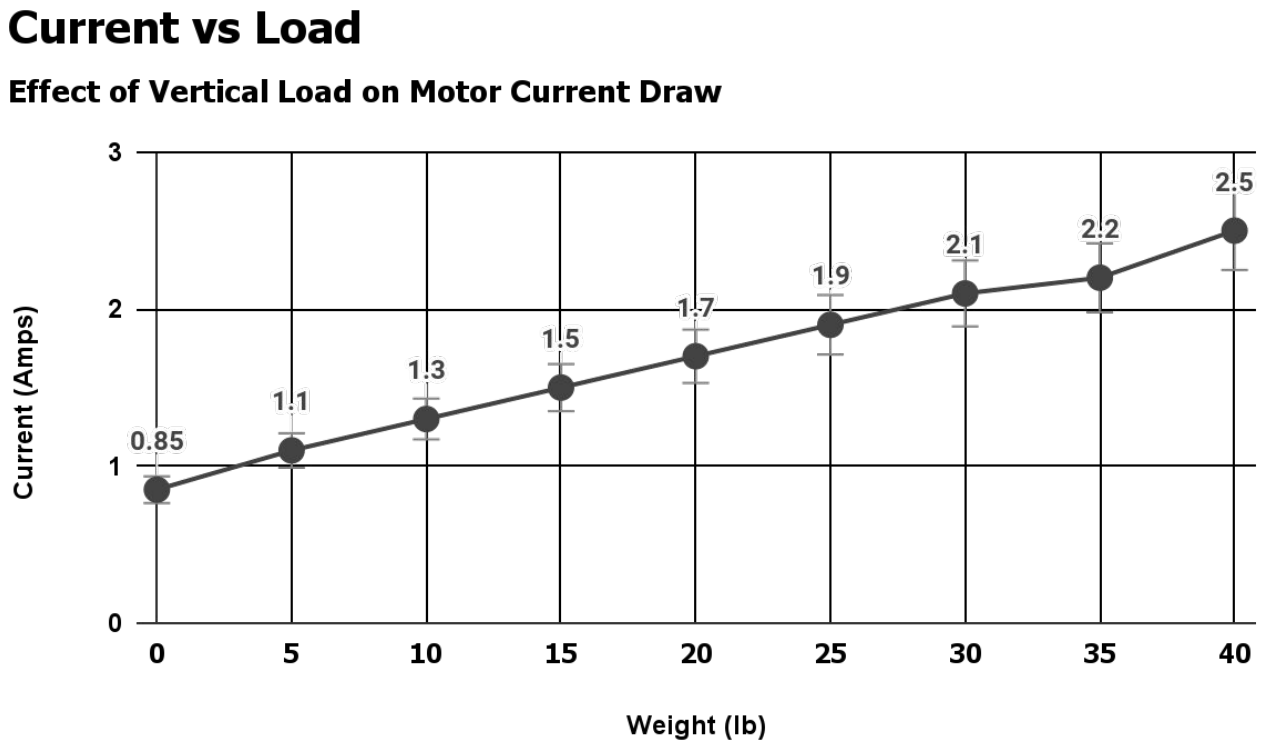


Testing and Validation



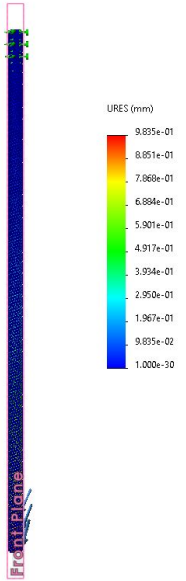
Full Standing Desk Cost Breakdown

Item	Units	Dimensions	Purpose	Total Cost
Bamboo Wood Sheet	1	36" x 24", 6 square feet	Table Top	$99.99
30W Electric Motor	2	N/A	Lifting Mechanism	$48.12
12V Power Supply	1	N/A	Power	$12.99
Square Steel Tube	4'	2.5", 0.083" Thick	Outer Telescoping Leg	$71.24
Square Steel Tube	4'	2", 0.065" Thick	Inner Telescoping Leg	$22.52
Steel Sheet	2' x 2'	0.135" Thick	Bracket Pieces	$47.20
Square Steel Tube	6'	0.75", 0.083" Thick	Frame	$15.58
Motor Controller	1	N/A	Lifting Mechanism	$20.79
Microcontroller	1	N/A	Control Panel	$9.95
Tactile Switch	6	N/A	Control Panel	$3.48
Steel Sheet	2' x 2'	0.135" Thick	Feet	$47.20
Stainless Steel Lead Screw	4'	1/2" Diameter	Lifting Mechanism	$71.16
Worm Gear	2	N/A	Lifting Mechanism	$29.76
Metal Housing	2	N/A	Lifting Mechanism	$30
Plastics & Miscellaneous	1	N/A	Miscellaneous	$40
Total				$569.98
Profit Margin				$80.02

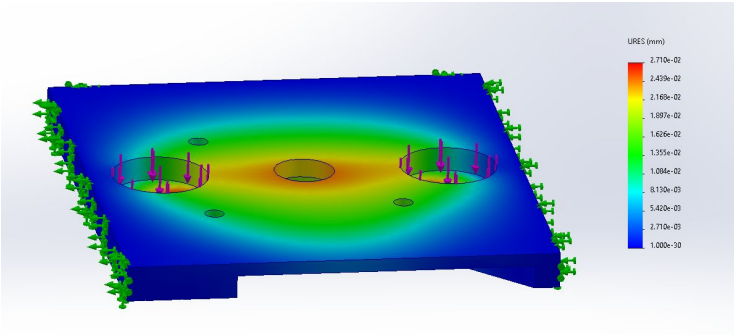
Linear Actuation Mechanism Selection

	Lead Screw	Hydraulics	Pneumatics	Rack and Pinion	Scissor Lift	Cascade Lift
Cost	✅	❌	❌	✅	❌	✅
Reliability	✅	❌	❌	❌	✅	❌
Complexity	✅	❌	❌	✅	❌	❌
Resolution	✅	❌	❌	✅	✅	✅
Packaging	✅	❌	❌	❌	❌	✅
Safety	✅	❌	❌	❌	✅	❌

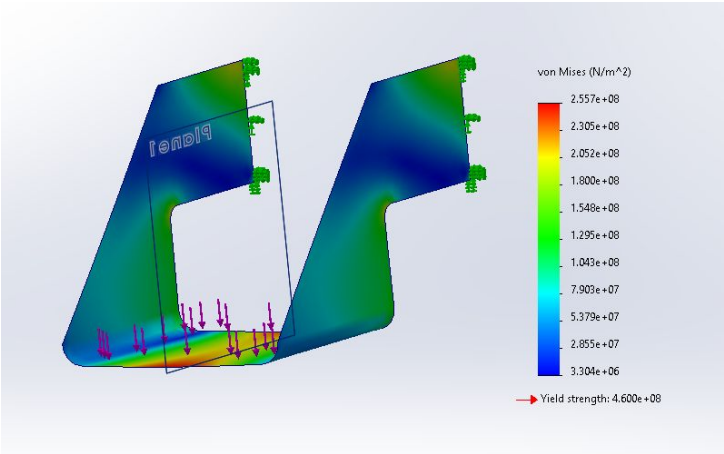
Finite Element Analysis



Lead Screw
Stiffness-limited part



Baseplate
Stiffness-limited part



Leg Holder
Strength-limited part

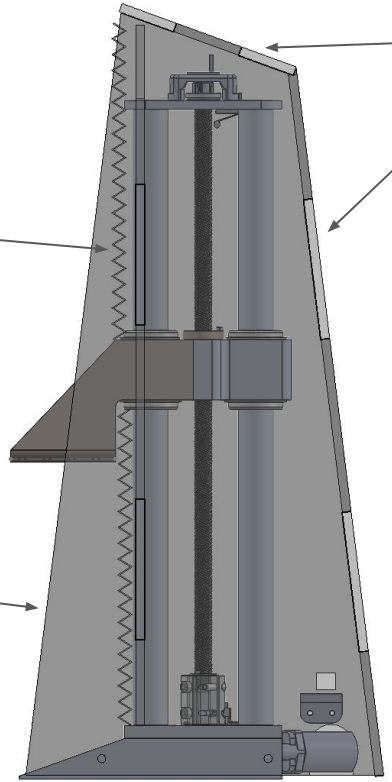
Load about ½ of yield strength. Fatigue not a worry

Enclosure

Slanted Exterior
(prevents stepping, deflects debris)

Custom Bellow
(3D printed TPU)

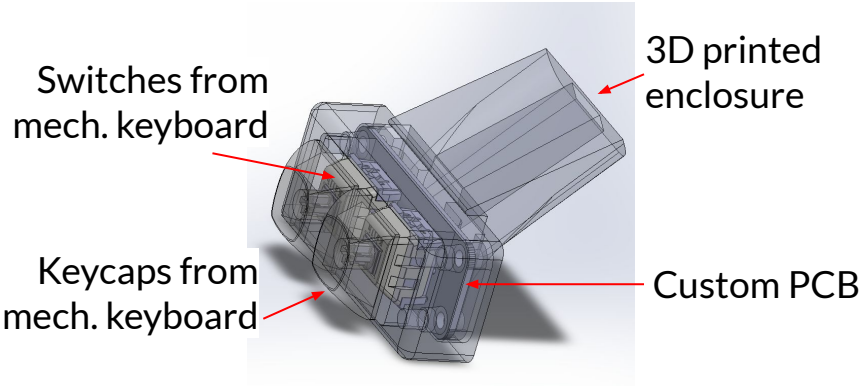
½” Acrylic Panels
(laser cut, acrylic solvent)



Peripherals

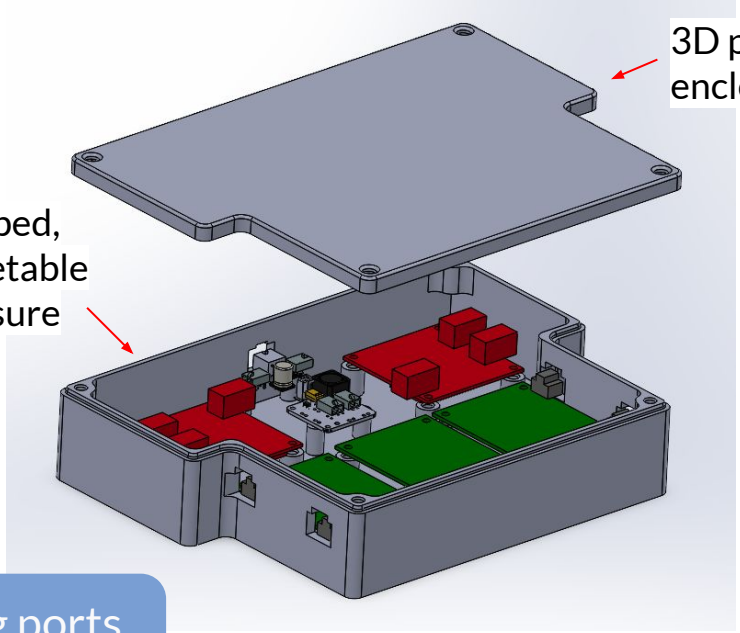
Control Panel

button controls | mounted on desk



Board Box

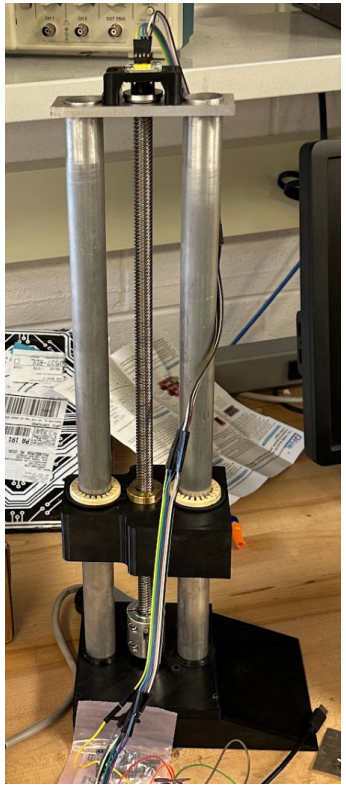
houses main boards | mounted under desktop



Log ports for cables

Lift Prototype

3D Print Prototype



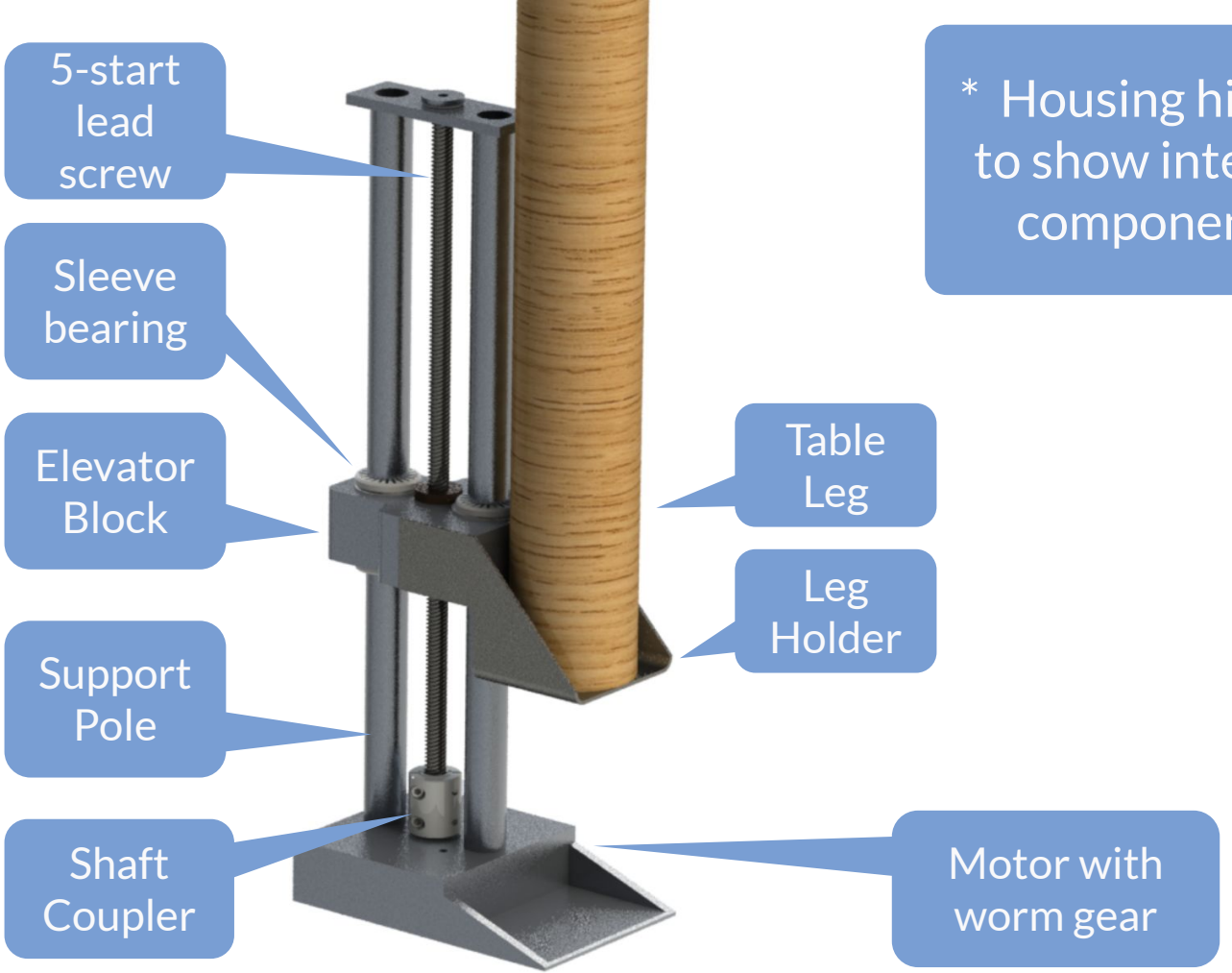
Learnings:

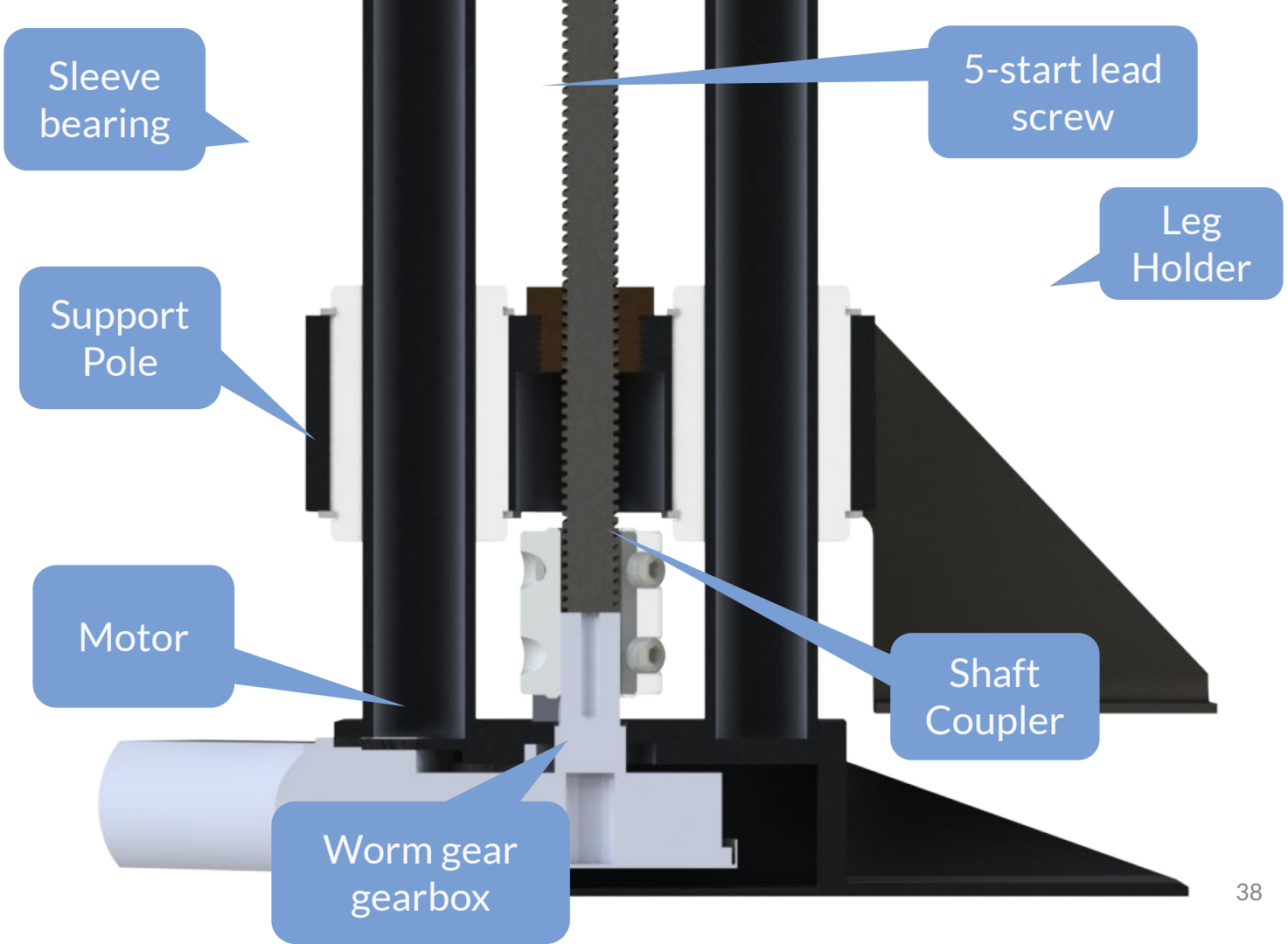
- Lift system, electronics, software worked
- Bad 3D print tolerances => high sliding friction
- Motor protruding from side was awkward packaging

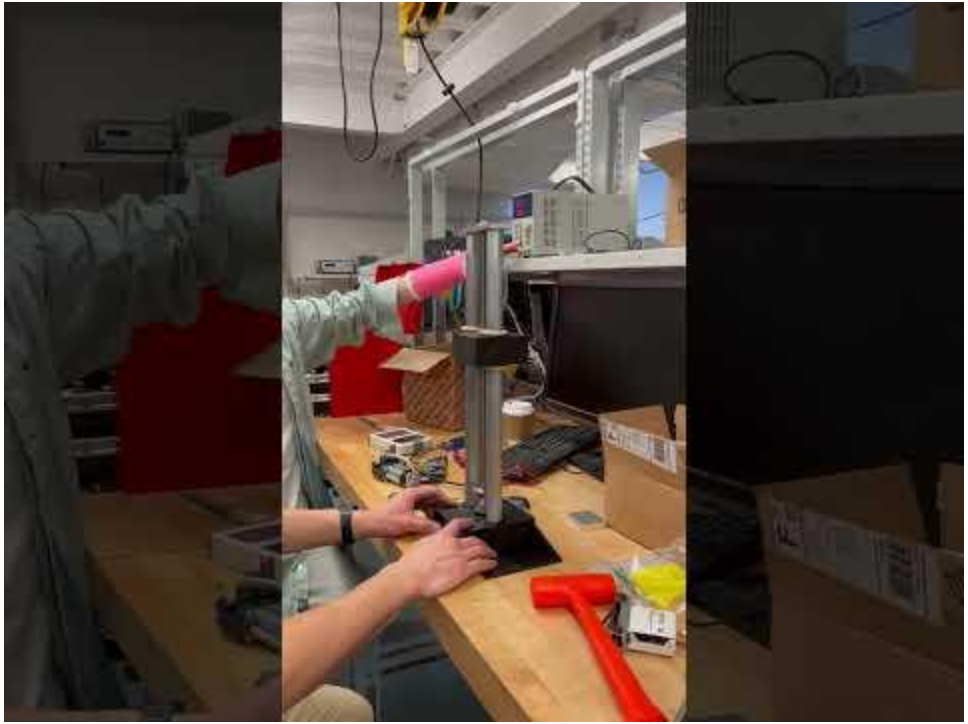
Aluminum Prototype

Learnings:

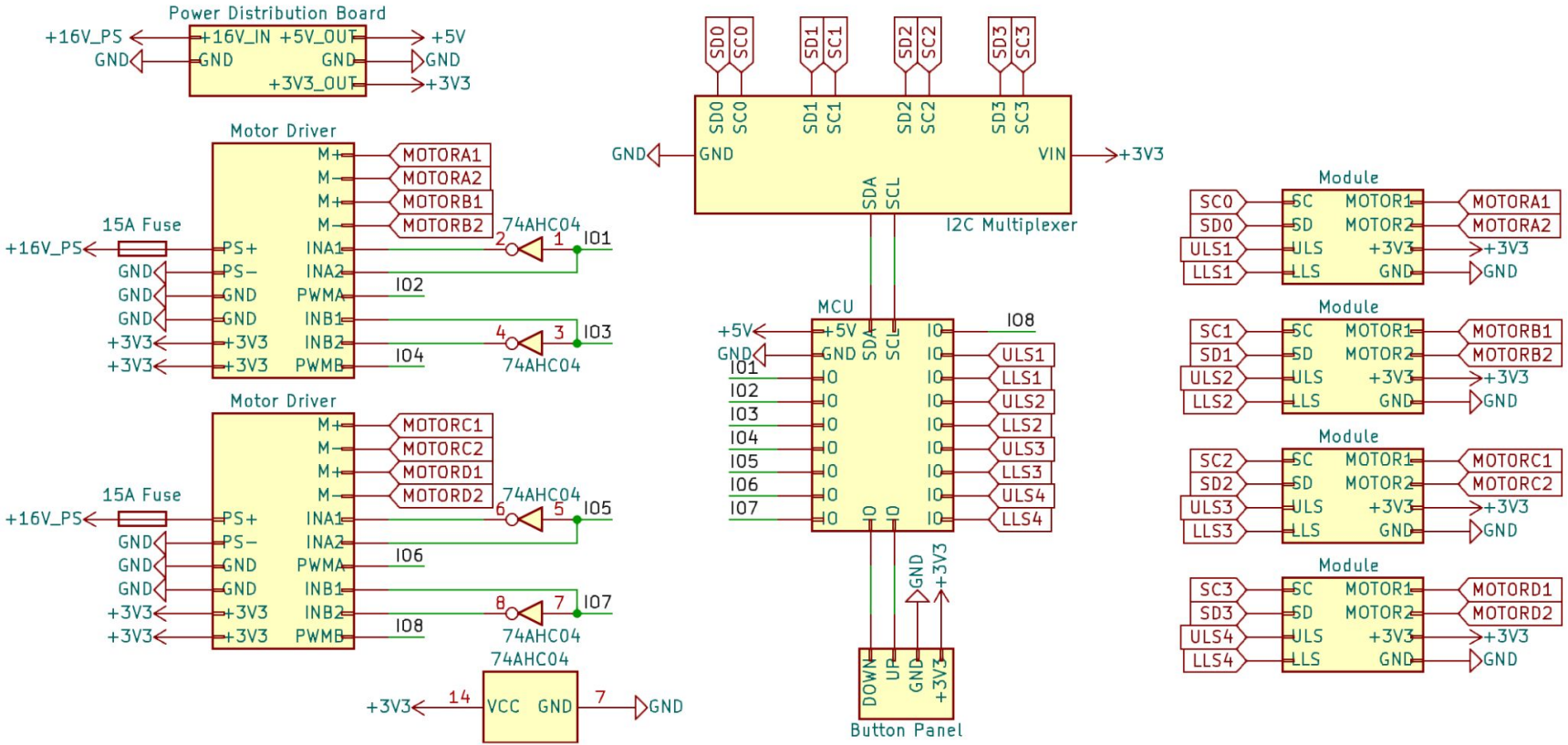
- Better tolerances => low friction!
- Long wires => more noise
- Very strong (watch your fingers)


5-start lead screw
Sleeve bearing
Elevator Block
Support Pole
Shaft Coupler
Table Leg
Leg Holder
Motor with worm gear
* Housing hidden to show internal components

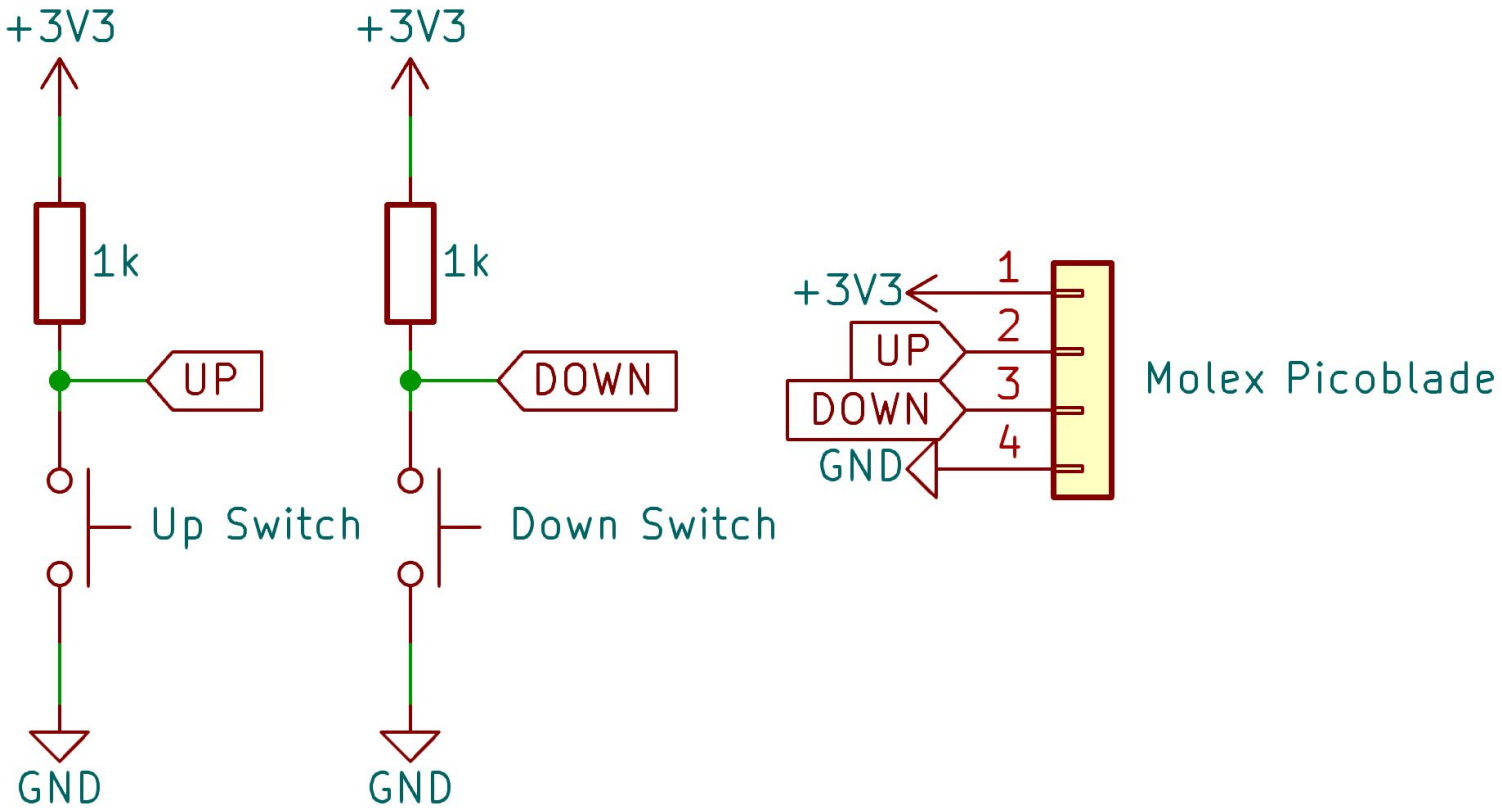

Sleeve bearing
5-start lead screw
Leg Holder
Support Pole
Motor
Shaft Coupler
Worm gear gearbox



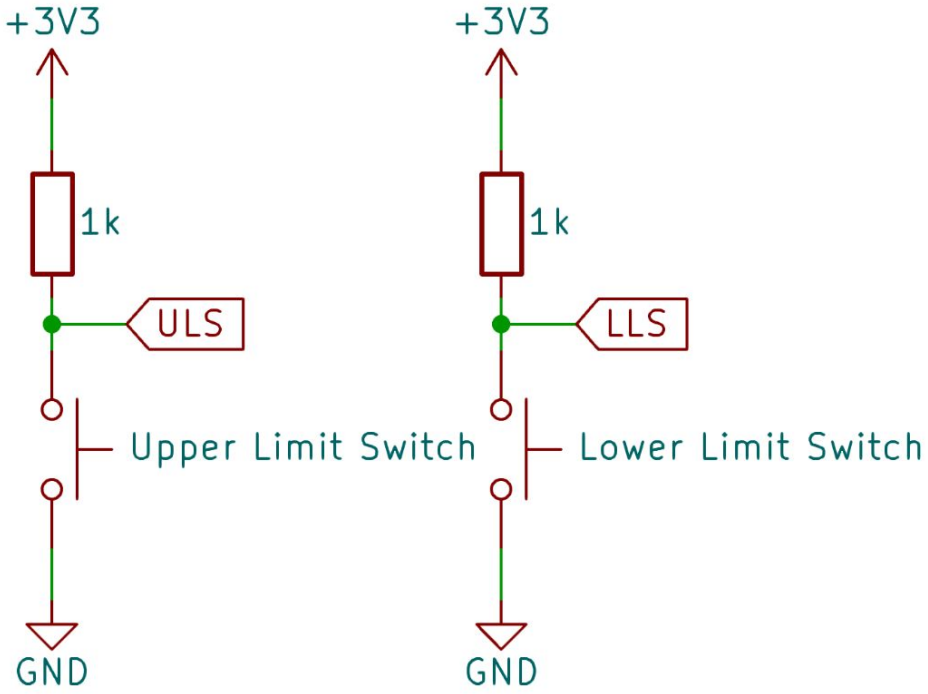
Electrical Architecture

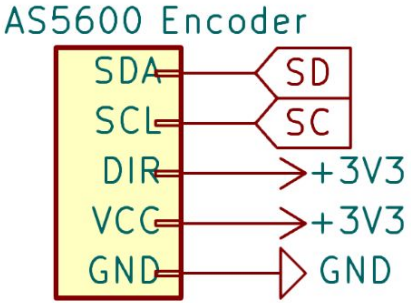


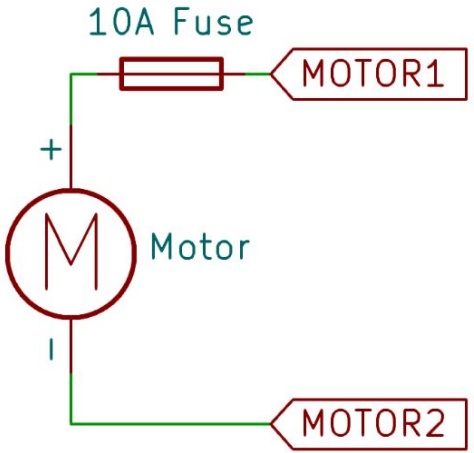
Button Panel Circuit



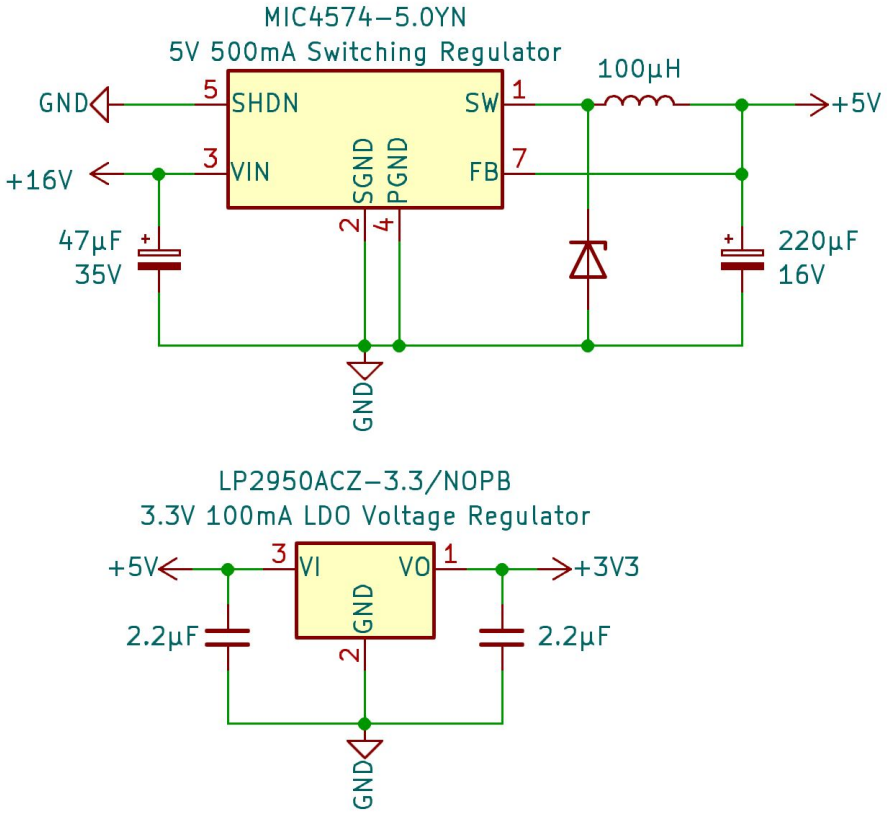
Leg Module Circuit





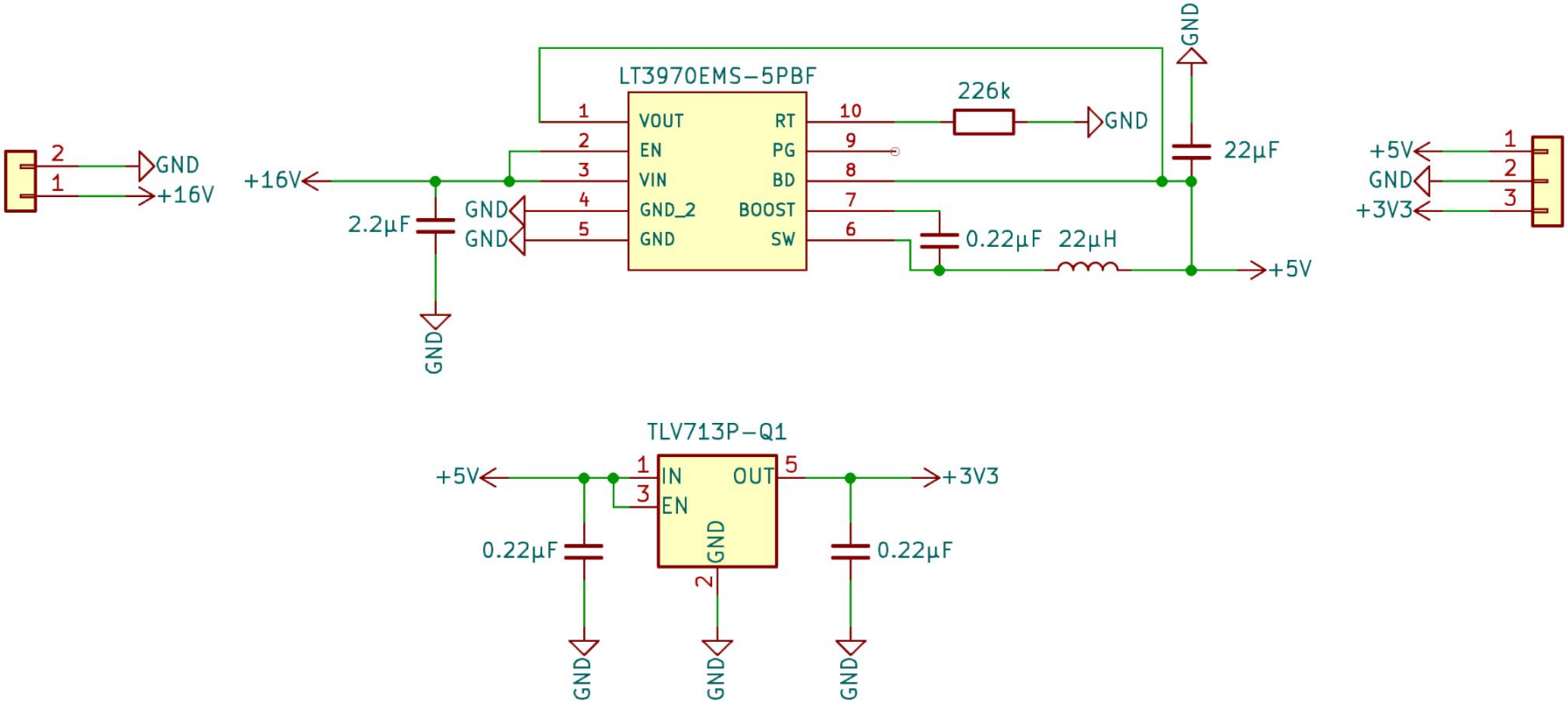


Power Distribution Circuit



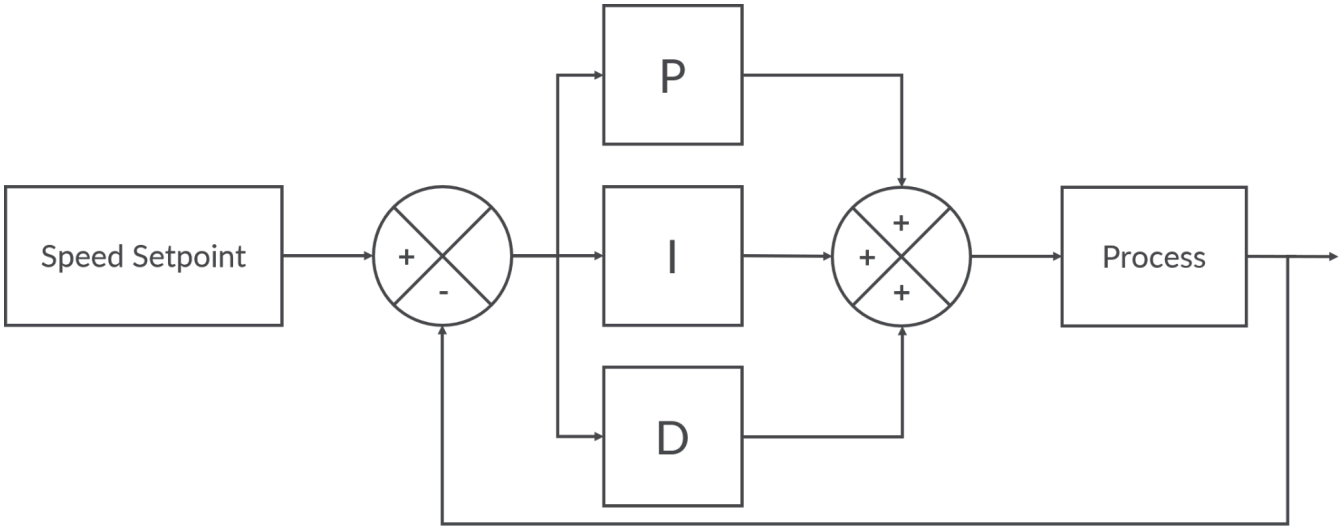
- Motors are “rated” for 12V
- 16V fixed power supply is for motors
  - Higher voltage is necessary for controls algorithm
  - Current is limited by software and fuses for overcurrent protection
- 5V is for powering ESP32 MCU
- 3.3V is for all logic

SMD Power Distribution Circuit



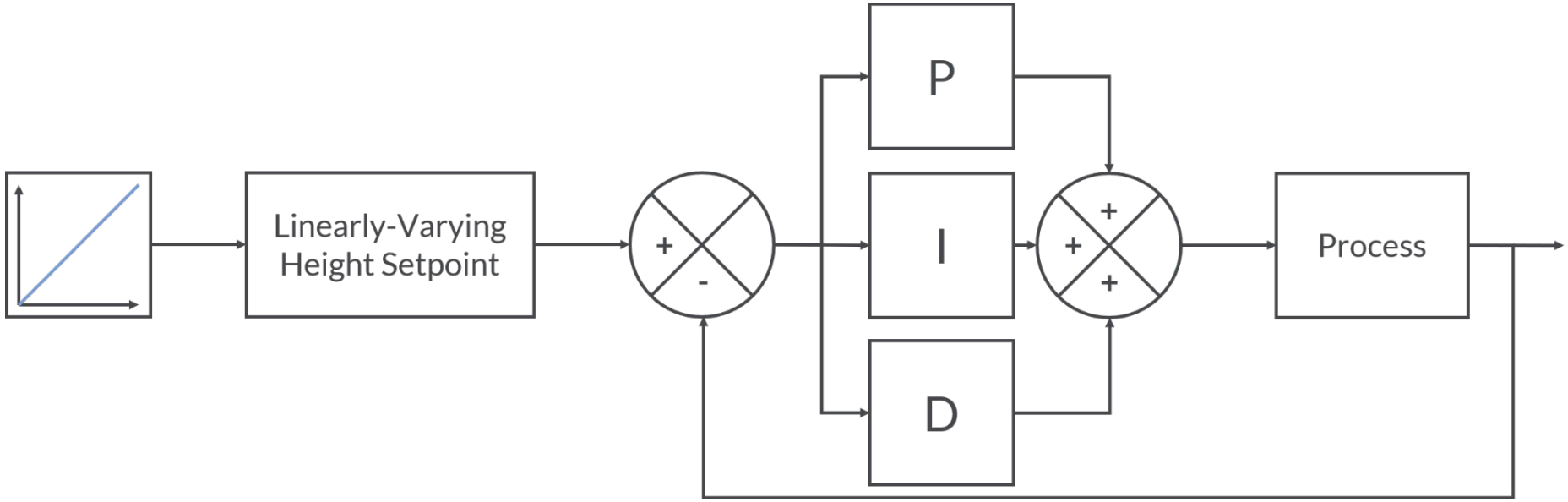
The Control System Problem

- With the same voltage, the motors move at slightly different speeds
- Both **speed and height** need to be identical for all motors

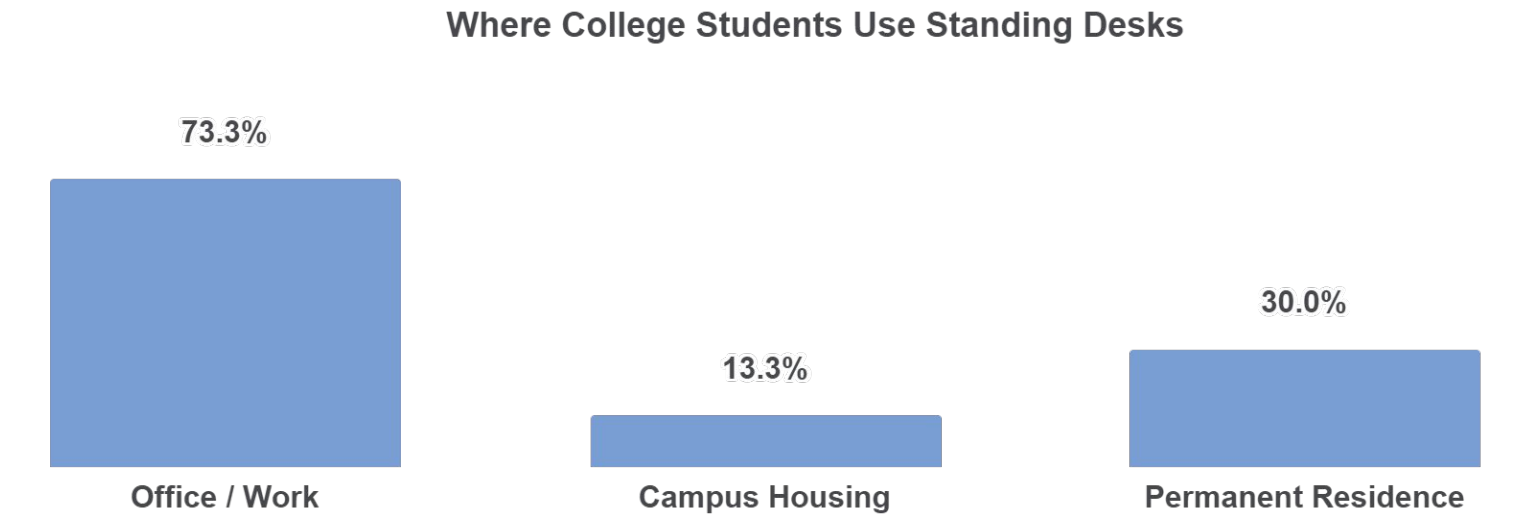


Naive Control System

Improved Control System



The Market



50%
of college students have used standing desks

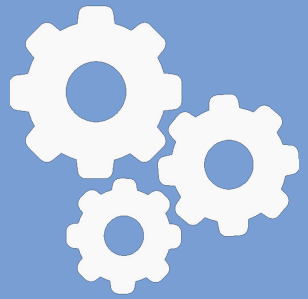
86.7%
of college students who have used standing desks DO NOT use a standing desk on campus

45%
of college students have used true standing desks

Our Customers

Business Owners

and other employees and employers who have a budget and are looking for **lower cost** solutions

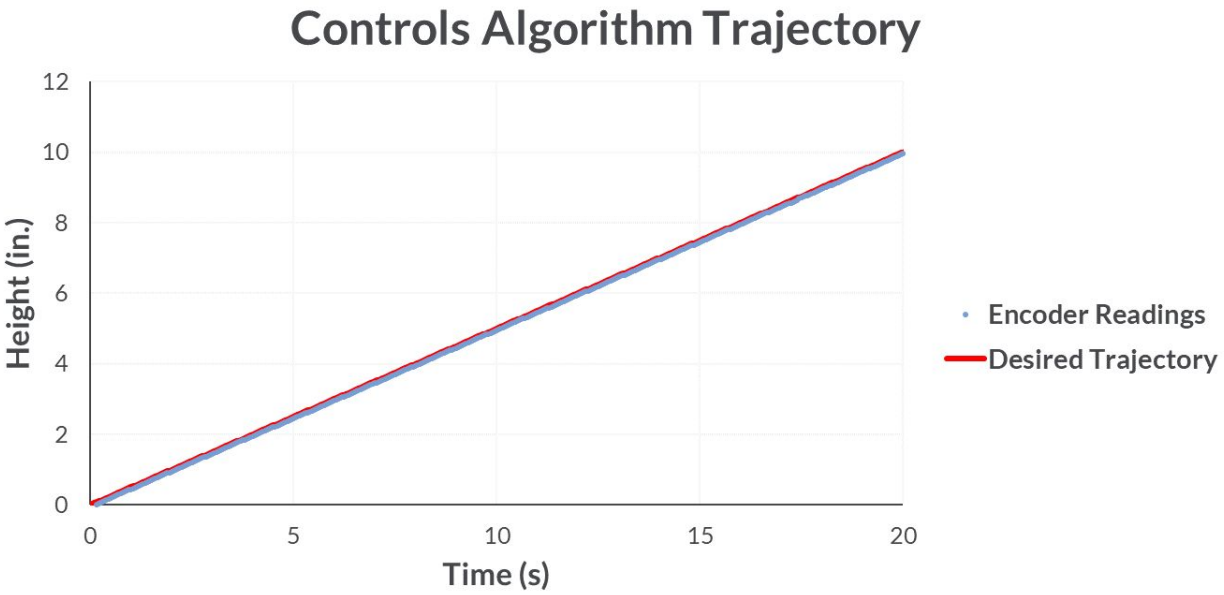


Artists

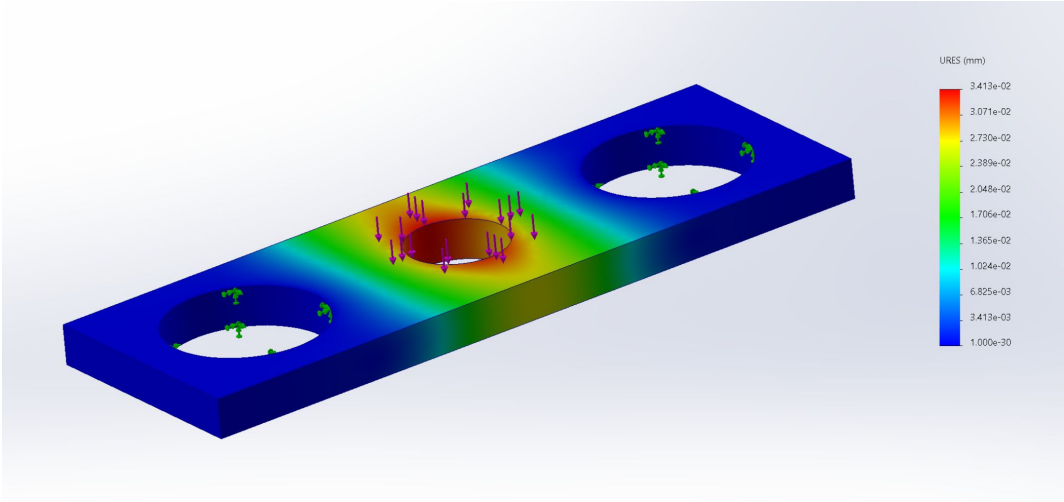
and other individuals who are looking for a **retrofittable** solution to keep their current setup

College Students

and other individuals who do not have a permanent desk setup and are looking for a **portable** solution


Controls Algorithm Trajectory
Height (in.)
12
10
8
6
4
2
0
0
5
10
15
20
Time (s)
Encoder Readings
Desired Trajectory

Design, Engineering, Prototyping

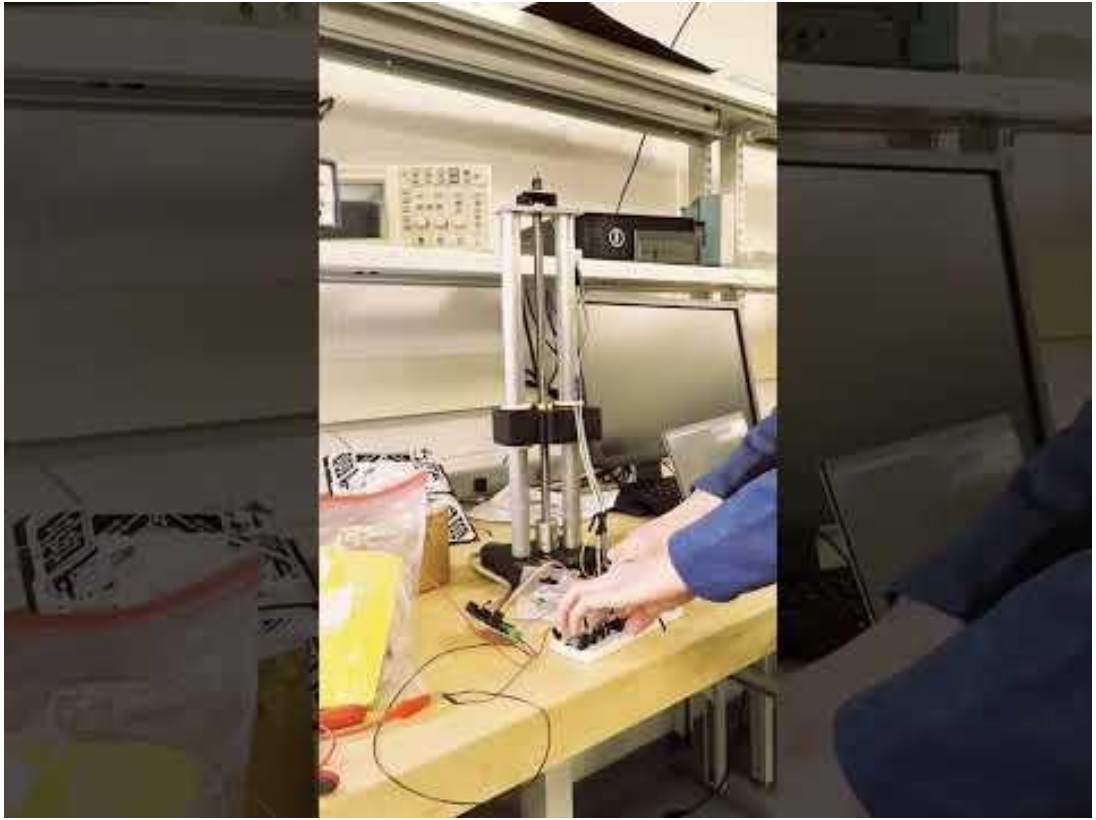


Top Plate

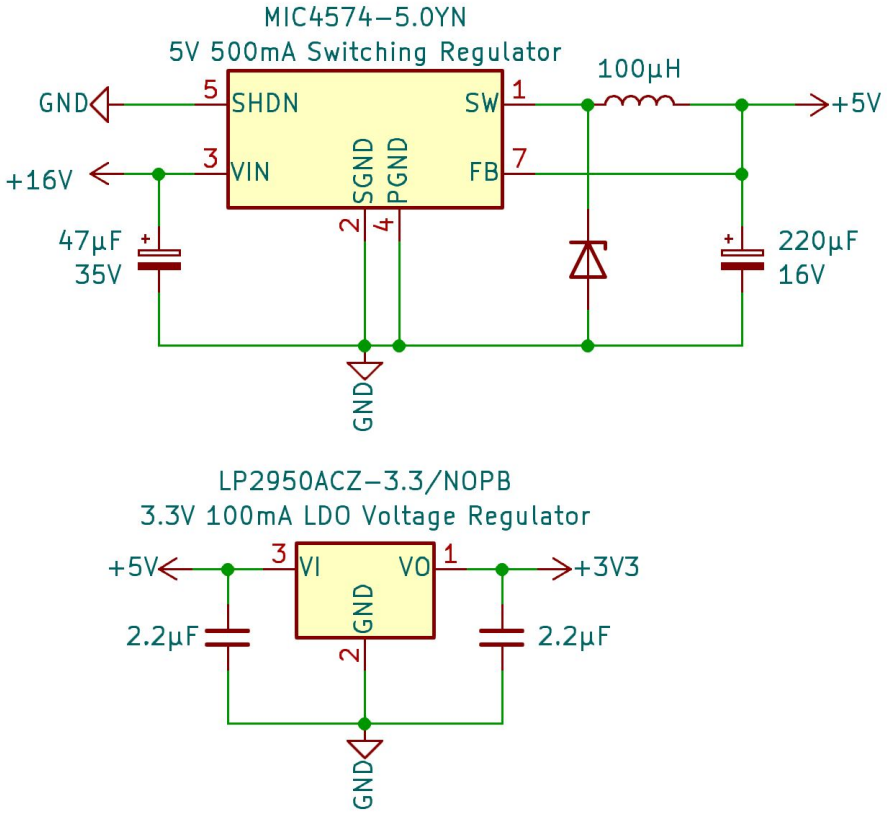
Stiffness limited part

Maximum load, deforms appropriately

PD Control System in Action



Power Distribution Circuit Explained



- Technically, 16V is required only for the motors and 3.3V can be used to power all other electronics and logic
- This circuit is designed with production in mind
- The ESP32 development board has a built in 5V to 3.3V LDO, but a production board would not
- To power the ESP32 and logic, a clean 3.3V source is required
- Switching regulator is efficient but noisy
- This circuit takes advantage of high efficiency switching regulator to reduce voltage and then uses an LDO linear regulator to produce a clean 3.3V source

Current Requirements

3.3V Electronics

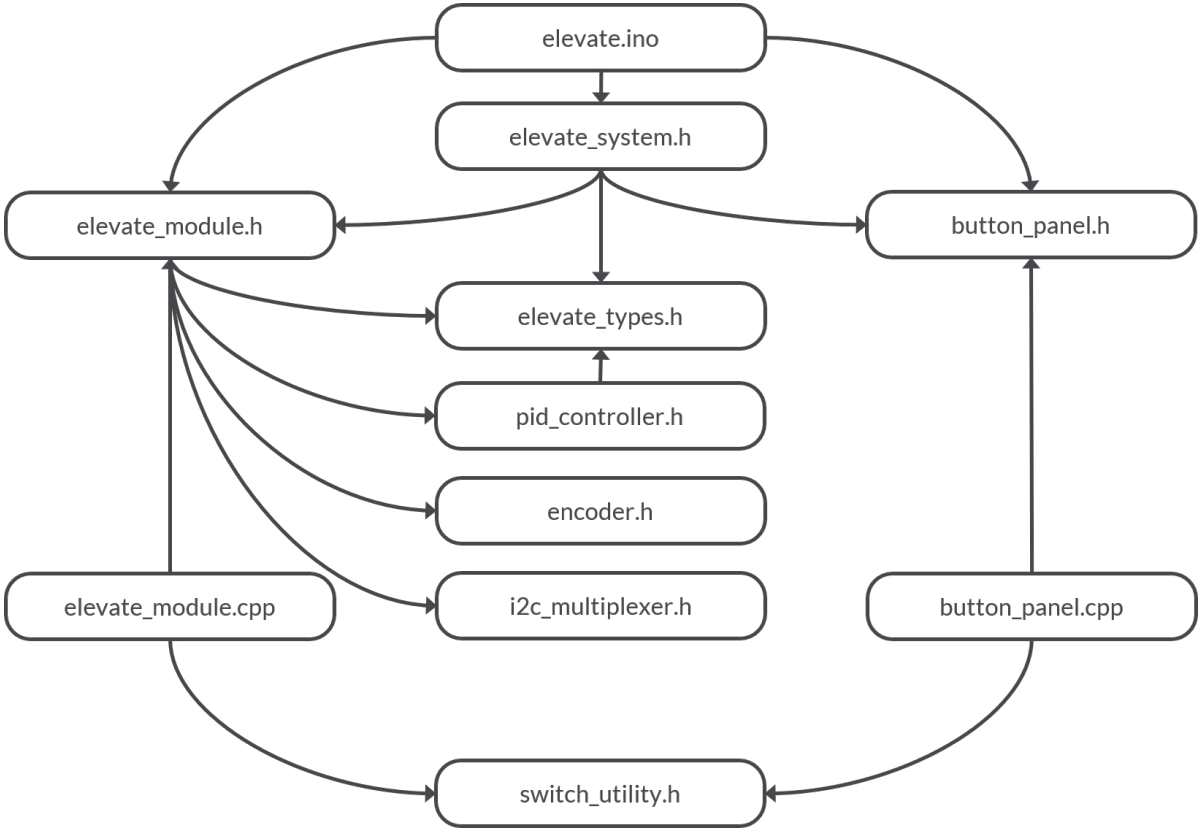
Component	Max Current (mA)	Quantity
I2C Multiplexer	0.035	1
Hex Inverter	0.04	1
Switches	3.3	10
AS5600 Encoder	6.5	4
Motor Drivers	10	2
Total	**79.075**	

5V Electronics

Component	Max Current (mA)	Quantity
LDO Regulator	150	1
ESP32	120	1
Total	**270**	

Data taken from product datasheets

Software Dependency Graph



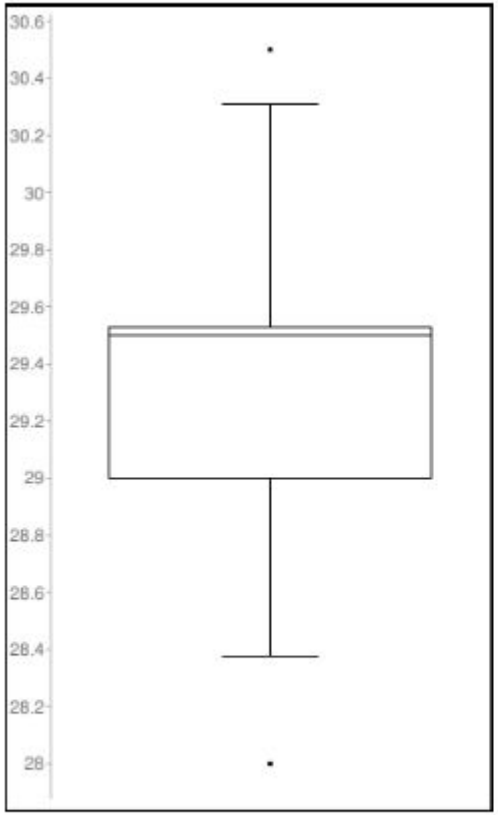
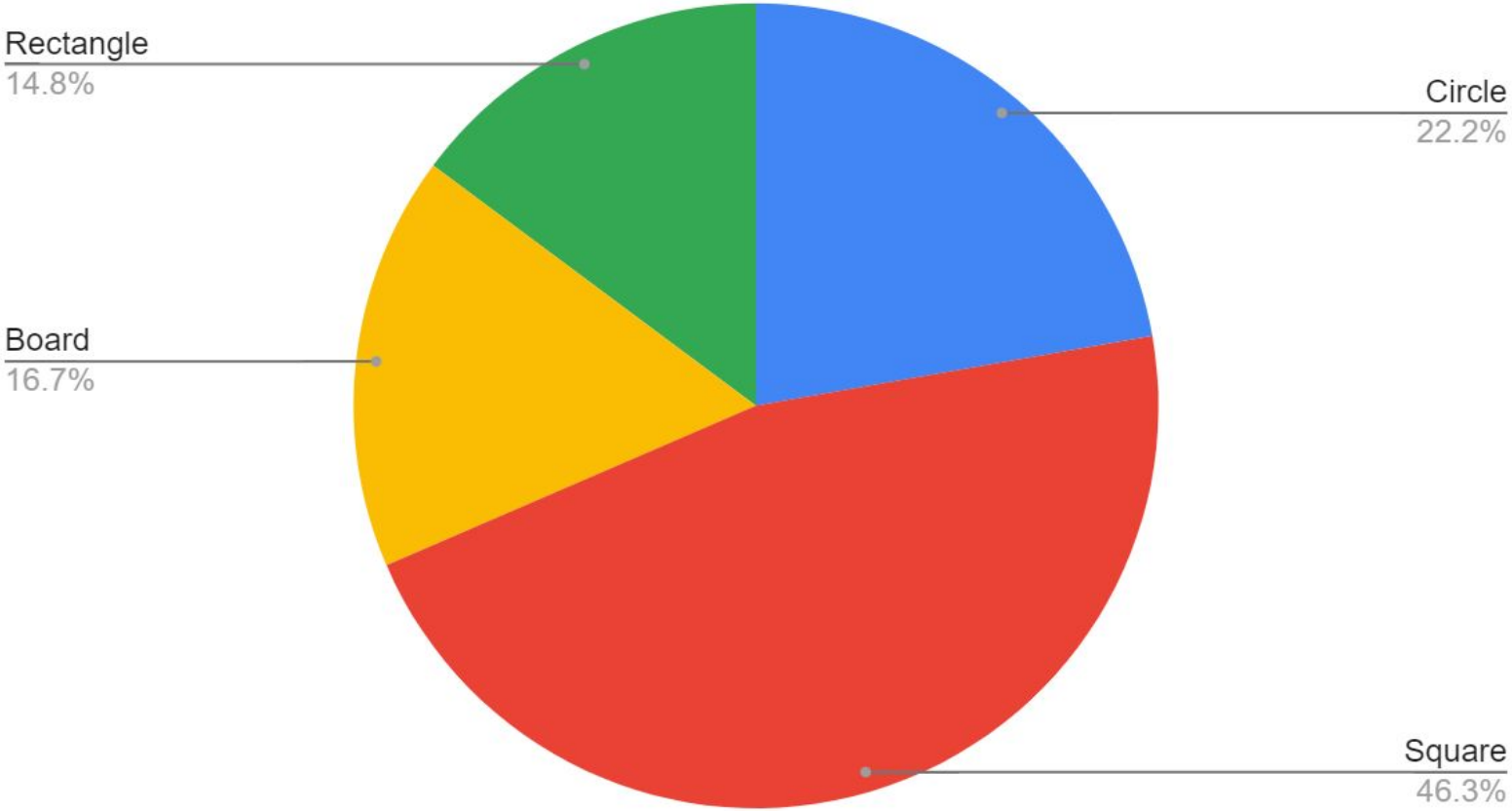


Figure 14. Boxplot of desk heights

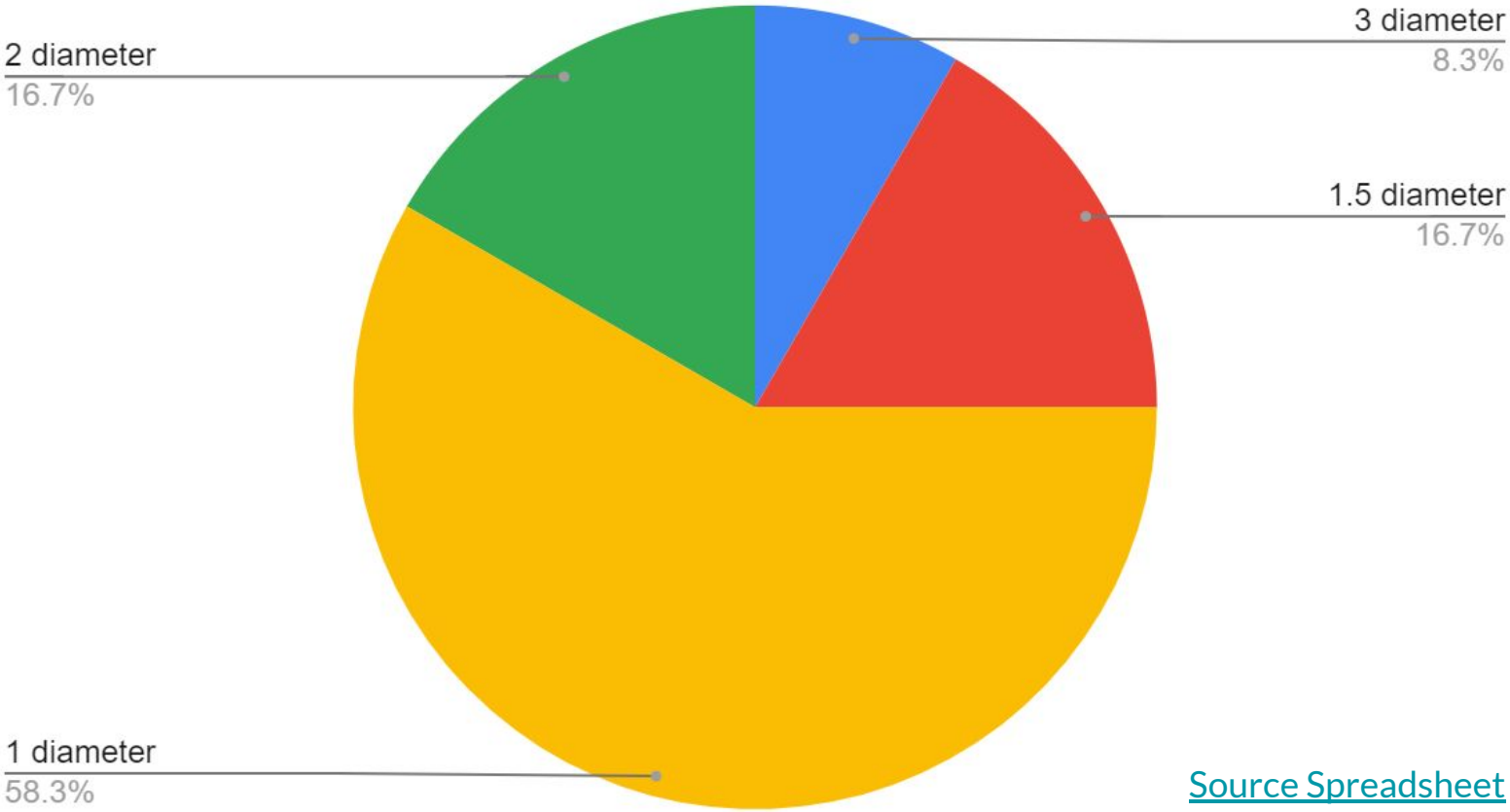
Minimum	min =	28
Maximum	max =	30.5
Range	R =	2.5
Size	n =	50
Sum	sum =	1463.8175
Mean	$\bar{x}$ =	29.27635
Median	$\tilde{x}$ =	29.5
Mode	mode =	29.5
Standard Deviation	s =	0.560108683
Variance	s^2 =	0.313721737
Mid Range	MR =	29.25
Quartiles		Quartiles: Q_1 --> 29 Q_2 --> 29.5 Q_3 --> 29.53
Interquartile Range	IQR =	0.53
Outliers		28, 30.5

Figure 15. Descriptive statistics for desk heights

Sample of Leg Footprints



Circle Legs



Source Spreadsheet

Software Statistics

- 17 files
- 1279 lines of code
- >80% self-written

$$\Delta E = mgh \tag{1}$$

$$\Delta E = 136.1kg \times 9.81m/s^2 \times 0.0254m \tag{2}$$

$$\Delta E = 33.9\text{J} \tag{3}$$

$$P = \Delta E/T \tag{4}$$

$$P = 33.9J \,/\, 1s \tag{5}$$

$$P = 33.9W \tag{6}$$

$$P_{cr} = \frac{\pi^2 EI}{(KL)^2} \quad (1)$$

$$P_{cr} = \frac{\pi^2 \times 200000000000\ Pa \times \frac{\pi}{4} \times (\frac{0.00912}{2} m)^4}{(0.65 \times 0.6096)^2} \quad (2)$$

$$P_{cr} = 4269N \quad (3)$$

$$P_{max} = 136.1kg \times 9.81m/s^2 \quad (4)$$

$$P_{max} = 1335.1N \quad (5)$$

$$Safety\ Factor = \frac{4269}{1335.1} \quad (6)$$

$$Safety\ Factor = 3.2 \quad (7)$$

$$\sigma = \frac{F}{A} \quad (1)$$

$$\sigma = \frac{136.1kg \times 9.81m/s^2}{\frac{\pi}{r} \times (0.00912m)^2} \quad (2)$$

$$\sigma = 20.4MPa \quad (3)$$

$$Safety\ Factor = \frac{350}{20.4} \quad (4)$$

$$Safety\ Factor = 17.2 \quad (5)$$

For this calculation, a desk with a weight of 100 lbs (45.4 kg) and a length of 24 in (0.6096 m) will be used. *F* is the horizontal force applied to the top of the desk in N, *h* is the desk height in m, *W* is the desk weight in N, and *l* is the length of the desk in m.

$$F \times h > W \times \frac{l}{2} \quad (1)$$

For a desk that is 29 in tall (0.7366 m), the tipping force is calculated.

$$F \times 0.7366 > 444.8 \times \frac{0.6096}{2} \quad (1)$$

$$F > 184.1N \quad (2)$$

For a desk that is 47 in tall (1.1938 m), the tipping force is calculated.

$$F \times 1.1938 > 444.8 \times \frac{0.6096}{2} \quad (1)$$

$$F > 113.6N \quad (2)$$