F24 Capstone
Catheter Roller Robot

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Project Description

- Clients work in Bioengineering Devices Lab in treatment of brain aneurysms in the circle of Willis
- Design, build, and test a robotic system that can translate and rotate a catheter into a benchtop vessel model remotely
- Allows testing of catheters in presence of x-rays
- Sponsor: Dr. Becker

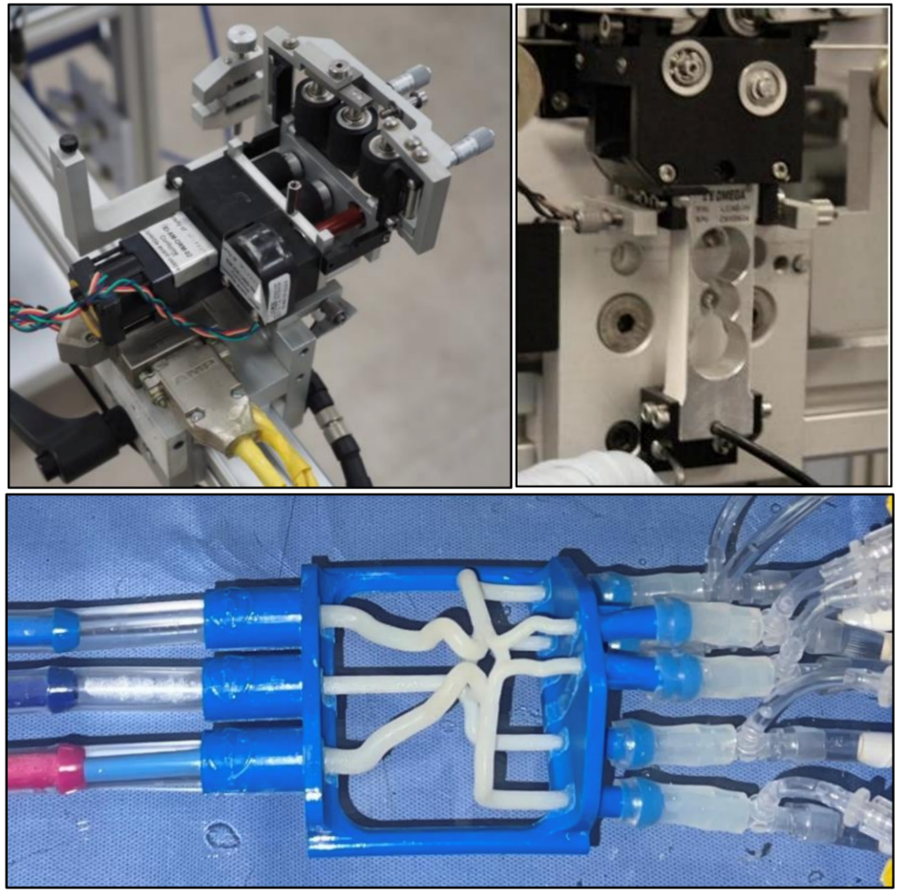


Figure 1. Top: Machine Solutions (MSI) IDTE Catheter Roller, Bottom: BDL Circle of Willis Model [1]

Functional Decomposition

Inputs

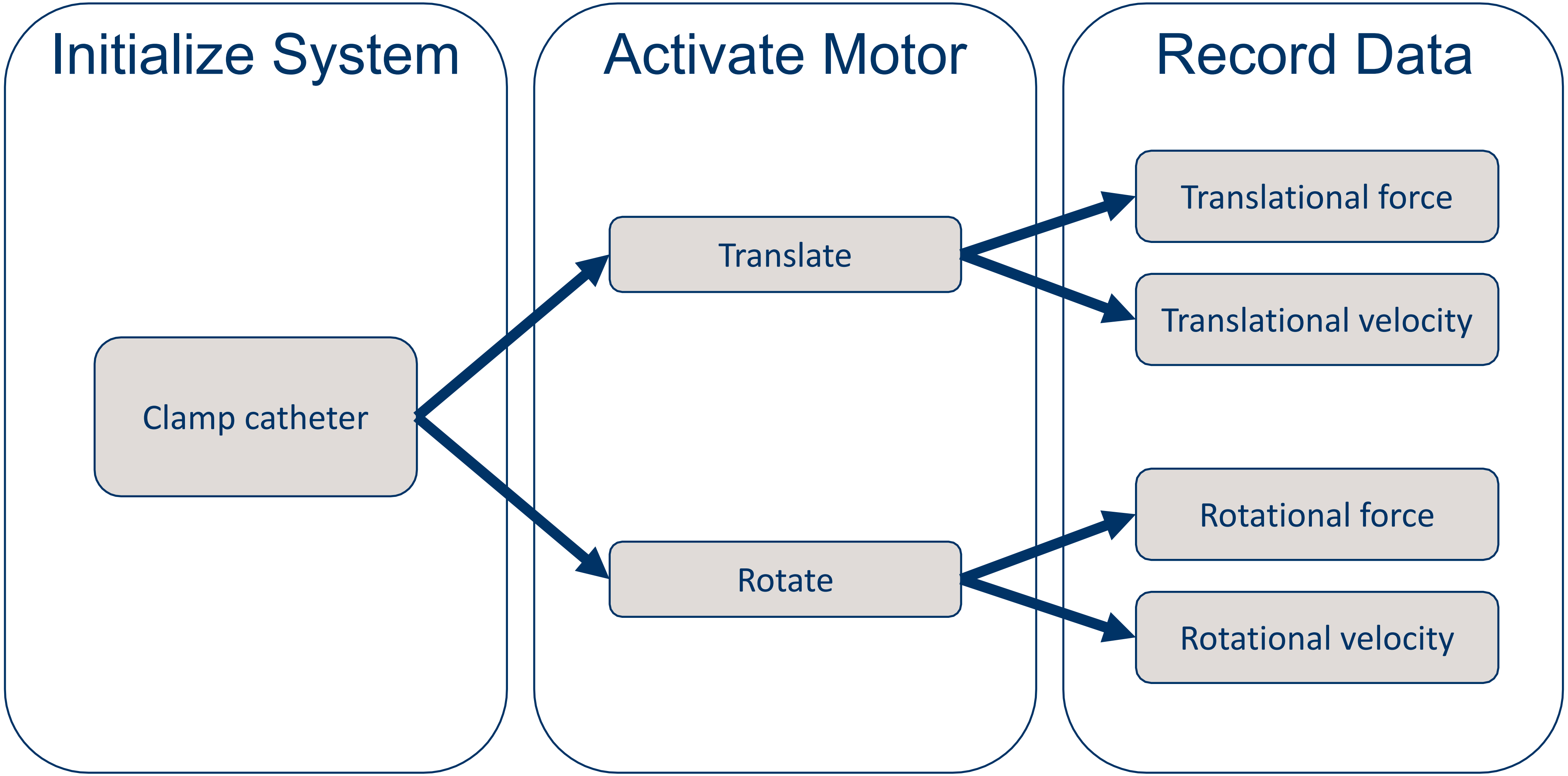
- Catheter mounting
- Energy/power
- Rotational motor
- Translational motor

→ **Catheter Motion** →

Outputs

- Real-time digital display
- Translational force
- Rotational force

Functional Flow Model



Concept Generation: Translation

- Rollers found to be best through SOTA research- Extrusion based design
- Rollers(Square design)
  - Four rollers in system – one motor / three free(all same diameter)
  - Advantages: Fewer distinct parts
  - Disadvantages: Larger overall system – more expensive design
- Rollers(Triangle design)
  - Four rollers in system – one large motor / three smaller free rollers
  - Advantages: Compact system
  - Disadvantages: High force/velocity on rollers
- Distance between rollers variable through manual input

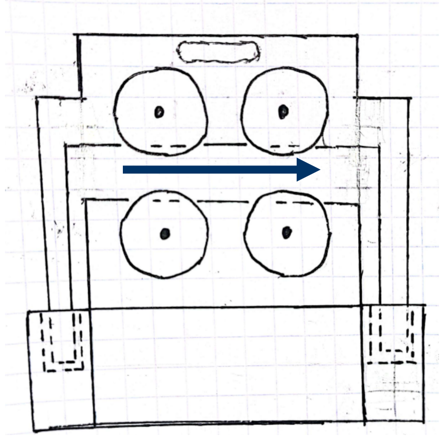


Figure 2. Design A

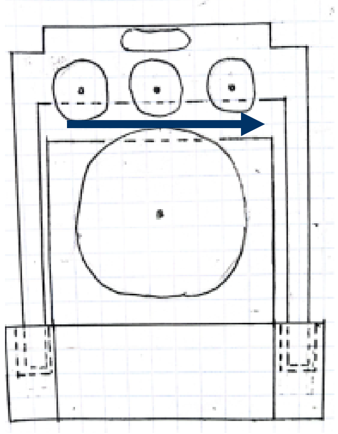


Figure 3: Design B

Concept Generation: Translation

Design A

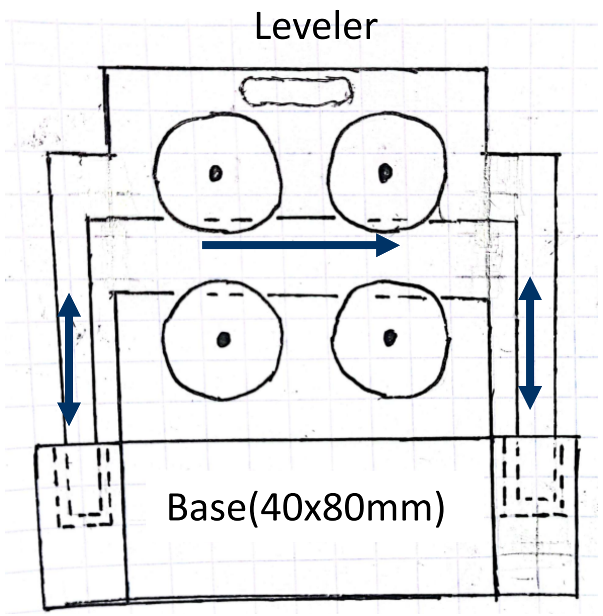


Figure 4. Design A - Front view

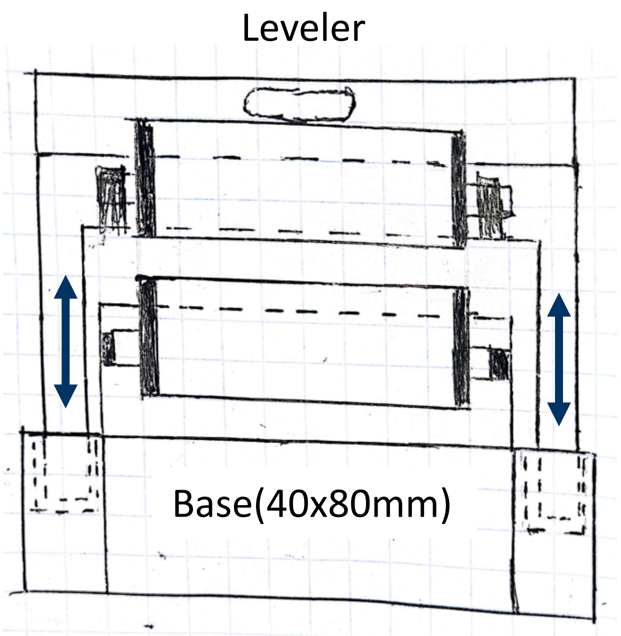


Figure 5: Design A - Side view

Design B

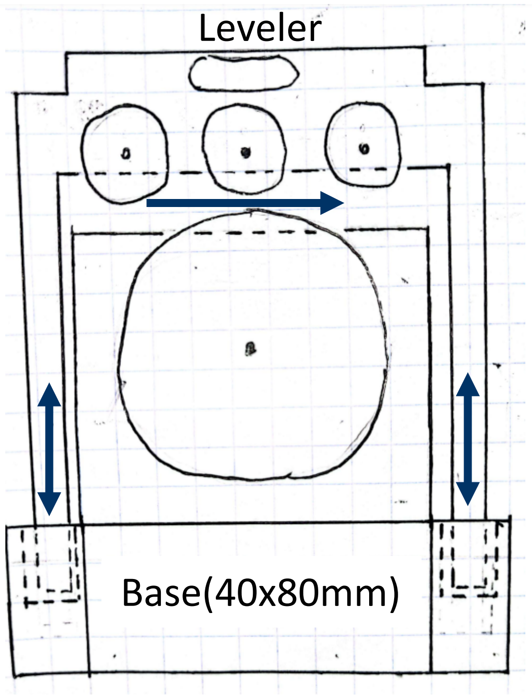


Figure 6. Design B – Front view

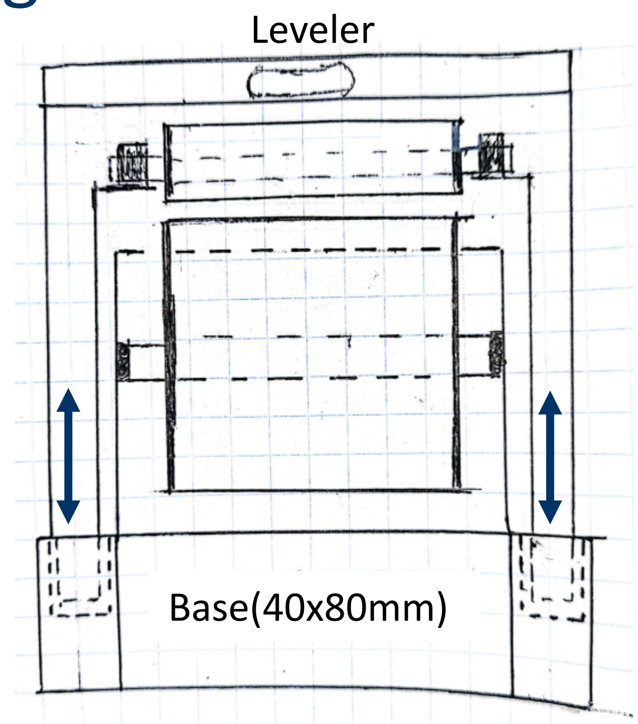


Figure 7. Design B – Side View

Calculations: Translation Design A

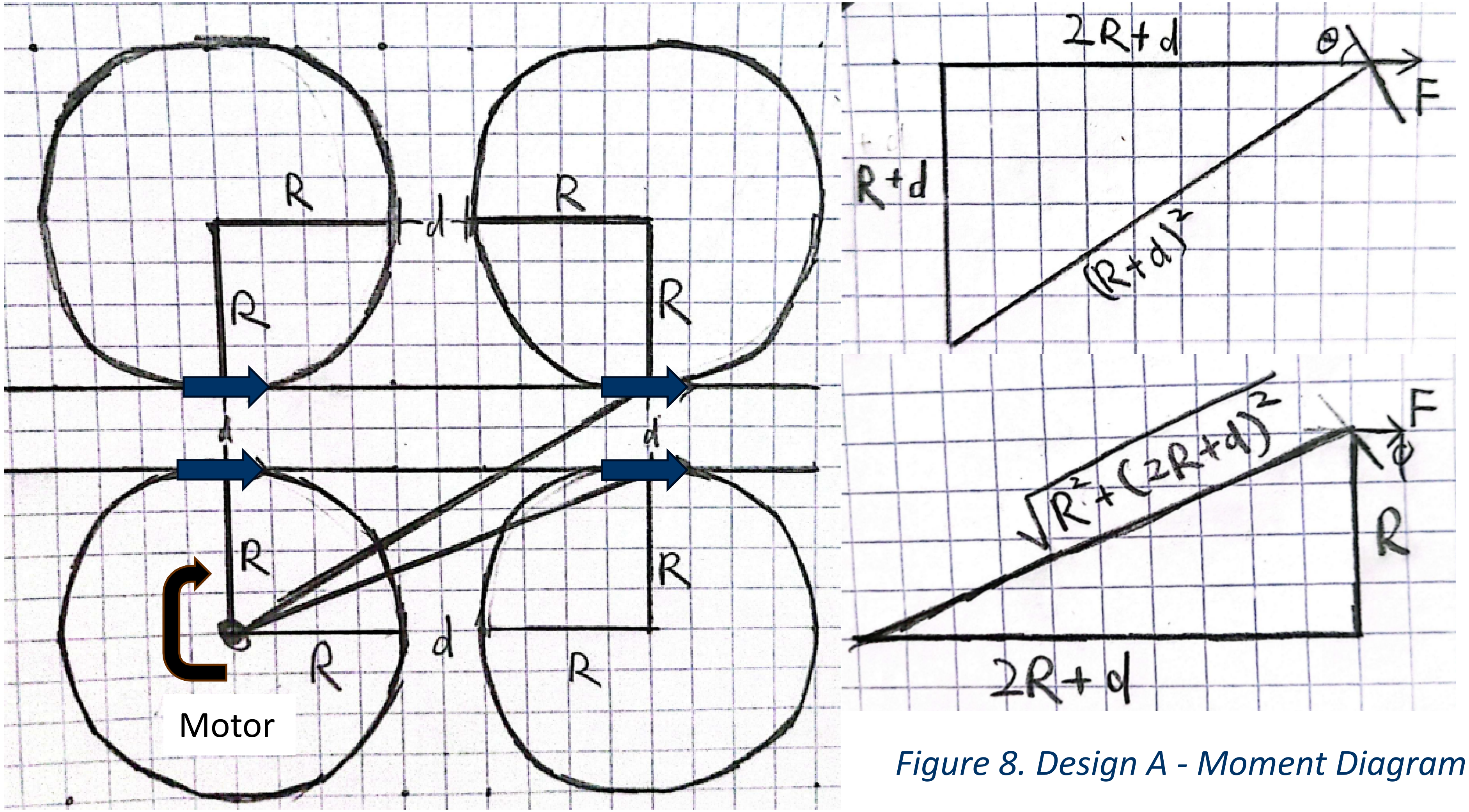


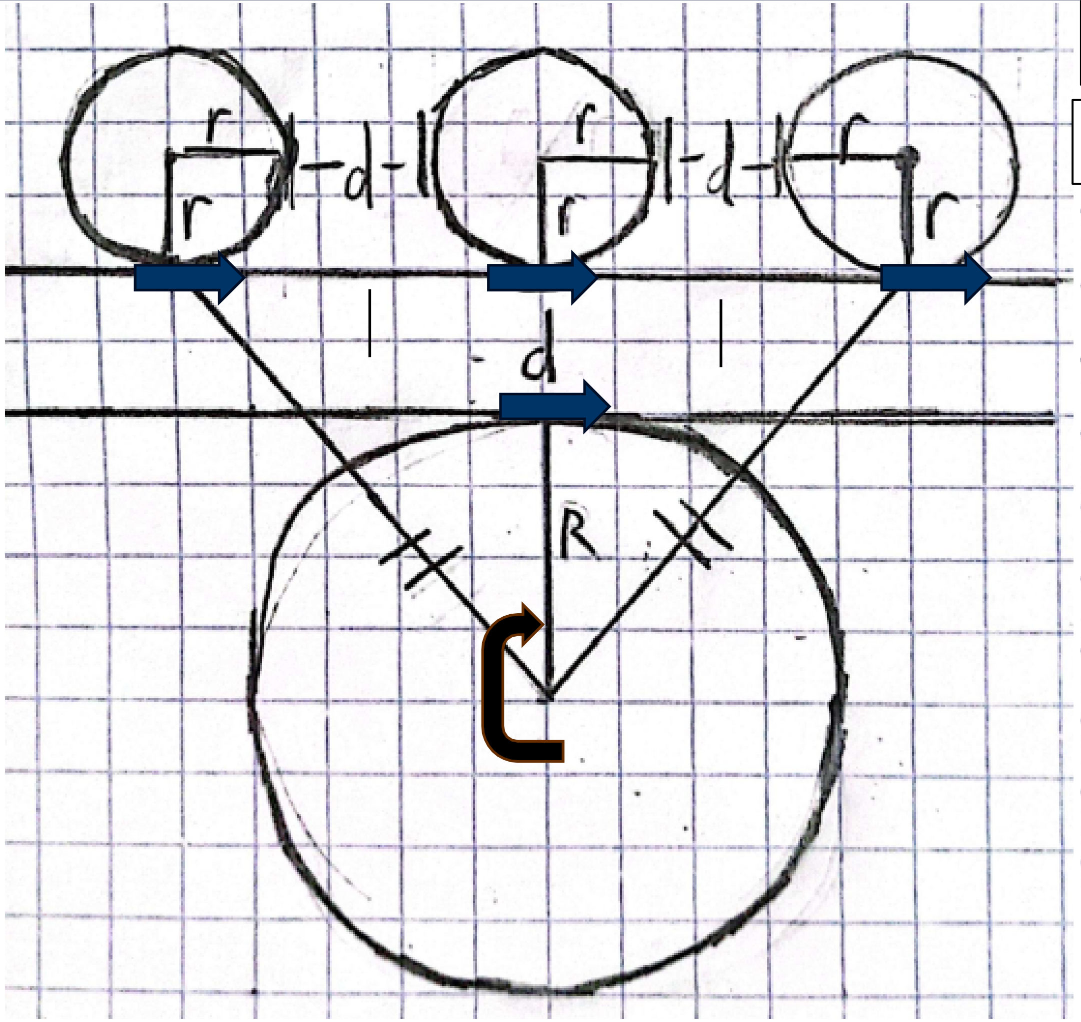
Figure 8. Design A - Moment Diagram

F = C

$$\theta = 90 - \tan^{-1}\left(\frac{R+d}{2R+d}\right)$$

$$\varphi = \tan^{-1}\left(\frac{2R+d}{R}\right)$$

Calculations: Translation Design B



F = C

r= R/3

$$\psi = 90 - \tan^{-1}\left(\frac{R+d}{\frac{2R}{3}+d}\right)$$

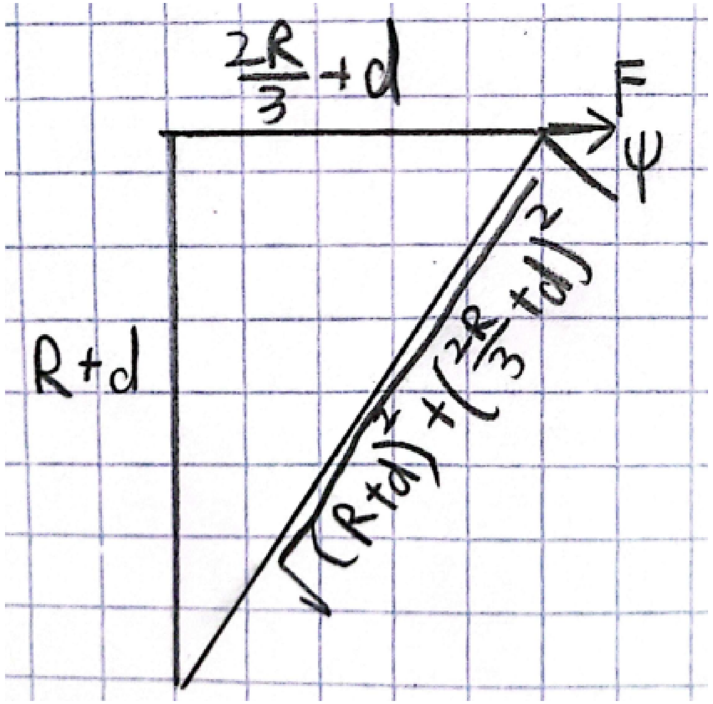


Figure 9. Design B - Moment Diagram

Calculations: Translation Compare

$$\Sigma M_{motorA} = F\left[2R + d + \cos(\theta)\sqrt{(R+1)^2 + (2R+d)^2} + \cos(\varphi)\sqrt{R^2 + (2R+d)^2}\right]$$

$$\theta = 90 - \tan^{-1}\left(\frac{R+d}{2R+d}\right) \quad \varphi = \tan^{-1}\left(\frac{2R+d}{R}\right)$$

$$\Sigma M_{motorB} = F\left[2R + d + 2\cos(\psi)\sqrt{R^2 + \left(\frac{2R}{3} + d\right)^2}\right]$$

$$\psi = 90 - \tan^{-1}\left(\frac{R+d}{\frac{2R}{3} + d}\right)$$

Assumptions: Ignore friction torques

Common values

```
F = 10; %N
R = 5; %(mm)
d = 1; %(mm)
```

DESIGN A

```
Rtwo = 2*R + d;
Rone = R + d;

COS1 = cosd(90-atand(Rone/Rtwo));
COS2 = cosd(atand(Rtwo/R));

Hyp1 = sqrt(Rone^2 + Rtwo^2);
Hyp2 = sqrt(R^2 + Rtwo^2);

M_A = F*(Rtwo + COS1*Hyp1 + COS2*Hyp2) %(N*mm)
```

```
M_A = 220
```

Figure 10. Design A Calculations(MATLAB)

DESIGN B

```
Rone = R + d;
Rtwo = 2*R + d;
Rthird = (2*R)/3 + d;

COS3 = 2*cosd(90-atand(Rone/Rthird));

Hyp3 = sqrt(Rone^2 + Rthird^2);

M_B = F*(Rtwo + COS3*Hyp3) %(N*mm)
```

```
M_B = 230
```

Figure 11. Design B Calculations(MATLAB)

In conclusion:

- Both designs give similar effects on the motor
- Comparing advantages and disadvantages from above, both have important design aspects.
- Advice from Client
  - Design A would perform better under criteria
  - Design B will be considered if future adjustments needed

Concept Generation Rotation

Design A

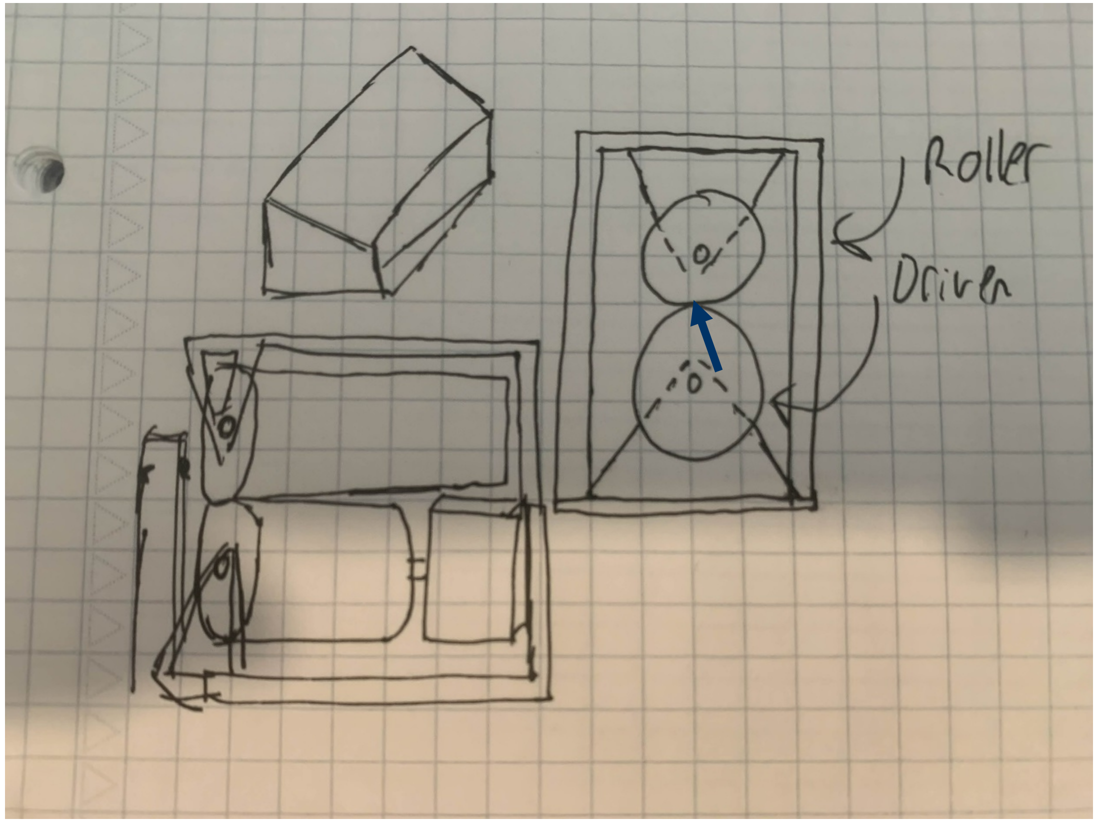


Figure 12. Roller Rotator

Design B

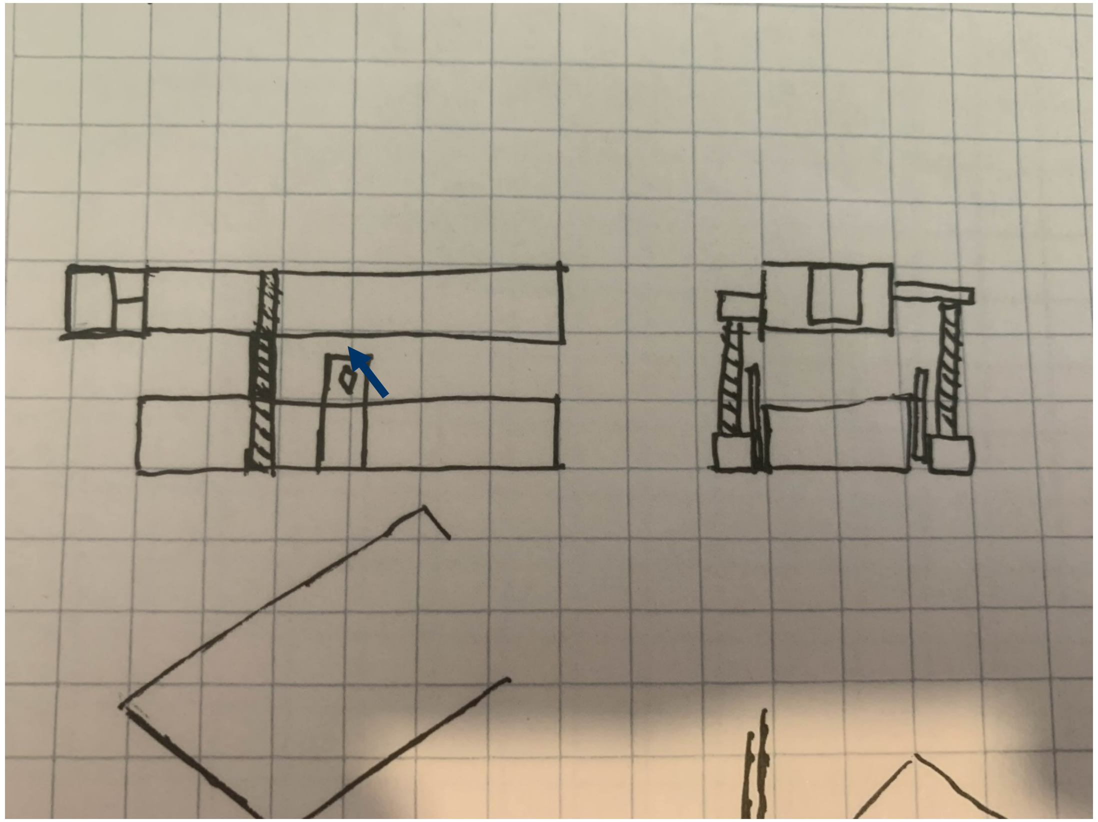


Figure 13. Friction plane rotator

Concept Generation: Rotation

Wheel rotation:

- Two rollers are preset clamped onto the catheter
- One roller is driven by a motor and will deliver torque to rotate the catheter
- The second roller is passive and will rotate freely.
- Pros:
  - Simplistic design
  - Direct torque
- Cons:
  - Little adjustability
  - Passive friction
  - Possible contact issues

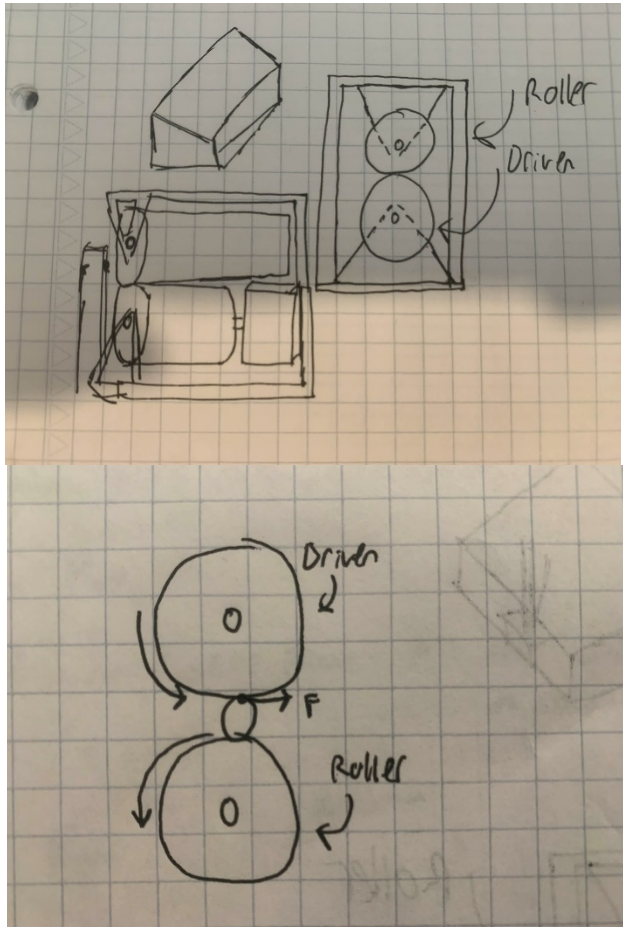


Figure 14. Force sketch of roller rotator

Concept Generation: Rotation

- Two plates clamp down on the catheter
- The top plate can translate left to right causing a torque on the catheter causing rotation
- One motor and a lead screw at the top will translate the top friction plate
- The top plate assembly will be on a platform that can raise and lower with the help of two motors
- Pros:
  - Uniform rotation on the catheter
  - Better clamping
  - Had been done before
- Cons:
  - More complicated assembly

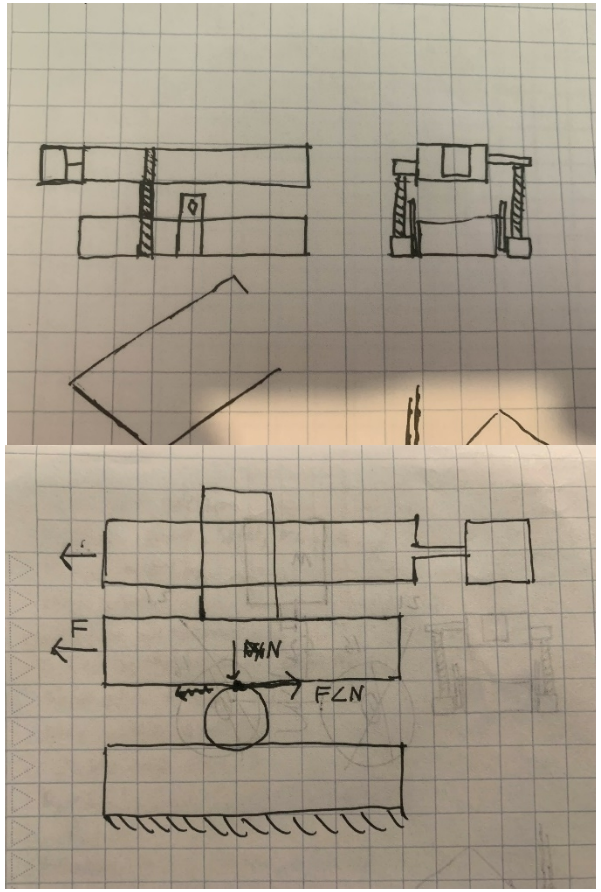


Figure 15. Force sketch of friction plane

Calculations: Rotation

1. Found linear distance the largest sized catheter will need to complete one rotation with l = (pi)*d

2. Found moment of inertia for a catheter. Using: $I = \frac{1}{2}Mr^2$ and converting it to $I = \frac{1}{2}p(pi)r^2Lr^2$. L was given as 2 ft, and r: 0.35 < r < 2.5 mm.

3. Google sheets was used to calculate necessary torques at different accelerations using T = a*I.

4. Density of catheter is unknown, so it is just a const.

5. Fmax = u*N. Friction coefficient was estimated using rubber on rubber which near 1. Conclusion: Torques required to rotate catheter are very small. The max force applied depends in the max friction. Overall, calculations show the rotation of the catheter doesn’t require much torque and neither design hold an advantage over the other.

Calculation: Rotation

Constant accelerations were generated to iteratively calculate the torques at different ‘operating times,’ which is the time it takes to complete a full rotation of the catheter.

plate:			1 rev = rad	Catheter diameter sizes		inertia Large:	1.87E-11	kgm^2	Mass of plate	6.52	g
smallest	15.7	mm	6.283185307	0.7	mm	Inertia Small:	7.18E-15	kgm^2	Normal force:	0.064	N
Largest	31.4	mm		5	mm	density:	1	const.	Worm (d):	8	in
							Friction plate rotation				
Velocity:			Acceleration		Toruqe_L	Torque_S	Force_L	Force_S			
time	rad/s	mm/s	rad/s^2	mm/s^2	Nm	Nm	N	N			
1	6.283185307	15.7	6.283185307	15.7	1.18E-10	4.51E-14	4.70E-08	1.58E-17			
2	3.141592654	7.85	1.570796327	3.925	2.94E-11	1.13E-14	1.18E-08	3.95E-18			
3	2.094395102	5.233333333	0.6981317008	1.744444444	1.31E-11	5.02E-15	5.22E-09	1.76E-18			
4	1.570796327	3.925	0.3926990817	0.98125	7.34E-12	2.82E-15	2.94E-09	9.87E-19			
5	1.256637061	3.14	0.2513274123	0.628	4.70E-12	1.81E-15	1.88E-09	6.32E-19			
6	1.047197551	2.616666667	0.1745329252	0.4361111111	3.26E-12	1.25E-15	1.31E-09	4.39E-19			
7	0.897597901	2.242857143	0.1282282716	0.3204081633	2.40E-12	9.21E-16	9.59E-10	3.22E-19			
8	0.7853981634	1.9625	0.09817477042	0.2453125	1.84E-12	7.05E-16	7.34E-10	2.47E-19			
9	0.6981317008	1.744444444	0.07757018898	0.1938271605	1.45E-12	5.57E-16	5.80E-10	1.95E-19			

Figure 16. excel sheet calculations for torque

Concept Generation: Sensors

Load Cells

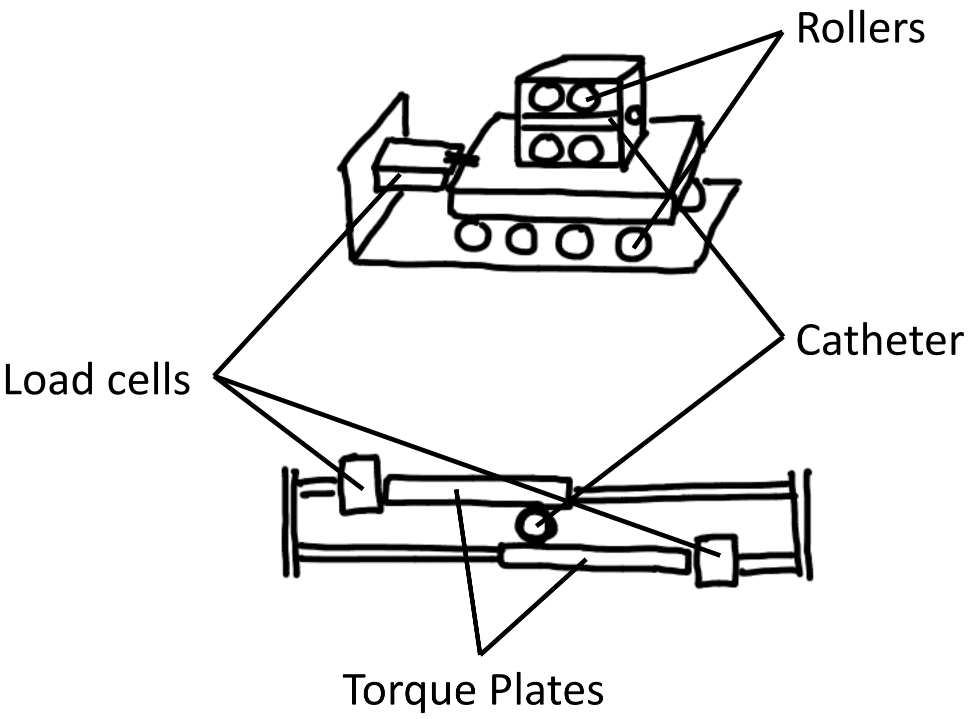


Figure 17. Load Cells for Translation and Rotation

RPM Sensors

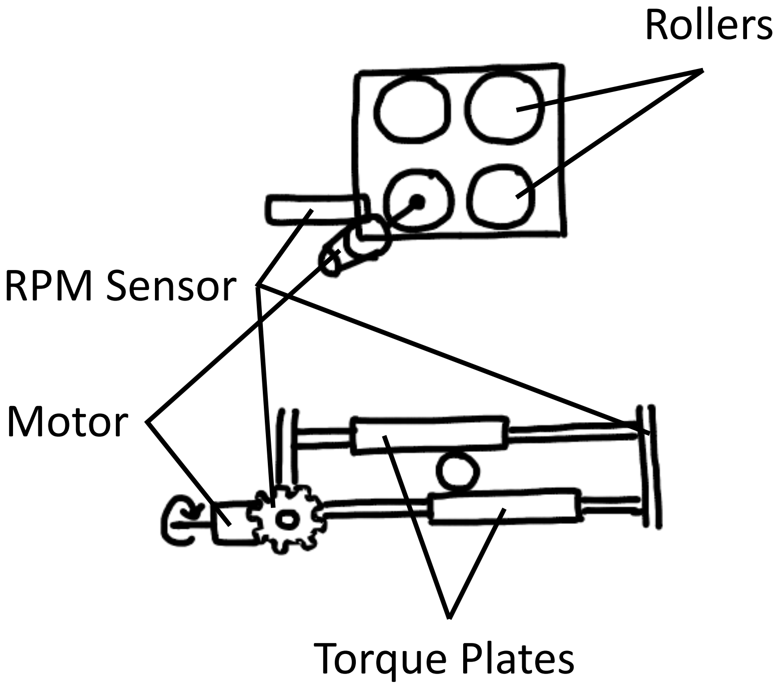


Figure 18. RPM Sensors for Translation and Rotation

Calculations: Sensors

- Force
  - $P = VI = Fv$
  - $v = r\omega$
  - $F = \frac{VI}{r\omega}$
- Torque
  - $\tau = F \times r$
  - $\tau = \frac{VI}{\omega}$
- Clamping
  - Catheter diameter/thickness ratio 10-12 (thick wall)
  - Hoop stress thick wall
    - $\sigma_h = \frac{(p_i - p_o)(D-t)}{2t}$
    - $p = \frac{F}{A}$

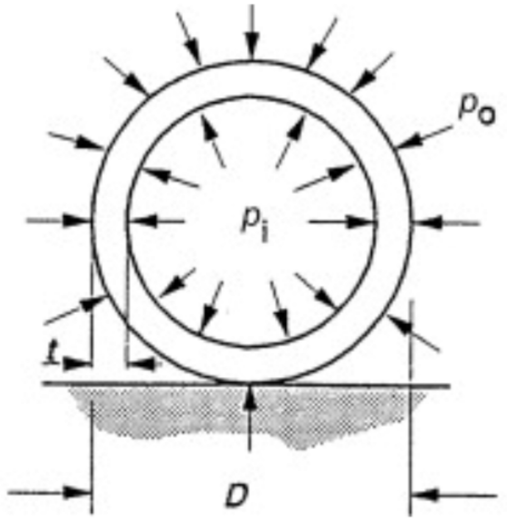
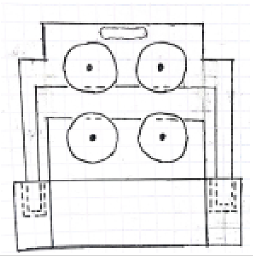
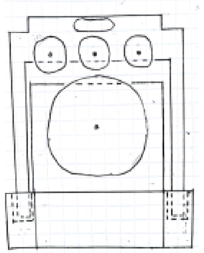
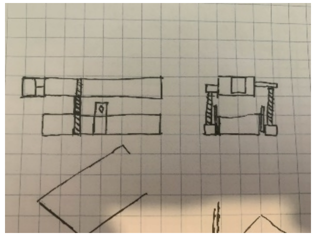
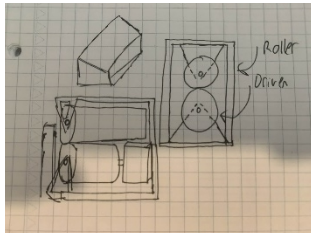
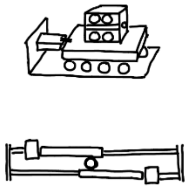
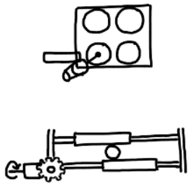


Figure 19. Hoop Stress Variables [2]

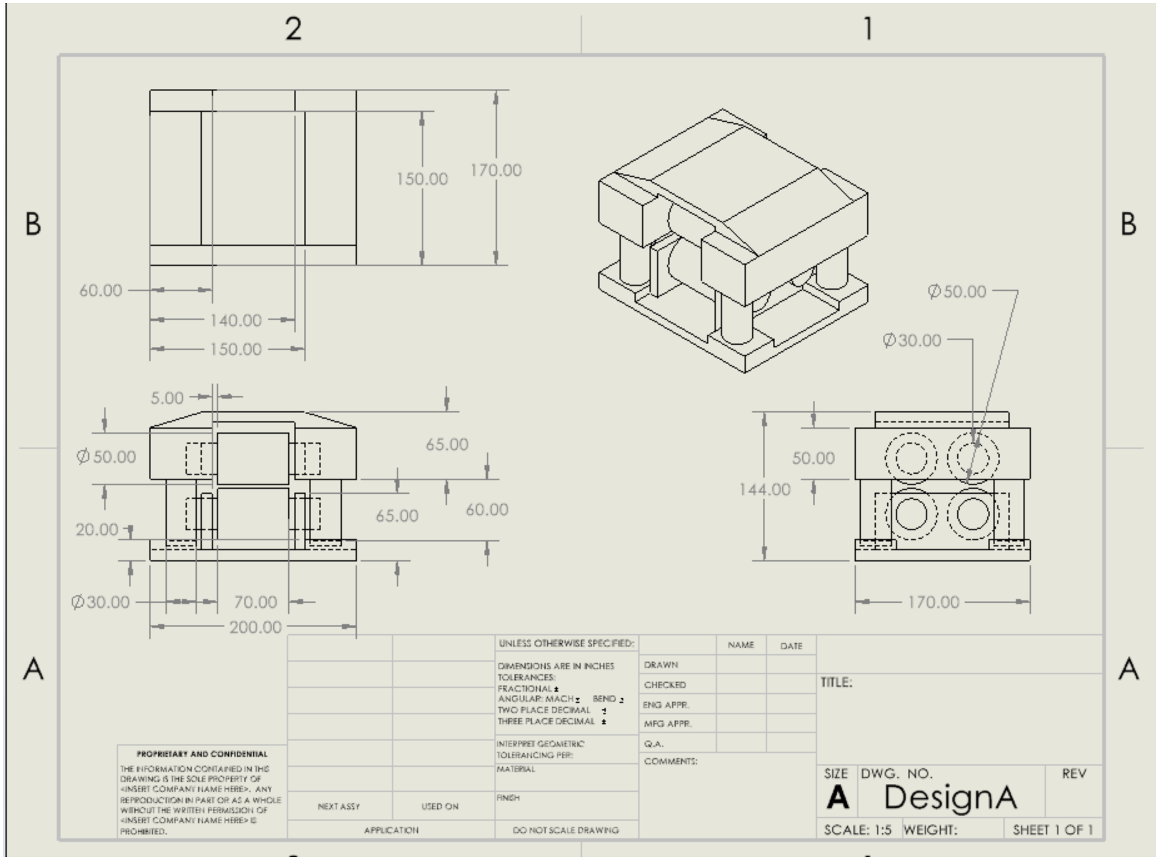
Morphological Matrix

Subsystems	1	2
A. Translation		
B. Rotation		
C. Sensors		

- Combinations
  - Design 1: A1, B1, C2
  - Design 2: A2, B1, C2
- From evaluation, We will be moving forward with design 1

Concept Evaluation: Translation

- Design A Drawing (dimensioned)
- Design A Isometric View



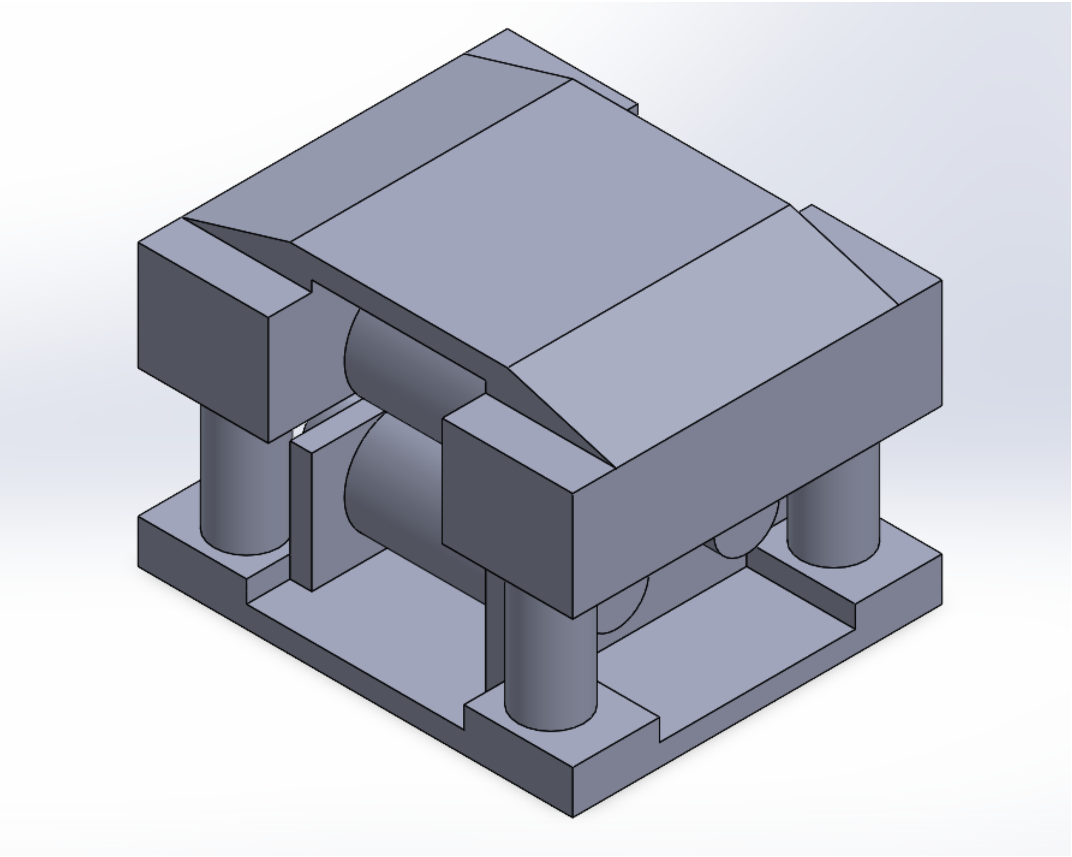
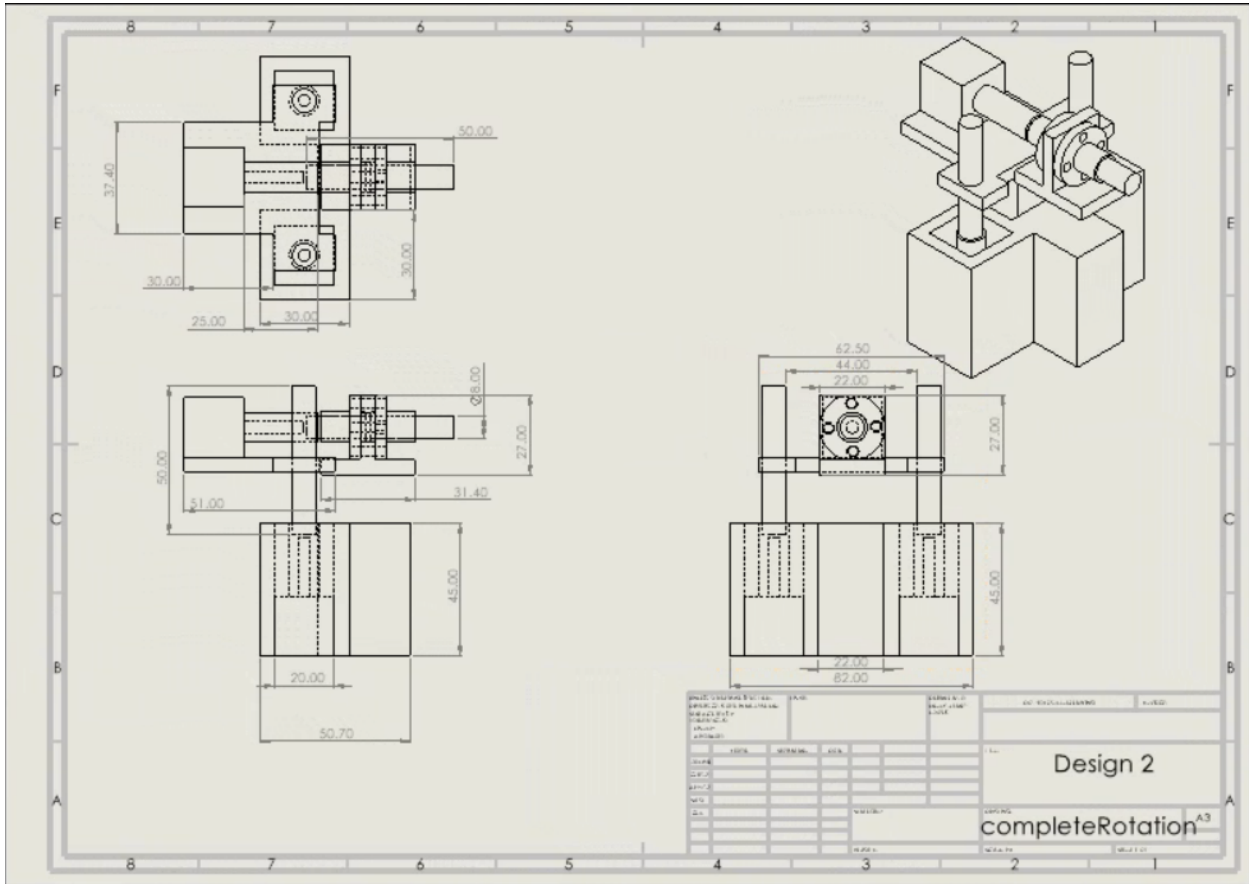


Figure 20. Design A (SOLIDWORKS)

Concept Evaluation: Rotation



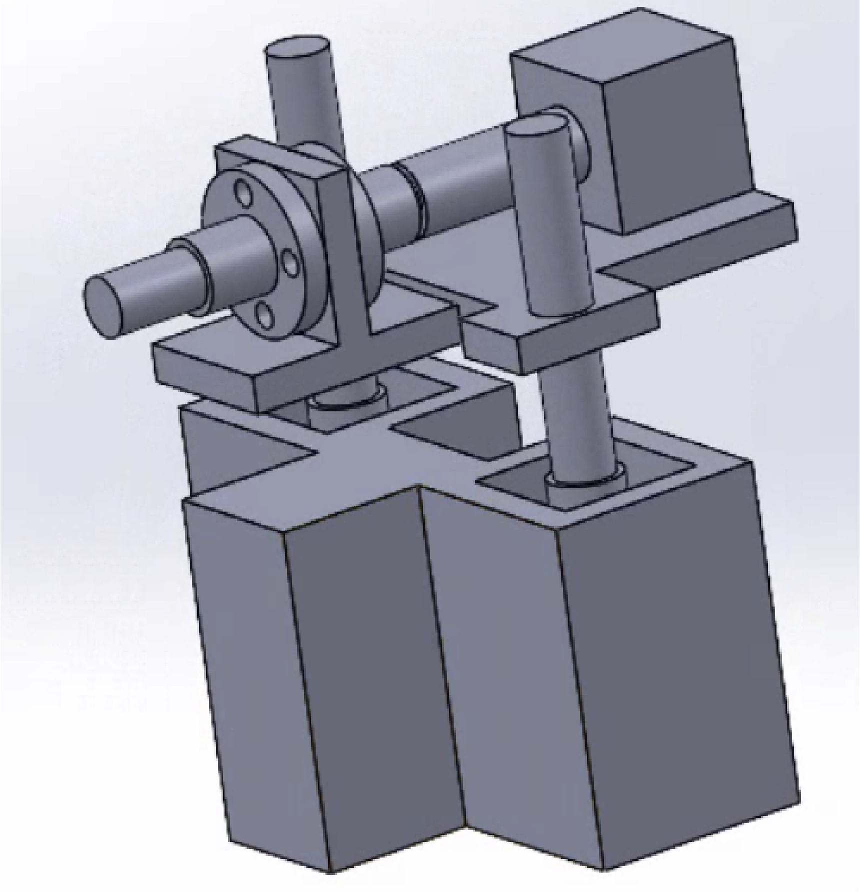
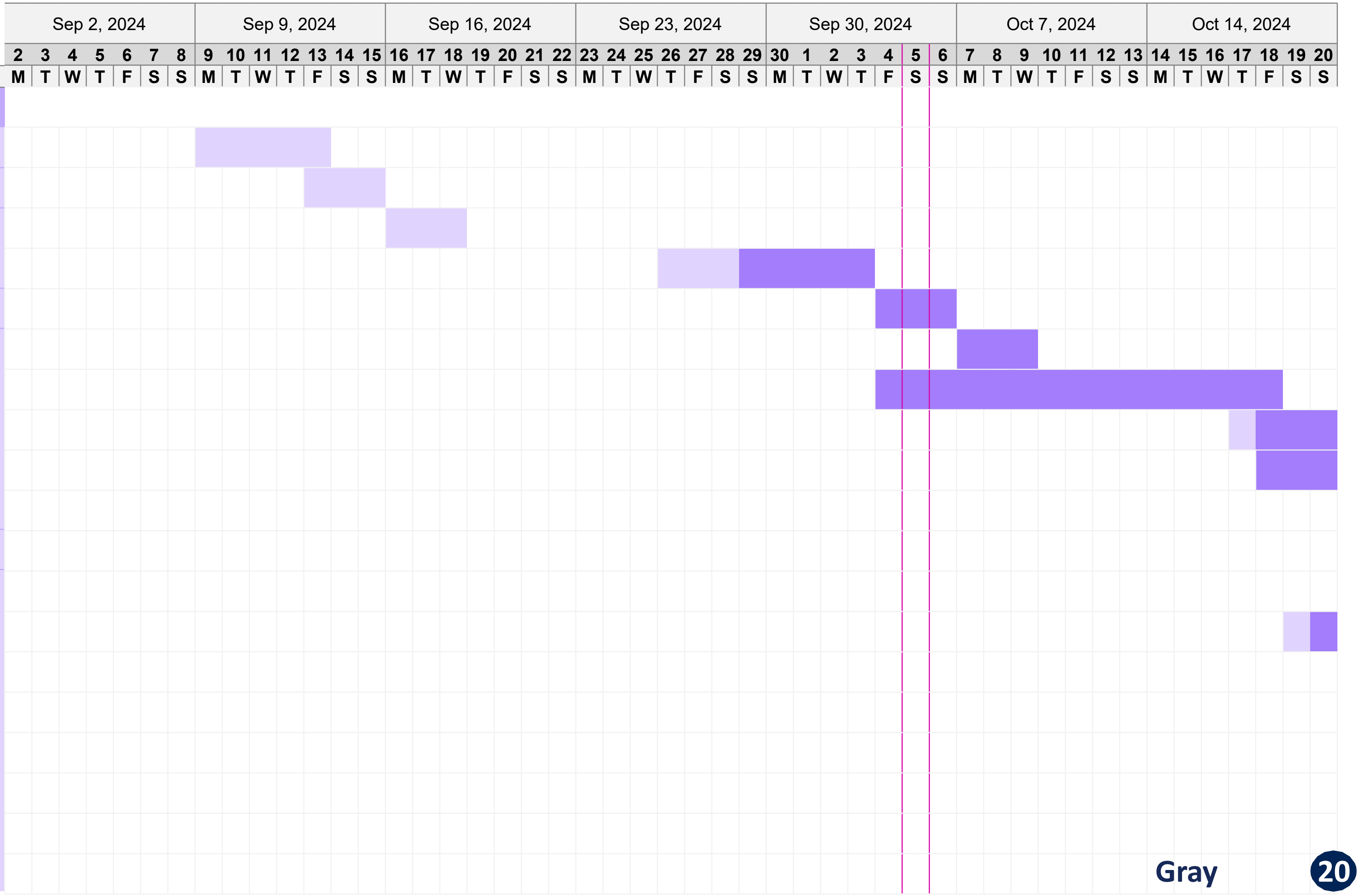


Figure 22. Rotation Design (SOLIDWORKS)

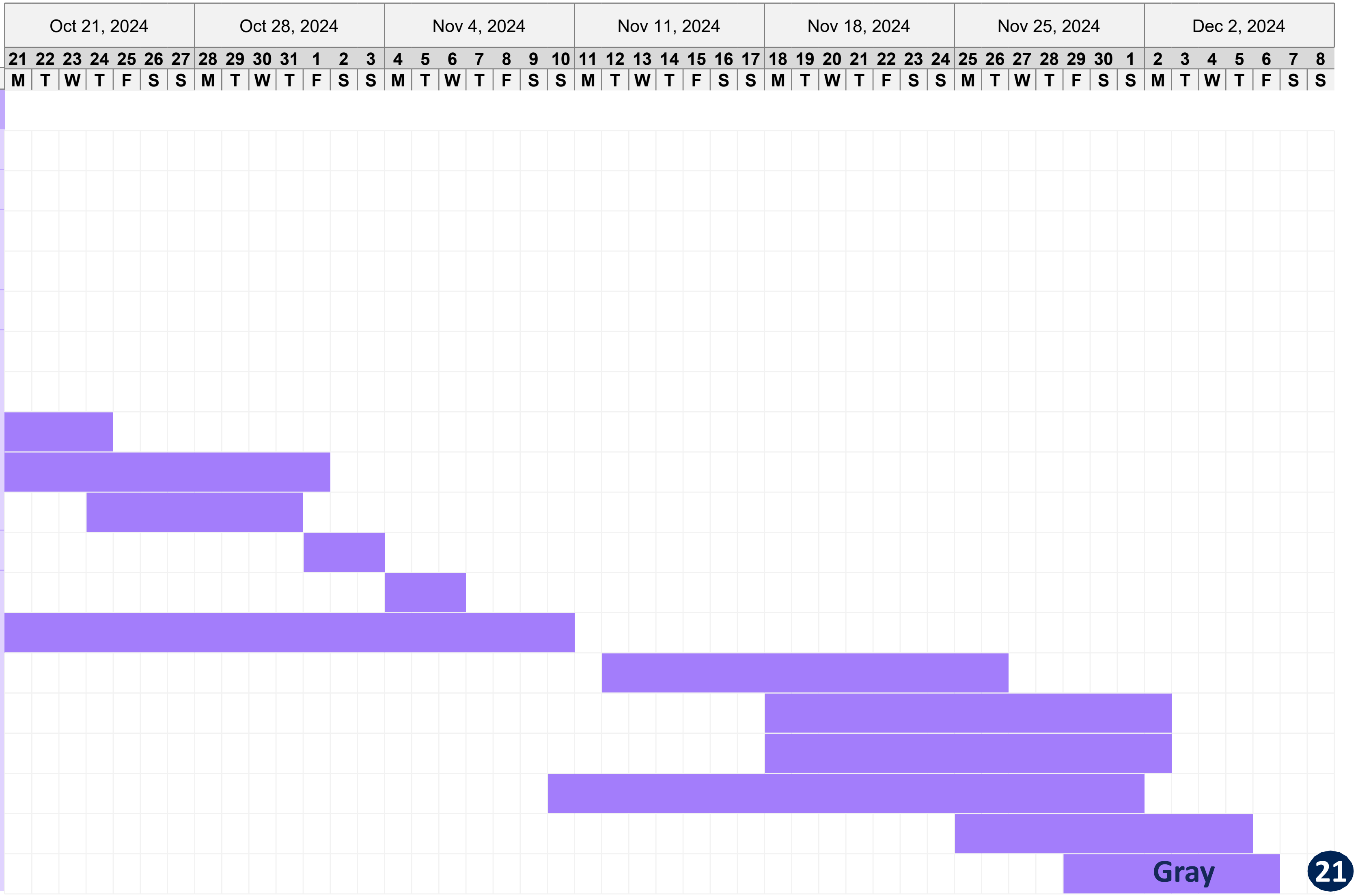
Schedule

TASK	ASSIGNED TO	PROGRESS	START	END
Course Deliverables				
Presentation 1 Slides	All	100%	9/9/24	9/13/24
Presentation 1 Practice	All	100%	9/13/24	9/15/24
Presentation 1 Revisions	All	100%	9/16/24	9/18/24
Presentation 2 Slides	All	35%	9/26/24	10/3/24
Presentation 2 Practice	All	0%	10/4/24	10/6/24
Presentation 2 Revisions	All	0%	10/7/24	10/9/24
Report 1	All	0%	10/4/24	10/18/24
Website Development 1	All	15%	10/17/24	10/24/24
Analytical Analysis Memo	All	0%	10/18/24	11/1/24
Presentation 3 Slides	All	0%	10/24/24	10/31/24
Presentation 3 Practice	All	0%	11/1/24	11/3/24
Presentation 3 Revisions	All	0%	11/4/24	11/6/24
Prototype 1 Demo	All	5%	10/19/24	11/10/24
Report 2	All	0%	11/12/24	11/26/24
Final CAD	All	0%	11/18/24	12/2/24
Final BOM	All	0%	11/18/24	12/2/24
Prototype 2 Demo	All	0%	11/10/24	12/1/24
Project Management	All	0%	11/25/24	12/5/24
Website Development 2	All	0%	11/29/24	12/6/24



Schedule

TASK	ASSIGNED TO	PROGRESS	START	END
Course Deliverables				
Presentation 1 Slides	All	100%	9/9/24	9/13/24
Presentation 1 Practice	All	100%	9/13/24	9/15/24
Presentation 1 Revisions	All	100%	9/16/24	9/18/24
Presentation 2 Slides	All	45%	9/26/24	10/3/24
Presentation 2 Practice	All	0%	10/4/24	10/6/24
Presentation 2 Revisions	All	0%	10/7/24	10/9/24
Report 1	All	0%	10/4/24	10/18/24
Website Development 1	All	15%	10/17/24	10/24/24
Analytical Analysis Memo	All	0%	10/18/24	11/1/24
Presentation 3 Slides	All	0%	10/24/24	10/31/24
Presentation 3 Practice	All	0%	11/1/24	11/3/24
Presentation 3 Revisions	All	0%	11/4/24	11/6/24
Prototype 1 Demo	All	5%	10/19/24	11/10/24
Report 2	All	0%	11/12/24	11/26/24
Final CAD	All	0%	11/18/24	12/2/24
Final BOM	All	0%	11/18/24	12/2/24
Prototype 2 Demo	All	0%	11/10/24	12/1/24
Project Management	All	0%	11/25/24	12/5/24
Website Development 2	All	0%	11/29/24	12/6/24



Budget

Income			
From Sponser			$5,000
From Fundraising	$500	Current:	$75.00
Total:			$5,500
Expenses			
Prototype 1			
Subsystem breakdown	Estimated cost/each	Number needed	Cost
Motors/drivers	110	3	330
MicroControllers	100	1	100
Power Supply	50	1	50
added cost			100
Total:			580
Prototype 2			
Subsystem breakdown	Esrinated cost/each	Number needed	Cost
Sensors	100	1	100
Remote contol	120	1	120
added cost			100
Total:			320
Final			
Case			300
added cost			200
Total:			500
Total:			1400
Percent used			25%
Percent left			75%

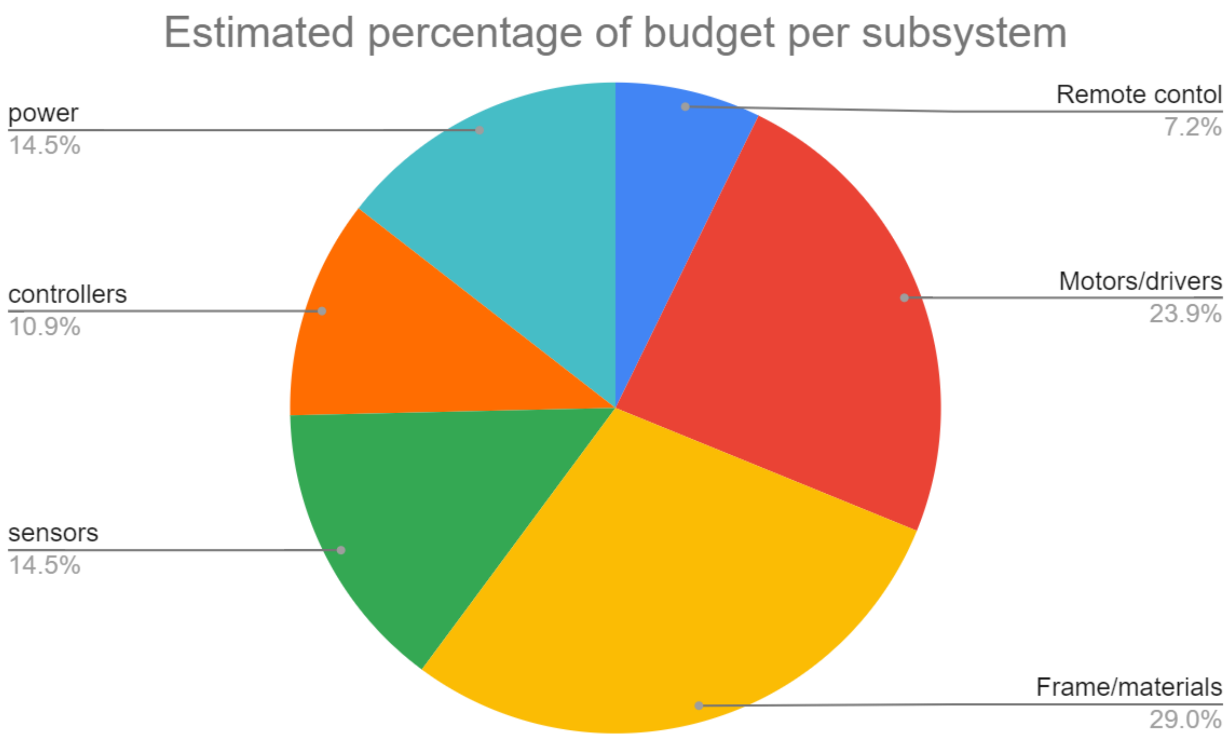


Figure 23. Budget breakdown by percentage

Bill of Materials

BOM				
Item	Cost	Quanity	Total cost	Link
Nema 8 stepper motors	$25.00	3	$75.00	https://www.ama
Nema 17 stepper motors	$23.00	2	$46.00	https://www.ama
Lead screw	$13.00	1	$13.00	https://www.ama
Arduino Leonardo	$25.00	1	$25.00	https://www.ama
Stepper motor drivers	$14.00	5	$70.00	https://www.ama
Voltage step down	$17.00	1	$17.00	https://www.ama
Power Supply	$31.00	1	$31.00	https://www.ama
Bearings 8mm ID (12pack)	$10.00	2	$20.00	https://www.ama
C-beam (1000mm)	$35.00	1	$35.00	https://openbuild
Sum:			$332.00	

References

[1] T. Becker, “Capstone Catheter Roller Fall24 v1,” unpublished.

[2] L. W. McKeen, *Fatigue and Tribological Properties of Plastics and Elastomers*, 3rd ed., 2016. [Online]. Available: https://www.sciencedirect.com/book/9780323442015/fatigue-and-tribological-properties-of-plastics-and-elastomers#book-info. Accessed: Oct. 6, 2024.

Thank you

Questions?