F24 Capstone
Catheter Roller Robot

Gray Becker

Joshua Hernandez

Joshua Parra

NAU NORTHERN ARIZONA UNIVERSITY

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

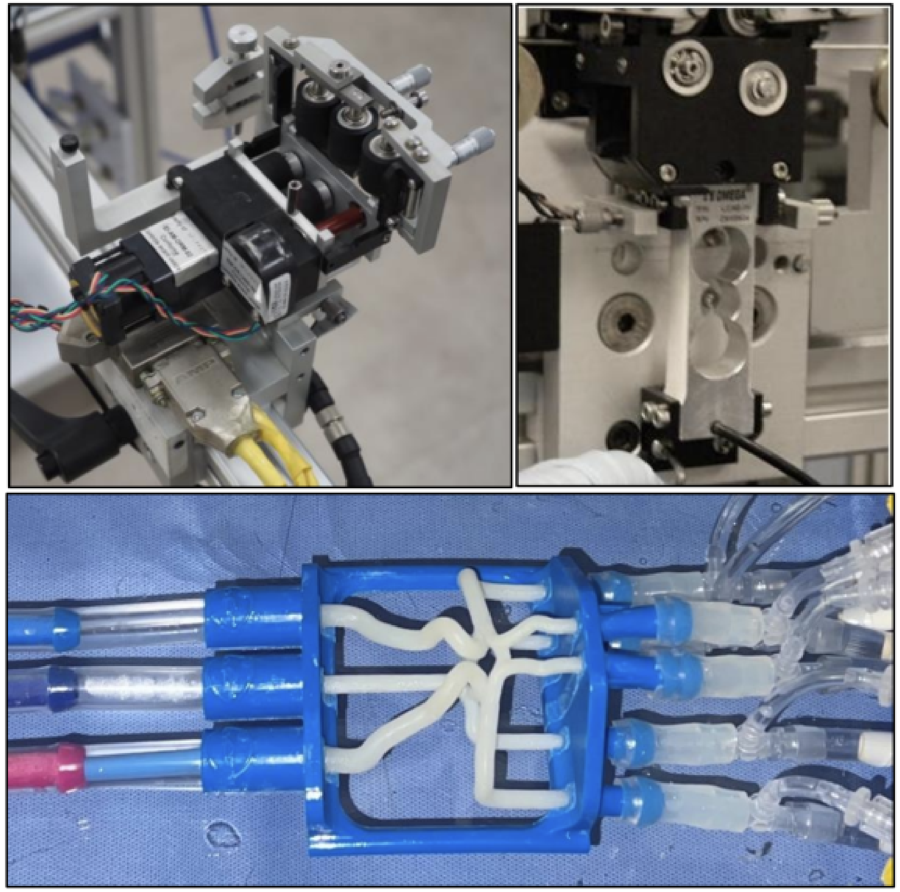

Figure 1. Top: Machine Solutions (MSI) IDTE Catheter Roller, Bottom: BDL Circle of Willis Model [1]

Schedule: Gantt Chart

Catheter Roller

F24toSp25_01 **Gray Becker**

SIMPLE GANTT CHART by Vertex42.com
https://www.vertex42.com/ExcelTemplates/simple-gantt-chart.html

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	0%	9/16/24	9/18/24
Presentation 2 Slides	All	0%	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	All	0%	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	0%	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	All	0%	11/29/24	12/6/24

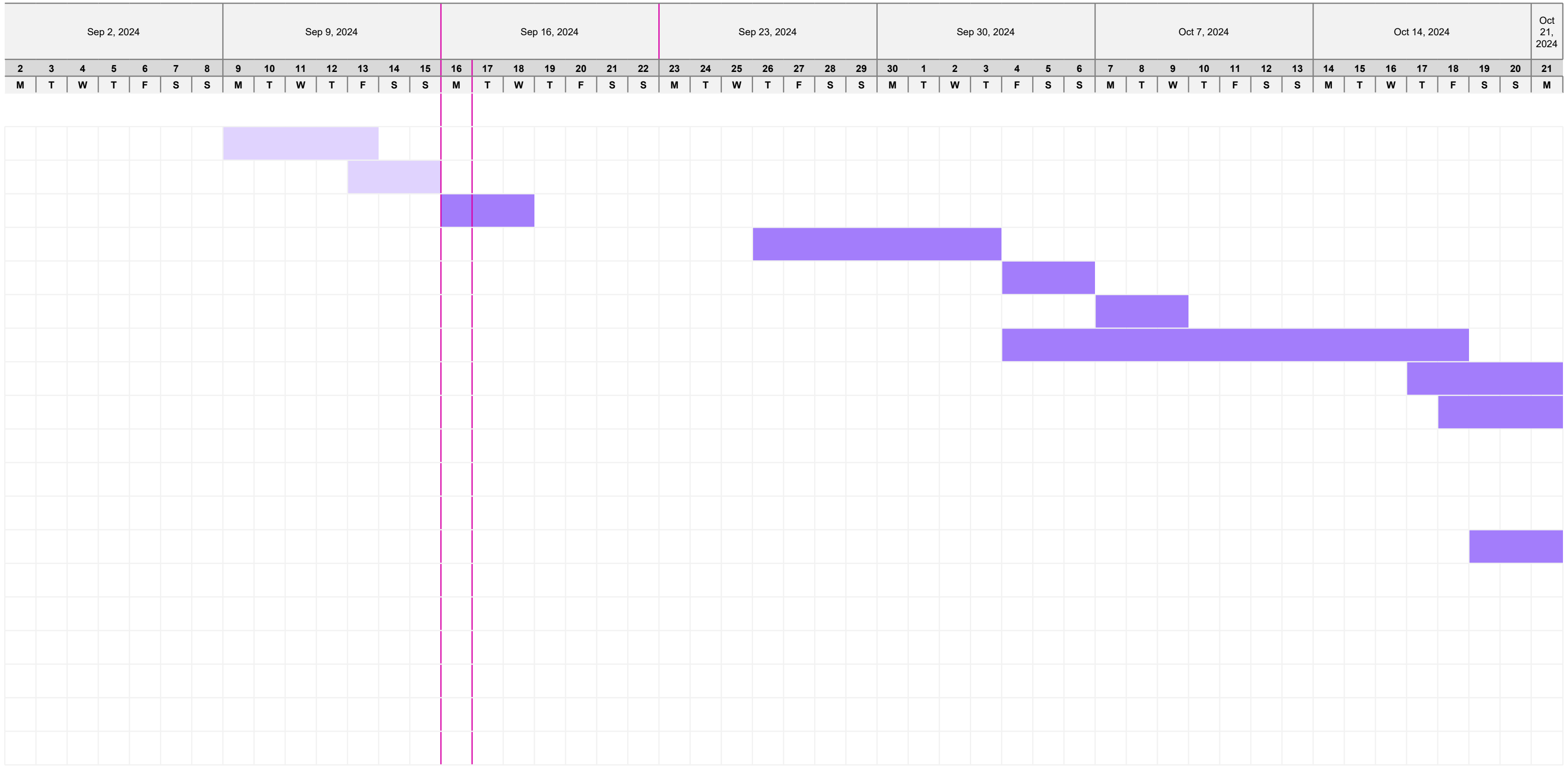

Figure 2. Catheter Roller Team Gantt Chart Course Deliverables – First Half

Schedule: Gantt Chart

Catheter Roller

F24toSp25_01 **Gray Becker**

SIMPLE GANTT CHART by Vertex42.com
https://www.vertex42.com/ExcelTemplates/simple-gantt-chart.html

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	0%	9/16/24	9/18/24
Presentation 2 Slides	All	0%	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	All	0%	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	0%	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	All	0%	11/29/24	12/6/24

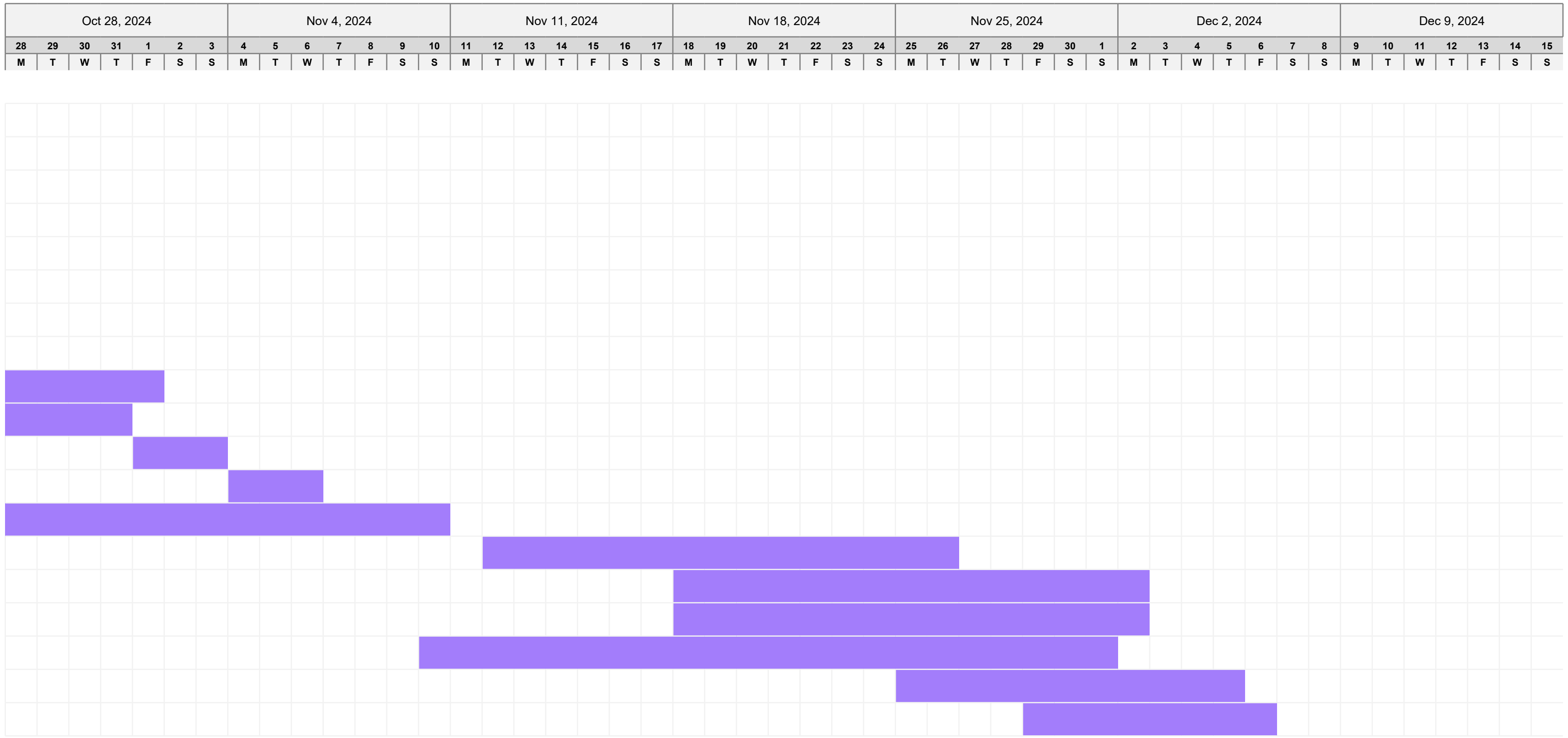

Figure 3. Catheter Roller Team Gantt Chart Course Deliverables – Second Half

Customer Requirements

- Translation and rotation of catheter
- Pre-programmed or controlled remotely
- Measure data instantaneously
- Emergency stop system
- Level the introducer and system to prevent kinking
- Force measurement equipment easy to replace
- Mechanism to prevent load cell damage
- Easy to disassemble/reassemble, transport case
- Force and distance calibrations and testing

Engineering Requirements

- Translation of catheter at least 2 ft
- Rotation of catheter at least 360 degrees
- Remote controlled from at least 10 ft away
- Sampling rate frequency between 5-30 Hz
- Handle catheter sizes between 2-15 French
- Measure push resistance force between 0.1-10 N
- Measure displacement of catheter with resolution of at least 0.1 mm
- System noise/tolerance: ± 0.05 N
- Total size under 1 cubic foot

Design Requirements

QFD

Translate catheter over distance								
Full rotation of catheter	3							
Controlled from a distance	1							
Fast sampling rate		3	3					
Handle variable diameters		1						
Measure push resistance	1			3	1			
Measure displacement resolution	9			3				
Low system noise/tolerance			1	9		3	3	
Limited volume	1		1			1	1	

Project title:	Catheter Roller
Project team:	F24toSp25_02
Date:	9/11/2024

Figure 4. QFD: Relative importance of Engineering Requirements [2]

Design Requirements

		Technical Requirements									Customer Opinion Survey				
Customer Needs	Customer Weights	Translate catheter over distance	Full rotation of catheter	Controlled from a distance	Fast sampling rate	Handle variable diameters	Measure push resistance	Measure displacement resolution	Low system noise/tolerance	Limited volume	1 Poor	2	3 Acceptable	4	5 Excellent
Translation and rotation of catheter	1	9	9	1	3	3		9	3				A		B C
Pre-programmed or controlled remotely	1	3	3	9			1		3			A			B C
Measure data instantaneously	3	1	1		9	1	3	3	9						A C
Emergency stop system	2			3					1				C		A
Level introducer and system to prevent kinking	3						9								A
Force measurement equipment easy to replace	4						3			1			A		
Mechanism to prevent load cell damage	3				3		3		1					A	
Easy to disassemble/reassemble, transport case	5			1						9	A		C		B
Force and distance calibrations and testing	3	3	3		1	3	3	3					C		A
Technical Requirement Units		ft	degrees	ft	Samples/sec	F	lbf	in	lbf	ft^3	Legend	System name			
Technical Requirement Targets		2	360	10	5 to 30	2 to 15	0.0225-2.25	0.0034	0.0112	<1	A	MSI interventional device testing equipment 3000			
Absolute Technical Importance		24	24	21	42	15	67	27	38	49	B	Microbot Medical: Liberty Robot			
Relative Technical Importance		1	2	3	7	4	6	5	8	9	C	Catheter Navigation Using Haptic			

Figure 5. QFD: Engineering and Customer Requirements [2]

Background and Benchmarking

Autonomous Robotic Intracardiac Catheter Navigation Using Haptic Vision [3]

- Robotics catheter system capable of navigation through the heart
- Computer software design (CPU, code, controls)
- Force sensor

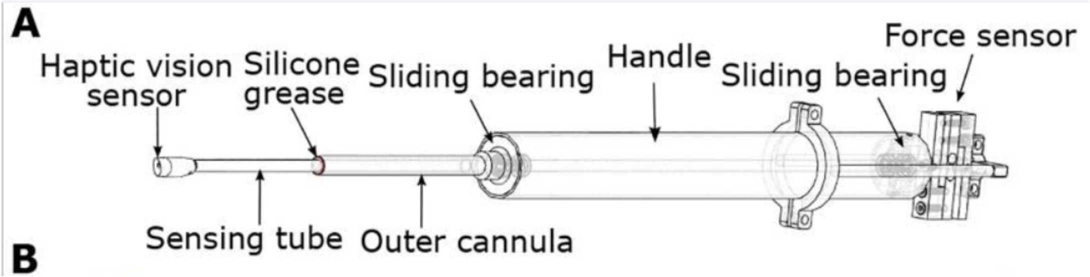

Figure 6. Force sensor diagram [3]

Background and Benchmarking

- Commercially available tool that aligns with our design criteria
- Can guide catheters through model vein networks
- It contains components such as pneumatic clamps, servo rollers, and measurement controls
- Provides testing data on various force and torque set ups

Machine Solutions IDTE 3000 [4]

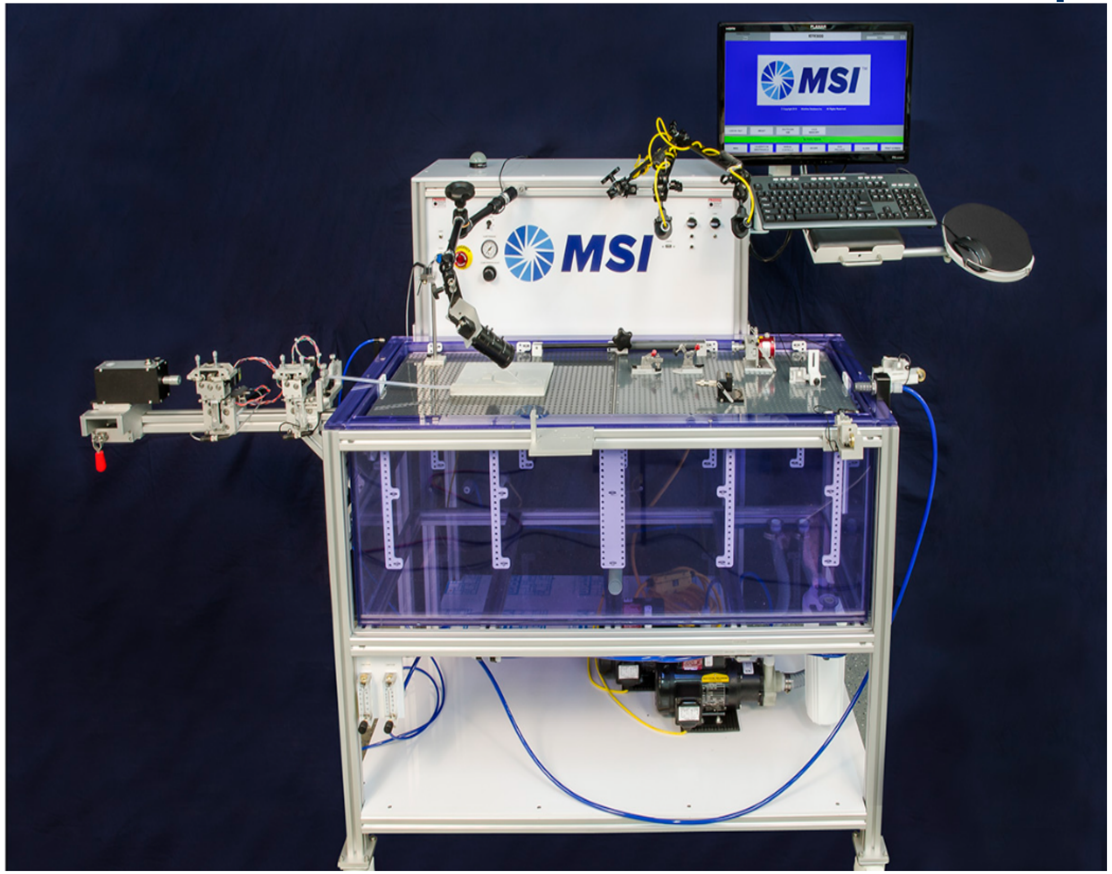

Figure 7. Machine Solutions IDTE [4]

Background and Benchmarking

Microbot Medical: Liberty Robot [5]

- Small disposable device attaching to patient's thigh
- Handheld remote similar to video game controller to advance microcatheters
- Works with off-the-shelf catheters from other manufacturers

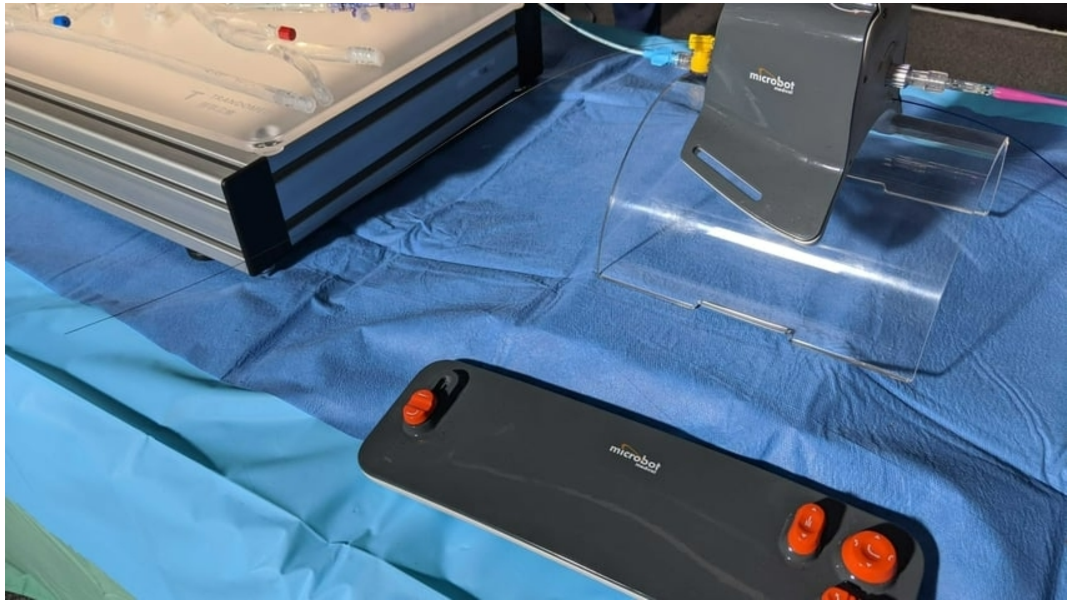

Figure 8. Microbot Liberty System Device and Controller [5]

Budget

Income			
From Sponser			$5,000
From Fundraising			$500
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%

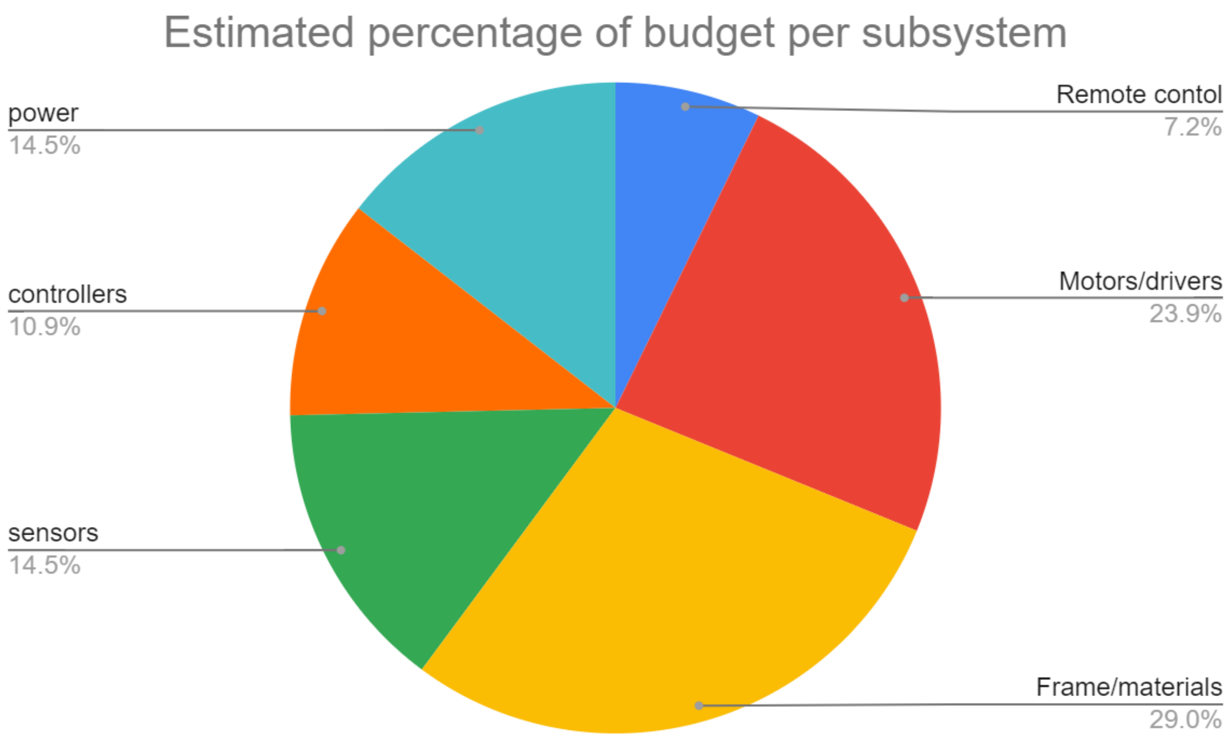

Figure 9. Budget breakdown by percentage

Literature Review

LabVIEW Fundamentals [6]	Basics and how to's from LabVIEW. Will help us if we decide to use LabVIEW for our program
Machinery's Handbook(pg. 754-1003) [7]	Pages cover common material properties and testing methods. Will help us select the right material for purchasing and manufacture parts
Friction characteristics and servo control of a linear peristaltic actuator [8]	Paper on a solution to non-linear pneumatics. Will help if we use pneumatics in our design
Prevention of Servo-Induced Vibrations in Robotics [9]	Explains how to minimize vibrations in robotic systems. Will help us reduce unnecessary motion transferred to the catheter
Software interfacing of servo motor with microcontroller [10]	Describes how to program a servo motor with MATLAB and a microcontroller. Will help us with programing our motor controls
ISO 25539-1:2017 [11]	This standard is about the conditions for the tests of endovascular devices.
ViVitro Labs Catheter Testing and Delivery System Testing [12]	Provides examples of procedures for different catheter tests. Can be used for system inspiration
The six factors you need to consider when picking a force sensor [13]	Lists the information to think about for using a force sensor. Will help us find one that fits our needs

Literature Review

Handbook to electric motors, 2nd ed. Chapter 2: types of motors and their characteristics [14]	Section 2.5: Motors for special applications, talks in depth about stepper motors their uses and how to decide which motor is best suited for your project based on your needed characteristics.
Nema standard for stepper motors [15]	A commonly used standard pertaining to motor size and dimensions. Allow for motors with many characteristics to still 'fit' in a standard size frame
Electromate stepper motor catalog [16]	Information on all motors using the NEMA standard. Will be useful in gathering relative information on commercially available motors in order to find the best option for our project.
Selection of Microcontroller board and stepper motor driver for FDM 3D printing to reduce power consumption [17]	This paper goes over microcontrollers and drivers for stepper motors. Will be helpful in choosing the correct controller for our needs while also keeping power consumption in mind
Handbook to electric motors, 2nd ed. Chapter 3: Motor Selection [18]	Section 3.1: Standards, Goes over standards of motors and helps you understand and use these standards showing how said standards can apply to a range of different motors.
Tech tip: How to choose and use stepper motor power supply from automationDirect [19]	An online video which helps with general rules of thumb to choose and appropriate power supply. Includes info about voltage and current at different rpms and what power supply is best.
Selecting the best power supply for your stepper motor or servo motor application [20]	An online article going over the different types of power supplies in technical detail. Will be very helpful In choosing the correct type of power supply based on characteristics needed for the application.
A design of the automatic anti-collision system [21]	Goes over embedded systems design to help with 'anti-collision,' in our case it can be repurposed for telling us when to emergency stop the machine before it breaks our artery model.

Literature Review

Theory and Design for Mechanical Measurements 7th Edition [22]	Measurements, uncertainties, and mechatronics of sensors, actuators, and controls. Determine how to obtain accurate and required data collection from client.
Shigley's Mechanical Engineering Design 11th Edition Chapter 19 [23]	Finite-element analysis of different geometries to find loads and torques. Determine potential design component points with high loads or torsion.
Modeling and Estimation of Tip Contact Force for Steerable Ablation Catheters [24]	Analysis of catheter shaft curvature to determine contact force with catheter tip. Measure reaction force of catheter indirectly.
Force Calibration for an Endovascular Robotic System with Proximal Force Measurement [25]	Indirect force measurement via motor transmission of forces to catheter tip. Measure reaction force of catheter indirectly.
Accurate Estimation of Tip Force on Tendon-Driven Catheters Using Inverse Cosserat Rod Model [26]	Equation and determination of relationship between catheter curvature and contact force. Measure reaction force of catheter indirectly.
ISO 10555-1:2023 [27]	Kink, torque, and tensile forces required for catheters. Inform design requirements for components interacting with catheter.
ZwickRoell Horizontal Testing of Catheter Systems [28]	Test machine for catheter coefficient of friction and breakaway torque. Example of indirectly measured insertion force, track force, and lubricity.
Nanoflex Robotics Advanced Magnetic Technology [29]	Magnetism to position and guide catheter tip through blood vessels. Example of external robotic manipulation to guide catheter through patient.

Mathematical Modeling

Critical Load(P_{cr}): Max load before deformation

$$I = \frac{\pi(R^4 - r^4)}{64}$$

$$= \frac{\pi(1.5^4 - 1^4)}{64}\left(\frac{1\ m}{1000\ mm}\right)^4$$

$$= 1.99 * 10^{-13}$$

$$P_{cr} = \frac{\pi^2 IE}{L^2}\ [30]$$

$$= \frac{\pi^2 * 1.99 * 10^{-13} m\text{^}4 * 2.6 * 10\text{^}8 Pa}{0.6096^2\ m^2}$$

$$= \boxed{0.0014\ N}$$

Knowns(*assumed)
Material = Pebax
R = 1.5 mm
(average F size)
r = 1 mm*(R - 0.5)
L = 0.6096m(2 ft)
E = 260 MPa
C = 1 mm*

Graph: Treat catheter like column

Assumptions: no deformation at ends, pin connections, no rotation

$$X = C\sin\left(\sqrt{\frac{P}{EI}}Y\right) = 0.001m * \sin\left(\sqrt{\frac{P}{5.185*10^{-5}}}Y\right)\ [30]$$

C = max deformation (tolerance between catheter and vein wall)

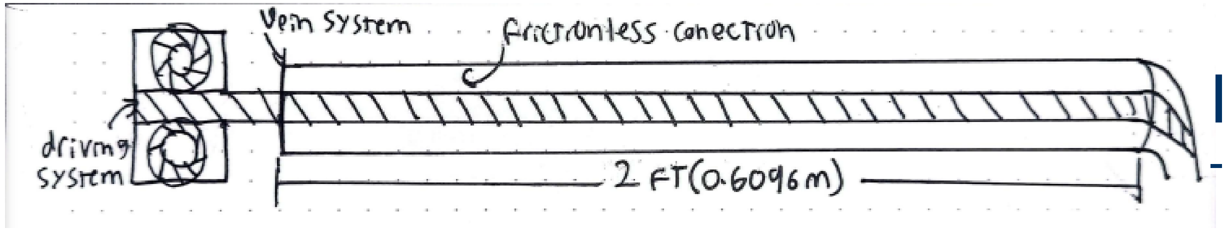

Figure 10. Diagram of model and assumptions

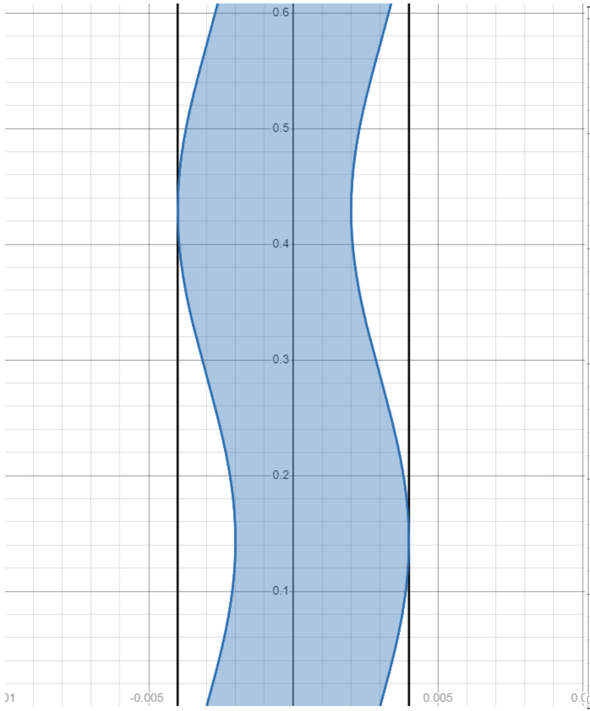

Figure 11. Deformation when P = 0.1N [31]

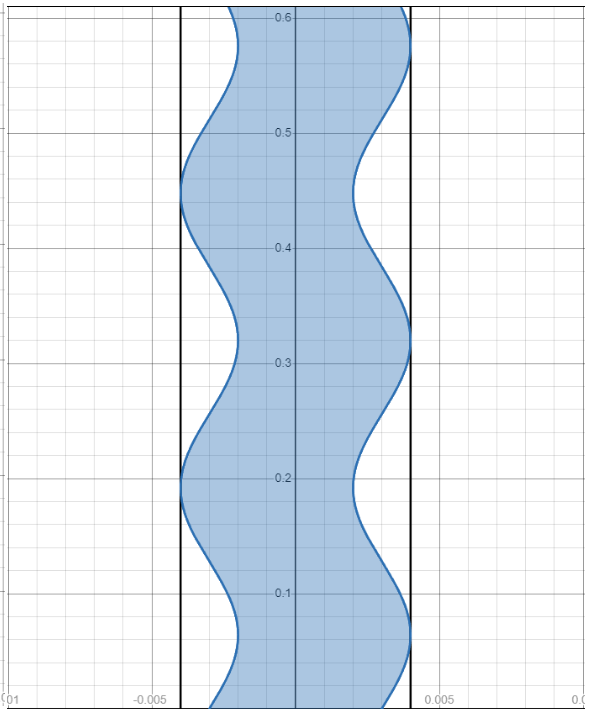

Figure 12. Deformation when P = 0.5 N [31]

In conclusion:

- Demonstrates how the catheter acts when pushed without rotation.
- Importance of balancing rotation and translation

- Deformation can occur at as low as 0.002 N, as shown in the calculations.
- Loads over 0.5 N can cause damage to catheter and vein

- Gives data on how to measure and calculate the push resistance

Mathematical Modeling

Power Supply Calculations

Motor choice speculation:

ER: 0.1 mm res.

Motor step size: 1.8°

$$\frac{L}{(\theta * (\frac{\pi}{180}))} = r$$

r ≤ 3.2 mm

ER: 0.1 to 10 N

Torque:

T ≥ 4.5 oz-in

Voltage: 5 V
Current: 0.5 A
Motor
Voltage: 24 V
Current: 2 A
2 Motors
Power Calculation:
P = V*I
96 W

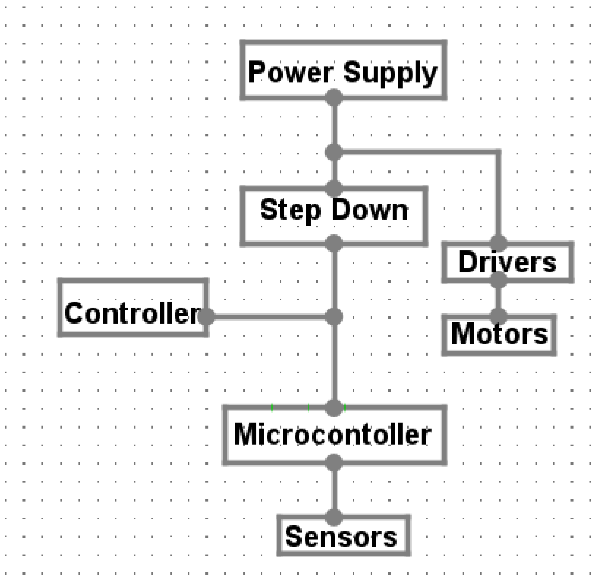

Figure 13. Power Supply tree breakdown

Conclusion:
Using ER to find a rough estimate of motor specs.
Finding equivalent real-life motor
Using real motors specs. for estimates V and I
Power supply: 96 W 24 V 4 Amps

Mathematical Modeling

- Finding cross-sectional area of undamaged, clamped catheter
  - Push force: $F_{fmax} = 10\ N$
  - Coefficient of friction (est. worst case): $\mu = 0.1$
  - $F_N = \frac{F_f}{\mu} = \frac{10\ N}{0.1} = 100\ N$
  - 55D Pebax: $\sigma_y = 12\ MPa$ [32]
  - $A_c = \frac{F}{\sigma} = \frac{100\ N}{12*10^6 Pa} = 8.33 * 10^{-6}\ m^2 = 8.33\ mm^2$
  - $d = 2 * \sqrt{\frac{A_c}{\pi}} = 2 * \sqrt{\frac{8.33\ mm^2}{\pi}} = 3.26\ mm \approx 10\ F$

References

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

[2] Copyright © 2005 Kevin Otto, www.robuststrategy.com, kevin_n_otto@yahoo.com,http://www.kevinotto.com/RSS/templates/QFD Template.xls, Modified from a template from Design4X Inc.

[3] G. Fagogenis et al., “Autonomous robotic intracardiac catheter navigation using Haptic Vision,” Science robotics, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6693882/ (accessed Sep. 16, 2024).

[4] M. Equipment, “Catheter and medical device testing equipment with water tank,” MSI, https://msi.equipment/product/idte_3000/ (accessed Sep. 12, 2024).

[5] C. Hale, “JPM: Microbot Medical unveils disposable device for remote catheter procedures.” Fierce Biotech. https://www.fiercebiotech.com/medtech/jpm-microbot-medical-unveils-disposable-device-for-remote-catheter-procedures (accessed Sept. 14, 2024).

[6] *LabVIEW Fundamentals*. National Instruments Corporation(accessed Sept. 13, 2024).

[7] E. OBERG, El al, “TOOLING AND TOOLMAKING,” in *Machinery’s Handbook*, 29th ed, INDUSTRIAL PRESS, INC., 2012, pp. 754–1003

[8] J. F. Carneiro and F. G. de Almeida, “Friction characteristics and servo control of a linear peristaltic actuator,” The International Journal of Advanced Manufacturing Technology, vol. 96, no. 5–8, pp. 2117–2126, Feb. 2018. doi:10.1007/s00170-018-1678-6

[9] P. Larsson, “Prevention of Servo-Induced Vibrations in Robotics ,” thesis, 2011

[10] A. Haidar, C. Benachaiba, and M. Zahir, “Software interfacing of servo motor with microcontroller ,” Journal of Electrical Systems, vol. 9, pp. 84–99. [Online]. Available: https://ro.uow.edu.au/eispapers/468/

[11] Cardiovascular implants — Endovascular devices, ISO 25539-1, 2017

[12] “Catheter testing and delivery system testing,” ViVitro Labs, https://vivitrolabs.com/services/catheters-and-delivery-systems/.

[13] J. Lyon, “The six factors you need to consider when picking a force sensor,” Interlink Electronics, https://www.interlinkelectronics.com/blog/the-factors-you-need-to-consider-when-choosing-a-force-sensing-solution (accessed Sep. 12, 2024).

[14] H. A. Toliyat and G. B. Kliman, *Handbook of Electric Motors*, 2nd ed. New York: Marcel Dekker, 2004, ch 2.

[15] NEMA ICS 16-2001.

[16] “Nema stepper motors - NEMA steppers: Electromate inc,” Electromate Inc., https://www.electromate.com/mechatronic-automation/mechatronic-automation-components/stepper-motors/nema-stepper-motors/ (accessed Sep. 14, 2024).

References

[17] V. Vladinovskis, "Selection of microcontroller board and stepper motor driver for FDM 3D printing to reduce power consumption," 2023 IEEE 64th International Scientific Conference on Power and Electrical Engineering of Riga Technical University (RTUCON), Riga, Latvia, 2023, pp. 1-6, doi: 10.1109/RTUCON60080.2023.10413037.

[18] H. A. Toliyat and G. B. Kliman, *Handbook of Electric Motors*, 2nd ed. New York: Marcel Dekker, 2004, ch 3.

[19] "Tech tip: How to choose and use Stepper Motor Power supplies from AutomationDirect," AutomationDirect, https://www.automationdirect.com/videos/video?videoToPlay=lTtYkofw-Jg#:~:text=We%20recommend%20two%20different%20ways,phase%20current%20of%206.3%20amps. (accessed Sep. 14, 2024).

[20] "Selecting the best power supply for your stepper or Servo Motor Application," Teknic, Inc., https://teknic.com/selecting-power-supply/ (accessed Sep. 14, 2024).

[21] H. Zhu, M. Zhou and S. Zhu, "A Design of the Automatic Anti-Collision System," 2009 International Workshop on Intelligent Systems and Applications, Wuhan, China, 2009, pp. 1-4, doi: 10.1109/IWISA.2009.5072613.

[22] R. S. Figliola and D. E. Beasley, *Theory and Design for Mechanical Instruments*, 7th Edition. Hoboken, NJ: Wiley, 2019. [Online]. Available: https://www.wiley.com/en-us/Theory+and+Design+for+Mechanical+Measurements%2C+7th+Edition-p-9781119475651. Accessed: Sep. 13, 2024.

[23] R. G. Budynas and J. K. Nisbett, "Finite-Element Analysis," in *Shigley's Mechanical Engineering Design*, 11th Edition. New York, NY: McGraw-Hill Education, 2020, ch. 19, pp. 955-974. [Online] Available: https://www.mheducation.com/highered/product/shigley-s-mechanical-engineering-design-budynas-nisbett/M9780073398211.html. Accessed: Sep. 13, 2024.

[24] M. Khoshnam, A. C. Skanes, and R. V. Patel, "Modeling and estimation of tip contact force for steerable ablation catheters," *IEEE Trans Biomed Eng.*, 2015. doi: 10.1109/TBME.2015.2389615.

[25] N. K. Sankaran, P. Chembrammel, and T. Kesavadas, "Force calibration for an endovascular robotic system with proximal force measurement," *International Journal of Medical Robotics and Computer Assisted Surgery*, vol. 16, no. 2, Apr. 2020, https://doi.org/10.1002/rcs.2045.

[26] A. Hooshiar, A. Sayadi, M. Jolaei, and J. Dargahi, "Accurate Estimation of Tip Force on Tendon-driven Catheters using Inverse Cosserat Rod Model," *2020 International Conference on Biomedical Innovations and Applications (BIA)*, Varna, Bulgaria, 2020, pp. 37-40, doi: 10.1109/BIA50171.2020.9244512.

[27] *Intravascular Catheters – Sterile and single-use catheters*, ISO 10555-1, 2023.

[28] "Horizontal Testing of Catheter Systems." ZwickRoell. https://www.zwickroell.com/industries/medicalpharmaceutical/catheters-and-stents/horizontal-testing-of-catheter-systems/ (accessed Sep. 13, 2024).

[29] Nanoflex. https://nanoflexrobotics.com (accessed Sep. 13, 2024).

[30] R. C. HIBBELER, "Chapter 13," in *Mechanics and Materials*, 10th ed, Pearson Education, Inc., pp. 686–689

[31] Graphs made in Desmos

[32] S. A. Lynn, S. B. Moore, A. C. Griffin, B. D. Hayes, and D. E. Tanner, "Evaluating the performance of a configurable finite element model as a tool in composite catheter design," 30th International Conference on Flexible Automation and Intelligent Manufacturing (FAIM2021), Athens, Greece, Jun. 2021, https://doi.org/10.1016/j.promfg.2020.10.138.

Thank you

NAU NORTHERN ARIZONA UNIVERSITY

Questions?