Humanoid Hand

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Project Description

A robotic hand that matches the capabilities of the human hand

Sponsored by:
Dr. Zach Lerner
Dr. Reza Razavian

[1]

Black Box Model

TAKEAWAYS:
>> Dyneema (or similar material) tendons
>> Ball bearings for joints
>> CFR printed parts
>> Mix of brushless motors and servos
>> Forward and reverse kinematics in the control algorithm

Quality Function Deployment

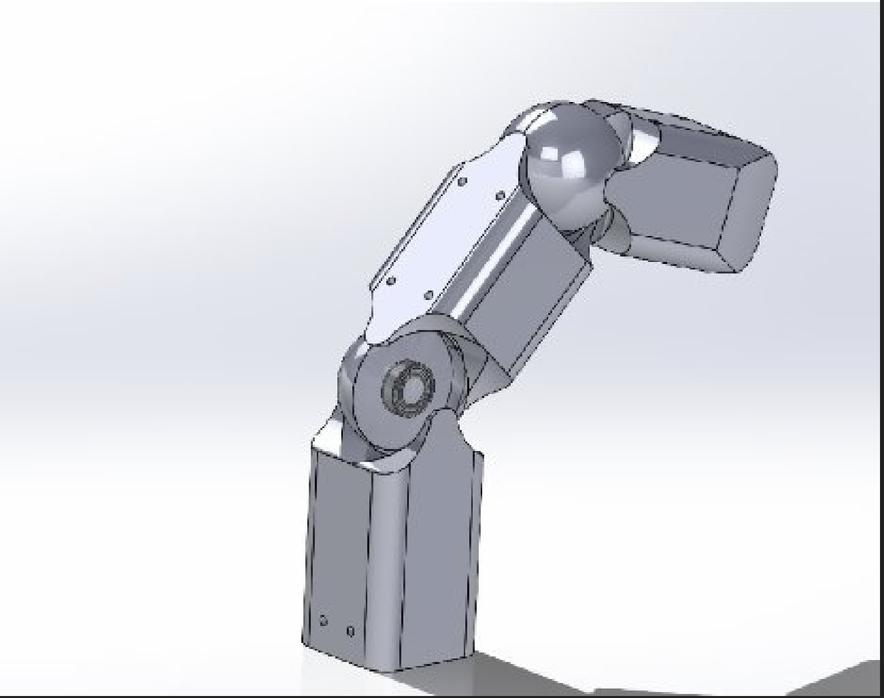
Customer Needs	Customer Weights(1-5)	Grip Force between 240-390N	Time from full extension to full closure is 150-300ms	Approximate size of human hand	Apx 3-4kg	Cost of manufacturing<$1500	apx 20 DOF	Can be opperated by Lerner or Reza with a <10min demo	Each joint ensured up to 10k motions	Able to predict finger segment placement within +/- 5mm based on sensor data	1 *Poor*	2	3 *Acceptable*	4	5 *Excellent*
		Technical Requirements									**Customer Opinion Survey**				
Strength	3	9	3	3	3	9	9	3	9	3		B		C	A
Speed	5	3	9	3	1	9	9	3	9	9			C	B	A
Accurate dimensions	2	3	3	9	9	3	9	3	9	3			A	C	B
Accurate weight	1	9	9	9	9	3	3	3	9	9		A	C		B
Budget	4	9	3	3	9	9	3	9	9	9	A		C		B
Many degrees of freedom	4	3	3	3	3	9	9	9	9	3	C			B	A
Uses stand form of power to function	5	1	1	9	9	9	1	9	3	3					ABC
Has basic and functional ui	4	1	1	1	3	3	3	9	1	9	C			B	A
Percision of motion	4	3	3	9	3	9	3	9	9	9			B		AC
Technical Requirement Units		N	s	s	kg	$	deg	min	#	mm					
Technical Requirement Targets		390	0.3	250	4	150	20	10	10k	5					
Absolute Technical Importance		126	114	160	158	246	170	222	226	204					
Relative Technical Importance		8	9	6	7	1	5	3	2	4					

Legend:	
A	Shadow Hand
B	Dex Hand
C	Optimus Hand

Concept Generation

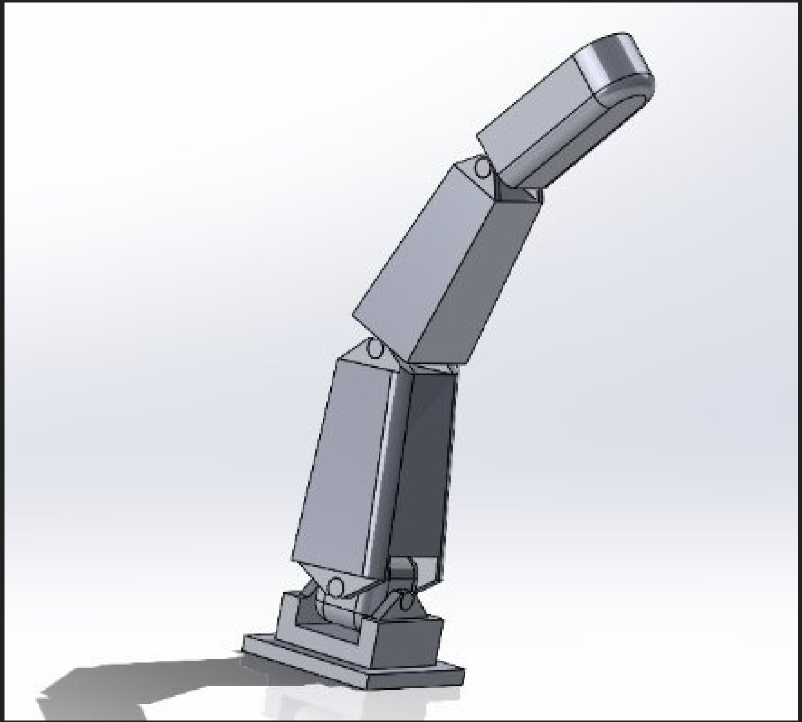
Concept Generation

- Designed for mechanical strength
- As little “play” in the joints as possible
- Easily modifiable to accommodate angle sensors and complex tendon routings
- Does not currently have sensor mounts or definitive tendon placement

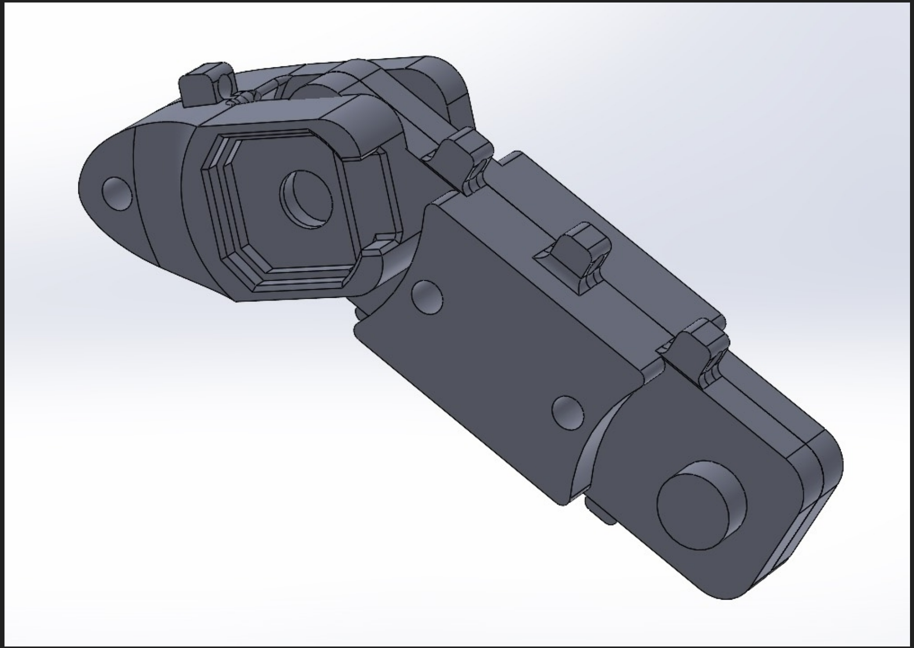


Concept Generation

- Designed for omnidirectional joint
- Uses snap joints for ease of assembly
- Only a proof of concept and practice for 3D printing



Concept Generation - Noah

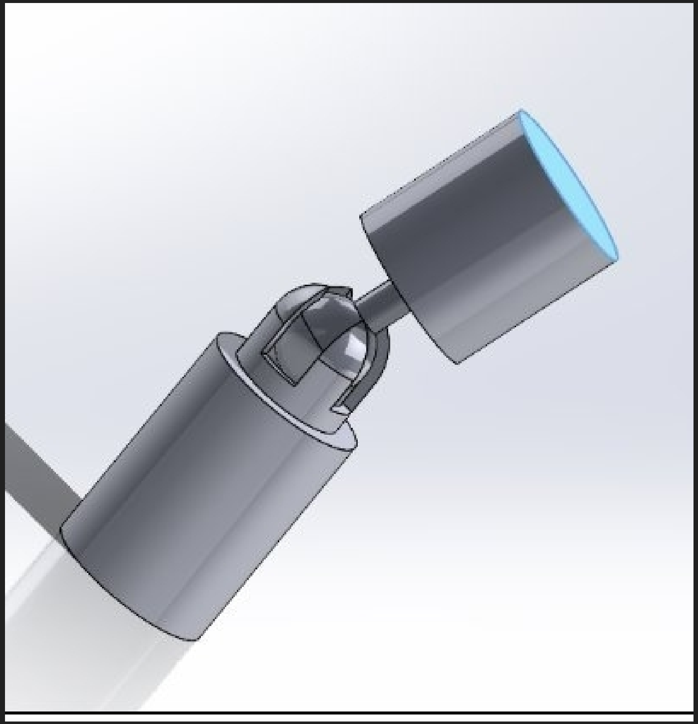


>> Functional rather than sleek

>> Serves as a testbed for angle sensing and tendon actuation

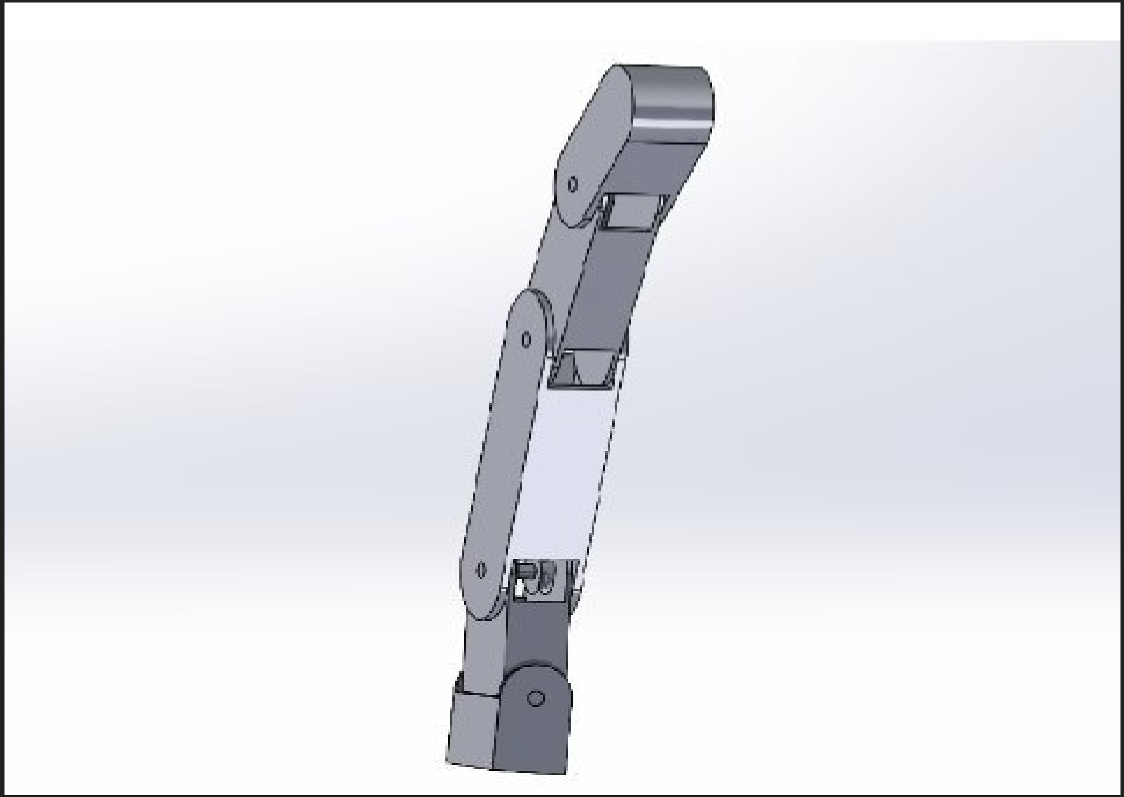
Concept Generation - Tyler

- Base joint multi directional or two separate joints
- Other joints one directional
- Ball and socket
- Flex angle sensor



Concept Generation

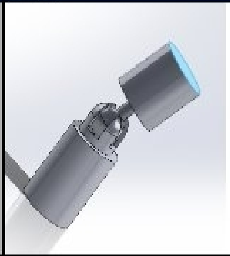
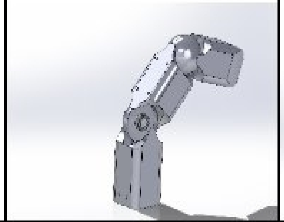
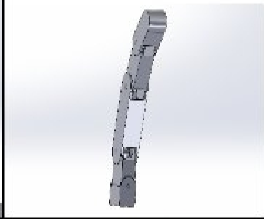
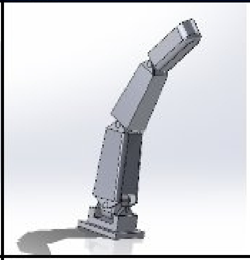
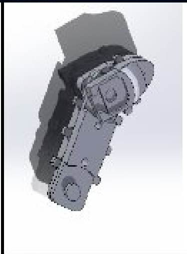
- Hollow body
- Pin hinges
- Tendon routing
- Base joint



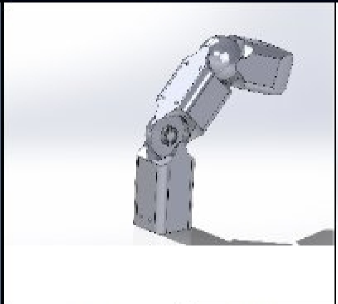
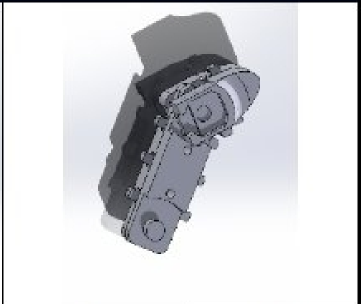
Concept Evaluation-Specification Table

Specification	Importance	Units	Target	Tol.	Comments
Grip Force	2	N	250-350	50	Average grip force of adult
Grip Speed	3	ms	200-300	50	Average reaction time of an adult
Size of Average hand	1	mm	190x85	50x25	Easy to store and more intuitive
Weight of average hand	1	kg	3.5	1	Portable and reflect biology
Cost of Manufacturing	3	$	1500	250	Budget
Many DOF	3	#	20	1	Reflects Biology
Easy to power	3	V	120	0	Operates off US electrical outlet
Easy to use interface	3	min	10	2	Time to teach sponsors interface
Precise and Accurate Motion	3	mm	1	.5	Position is known within this area
Longevity	3	#	10,000	250	Able to be actuated near infinite life

Concept evaluation - Pugh Chart

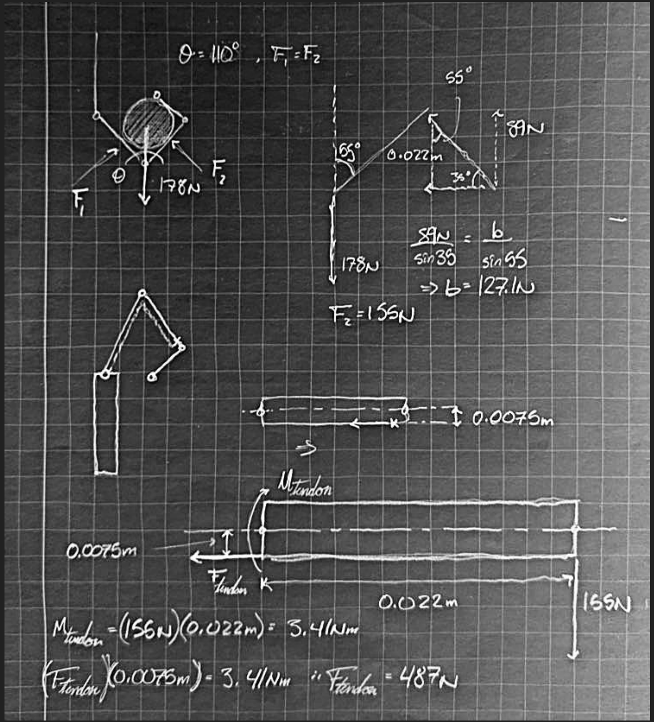
Concept	Design 1	Design 2	Design 3	Design 4	Design 5
Criteria					
Strength	- (thin shaft and socket reduces maximum load allowable)	+ (thick integrated joints allows for increased loading)	- (pin hinges and hollow body reduces allowable load)	Datum	+ (thick integrated joints bear loads well)
Speed	S	S	S	Datum	S
Budget	+ (less prints needed and less volume to print)	- (more material used at joints and overall increases price)	+ (hollow body reduces filament need)	Datum	+ (thinner and less total volume reduces price)
Many degrees of freedom	+ (can move 90+ degrees in either direction)	+ (can move almost 90 degrees)	+ (many joints over 90 degrees in many directions)	Datum	S
Accurate dimensions	- (smaller and thinner than human hand)	+ (More similar overall dimensioins)	- (thinner and longer than human and)	Datum	+ (accurate dimensions except extruded tendon routing)
Reliability	- (socket and shaft will wear and fail due to little material)	+ (integrated joints with bearing have high repeatability and durability)	S	Datum	+ (integrated joints with bearing have high repeatability and durability)
Positonal accuracy	- (no way to intergate angle sensors)	+ (easily integrate angle sensors into the design)	- (needs major adjustment for sngle sensors)	Datum	+ (angle sensor slot already integrated)
Accurate weight	+ (reduced material more accurate to human finger)	- (volume leads to increased excess weight)	+ (hollow body reduces weight and makes it more accurate)	Datum	- (solid body makes for potentially heavier design)
Σ+	3	4	3	n/a	5
Σ-	4	2	3	n/a	1
Σsimilar	1	1	2	n/a	2

Concept Evaluation - Decision Matrix

		Design 2		Design 4		Design 5	
Criteria	Weight						
		unweighted score	weighted score	unweighted score	weighted score	unweighted score	weighted score
Strength	0.1	90	9	75	7.5	93	9.3
Speed	0.2	85	17	85	17	85	17
Positional accuracy	0.2	75	15	75	15	100	20
Budget	0.05	85	4.25	80	4	85	4.25
Many degrees of freedom	0.2	80	16	75	15	75	15
Accurate dimensions	0.05	90	4.5	85	4.25	90	4.5
Reliability	0.15	87	13.05	86	12.9	90	13.5
Accurate weight	0.05	80	4	90	4.5	80	4
Total:	1	Sum:	82.8	Sum:	80.15	Sum:	87.55

Engineering Calculations

Noah - Motor Torque



Python Script

↓

Inputs

↓

Required Motor Torque
=~
2.28Nm

Markus- Motor Speed

- Typical tendons in hand range from 30-50mm
  - Allowable up to 50% increase in hand size so range 45-75mm [4]
- Total reaction time is 300ms assume 25ms for code

$$v = \frac{d}{t} = \frac{40\ \mathrm{mm}}{0.275\ \mathrm{s}} = 145.45\ \mathrm{mm/s}$$

$$\omega = \frac{145.45}{5} = 29.09\ \mathrm{rad/s}$$

$$\mathrm{RPM} = \omega \times \frac{60}{2\pi} = 29.09 \times \frac{60}{6.283} \approx 278\ \mathrm{RPM}$$

- For 5mm spool RPM is 278
- For 10mm RPM is 139
- Ie ≈ 4.6/s or 2.3/s
- Larger spools decrease motor RPM needed at expense of pulling force

Target Degrees of Freedom and Angle Actuation

Target DOF and angles for full actuation, pointing with index, and holding a ball:

Finger	DOF	Base Joint Max Angle (deg)	Middle Joint Max Angle (deg)	Tip Joint Max Angle (deg)	Max Total Angle (deg)	Max Splay Angle (deg)
Index	4	100	135	90	265	45
Middle	4	100	135	90	325	25
Ring	4	100	135	45	280	30
Pinky	4	100	120	90	310	45
Thumb	4	90	X	90	270	90
Thumb Hinge	1	90	X	X	90	X

Full Actuation: Max Angles

Finger	DOF	Base Joint Angle (deg)	Middle Joint Angle (deg)	Tip Joint Angle (deg)	Total Angle (deg)	Splay Angle (deg)
Index	4	45	45	30	120	15
Middle	4	45	45	30	120	15
Ring	4	45	45	25	115	10
Pinky	4	45	45	15	105	25
Thumb	4	60	X	20	80	90
Thumb Hinge	1	80	X	X	80	X

Holding a Ball 2.5in Diameter

Finger	DOF	Base Joint Angle (deg)	Middle Joint Angle (deg)	Tip Joint Angle (deg)	Total Angle (deg)	Splay Angle (deg)
Index	4	0	0	0	0	0
Middle	4	100	135	90	325	0
Ring	4	100	135	45	280	0
Pinky	4	100	120	90	310	0
Thumb	4	45	X	45	90	90
Thumb Hinge	1	90	X	X	90	X

Pointing with index Finger

Target Degrees of Freedom and Angle Actuation Cont.

The middle and tip angles can then be related:

Finger	Middle Joint Max Angle (deg)	Tip Joint Max Angle (deg)	Tip/Middle Ratio
Index	135	90	.667
Middle	135	90	.667
Ring	135	45	.333
Pinky	120	90	.75

Finger	Middle Joint Angle (deg)	Tip Joint Angle (deg)	Tip/Middle Ratio
Index	45	30	.667
Middle	45	30	.667
Ring	45	25	.556
Pinky	45	15	.333

Finger	Tip/Middle Ratio	Tip Joint Angle Equation
Index	.667	$\theta_{Tip} = .667\theta_{Mid}$
Middle	.667	$\theta_{Tip} = .667\theta_{Mid}$
Ring	.556	$\theta_{Tip} = .556\theta_{Mid}$
Pinky	.333	$\theta_{Tip} = .333\theta_{Mid}$

- The tables show that the tip joint angle can be represented as a function of the middle joint
- The equations can be used in a program to read outputs of an angle sensor at the middle joint to actuate the finger tip accordingly

Tyler

- Measurements for the human hand
- Goal is to replicate exact replica of hand
- Upper limit x1.5

	Length(inches)	width (inches)	Other (inches)	Length upper Limit	width upper length	other upper limit
overall length	7.6			11.4		
overall breadth		3.5			5.25	
average circumference			8.6			12.9
Index Finger	4.125			6.1875		
top segment	1.125	0.625		1.6875	0.9375	
middle segment	1.125	0.75		1.6875	1.125	
base segment	1.875	0.875		2.8125	1.3125	
Middle finger	4.75			7.125		
top segment	1.125	0.625		1.6875	0.9375	
middle segment	1.3125	0.75		1.96875	1.125	
base segment	2.3125	0.875		3.46875	1.3125	

3-Link Forward Kinematics

Givens:

$$L_1 = 25 \text{ mm}, \quad L_2 = 20 \text{ mm}, \quad L_3 = 15 \text{ mm}$$

$$\theta_1 = 0^\circ, \quad \theta_2 = -90^\circ, \quad \theta_3 = -45^\circ$$

General Equations:

$$x_1 = L_1 \cos(\theta_1)$$

$$y_1 = L_1 \sin(\theta_1)$$

$$x_2 = x_1 + L_2 \cos(\theta_1 + \theta_2)$$

$$y_2 = y_1 + L_2 \sin(\theta_1 + \theta_2)$$

$$x_3 = x_2 + L_3 \cos(\theta_1 + \theta_2 + \theta_3)$$

$$y_3 = y_2 + L_3 \sin(\theta_1 + \theta_2 + \theta_3)$$

Substituting Values:

$$x_1 = 25 \cos(0) = 25 \text{ mm}$$

$$y_1 = 25 \sin(0) = 0 \text{ mm}$$

$$x_2 = 25 + 20 \cos(-90) = 25 + 20(0) = 25 \text{ mm}$$

$$y_2 = 0 + 20 \sin(-90) = 0 + 20(-1) = -20 \text{ mm}$$

$$x_3 = 25 + 20 \cos(-90) + 15 \cos(-135)$$

$$x_3 = 25 + 0 + 15(-0.707) = 25 - 10.605 = 14.395 \text{ mm}$$

$$y_3 = 0 + 20 \sin(-90) + 15 \sin(-135)$$

$$y_3 = 0 - 20 + 15(-0.707) = -20 - 10.605 = -30.605 \text{ mm}$$

Final Position:

$$(x_3, y_3) = (14.395, -30.605) \text{ mm}$$

Grip Material Analysis

From previous finger force calculations: $F_n = 106\,\mathrm{N}$ -max normal force based on 36 Kg grip force

- Friction force based on rubber coefficient - 0.8 $F_f = \mu \times F_n$

$$F_f = 0.8 \times 106\,\mathrm{N} = 84.8\,\mathrm{N}$$

- Calculated mass of object: $m = \frac{F_f}{g} = \frac{84.8\,\mathrm{N}}{9.81\,\mathrm{m/s^2}} = 8.64\,\mathrm{kg}$

Grip Material Analysis

- Grip force is 8.64 kg - 84.8 N
- Safety Factor of 1.5

$$F_{\text{grip, design}} = \frac{F_{\text{grip}}}{SF}$$

$$F_{\text{grip, design}} = \frac{84.8\,\text{N}}{1.5} = 56.5\,\text{N}$$

- New Calculated Mass:

$$m_{\text{design}} = \frac{F_{\text{grip, design}}}{g}$$

$$m_{\text{design}} = \frac{56.5\,\text{N}}{9.81\,\text{m/s}^2} = 5.76\,\text{kg}$$

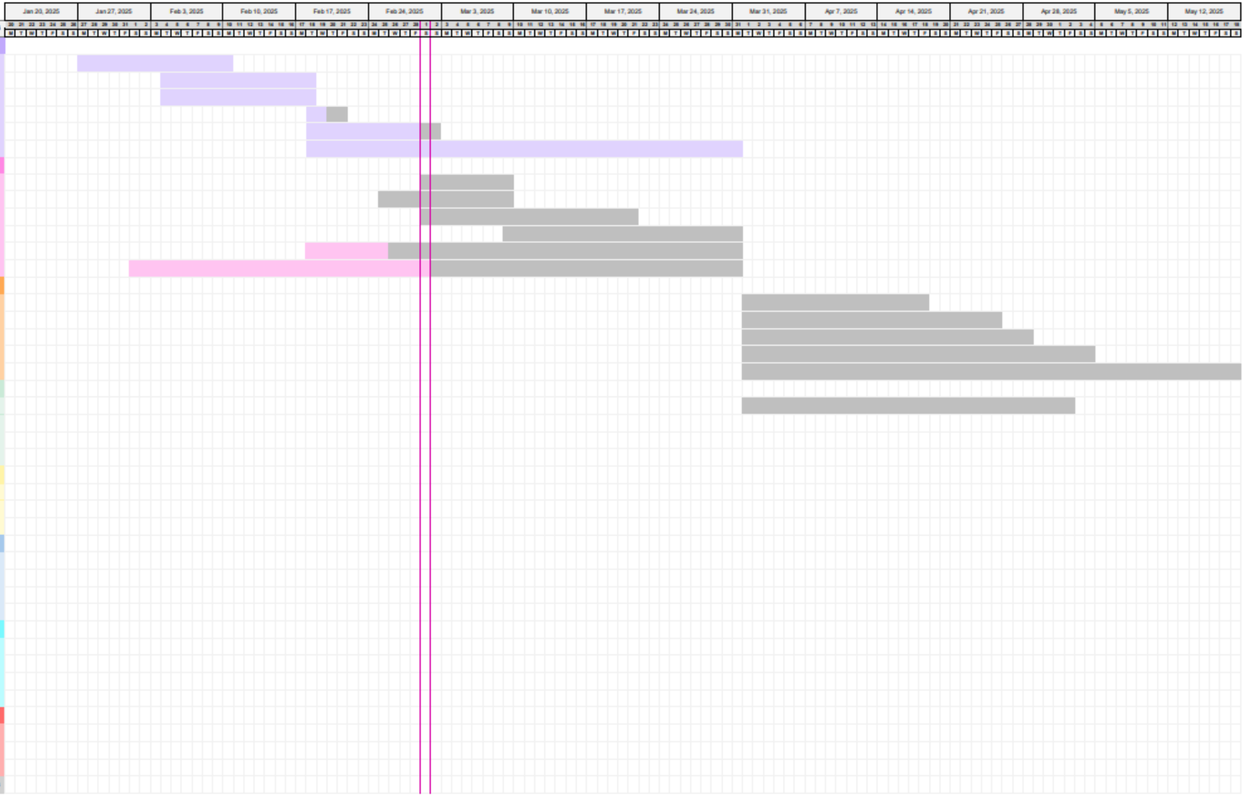
Schedule

Humanoid Hand Gantt Chart

Project start: **Mon, 1/13/2025**

Display week: **2**

TASK	ASSIGNED TO	PROGRESS	START	END	EST. HOURS	ACTUAL HOURS
Phase 1 (1st Prototype Demo)						
Work on Presentation 1	Team	100%	1/27/25	2/10/25	10.00	20.00
Establish Finger Design	Team	100%	2/4/25	2/18/25	30.00	40.00
Establish Control Scheme	Joseph, Noah	100%	2/4/25	2/18/25	10.00	20.00
Order Preliminary Parts	Justin	50%	2/18/25	2/21/25	1.00	
Presentation 2	Team	90%	2/18/25	3/3/25	10.00	
Joint Prototype	Team	100%	2/18/25	3/31/25	40.00	50.00
Phase 2 (Phalange Prototype)						
Report 1	Team	0%	3/1/25	3/9/25	30.00	
Website Check 1	David, Markus	0%	2/25/25	3/9/25	10.00	
Analysis Memo	Team	0%	3/1/25	3/21/25	20.00	
Presentation 3	Team	0%	3/9/25	3/31/25	10.00	
Finger Prototype	Team	20%	2/18/25	3/31/25	60.00	
1st Prototype Demo	Team	50%	2/1/25	3/31/25	5.00	
Phase 3 (Whole Hand)						
Report 2	Team	0%	4/1/25	4/18/25	20.00	
Final CAD and Final BOM	Tyler, Noah	0%	4/1/25	4/25/25	10.00	
2nd Prototype Demo	Team	0%	4/1/25	4/28/25	5.00	
Website Check 2	David, Markus	0%	4/1/25	5/4/25	10.00	
Whole hand Prototype	Team	0%	4/1/25	4/31/25	60.00	
Phase 4 (Startup of 486C)						
Project Management for 486C	Team	0%	4/1/25	5/2/25	10.00	
Project Management	Team	0%	8/28/25	8/30/25	10.00	
Engineering Calculations	Team	0%	8/28/25	9/4/25	10.00	
Double check Prototype and adjus	Team	0%	8/28/25	9/31/25	30.00	
Phase 5 (Building)						
Hardware Status Update - 33%	Team	0%	8/28/25	9/25/25	60.00	
Hardware Status Update - 67%	Team	0%	8/28/25	10/16/25	60.00	
Hardware Status Update - 100%	Team	0%	8/28/25	11/6/25	60.00	
Phase 6 (Collection of Stuff)						
Website Check 3	David, Markus	0%	8/28/25	10/9/25	10.00	
Finalized Testing plan	Team	0%	10/16/25	10/30/25	10.00	
Final CAD Packet	Team	0%	11/1/25	11/20/25	5.00	
Final Report & Final Website chec	Team	0%	11/1/25	11/27/25	30.00	
Phase 7 (E-Fest)						
UGrads registration	Team	0%	10/23/25	10/24/25	1.00	
Draft of poster	Team	0%	10/1/25	10/30/25	15.00	
Final Poster & PPT	Team	0%	11/1/25	11/13/25	20.00	
Presentation	Team	0%	12/8/25	12/8/25	5.00	
Conclusion						
Initial Testing Results Video	Team	0%	11/6/25	11/20/25	5.00	
Product demo	Team	0%	11/6/25	11/27/25	5.00	
Client Handoff	Team	0%	12/11/25	12/11/25	1.00	
					Total Est. Hours	Total Actual Hours
					688.00	130.00



Budget

	Budget Robotic Hand							
	Total Budget							$2,000
Item #	Item	Description	Planned Aquisiton Date	Actual Acquisiton Date	Price Per Unit	# of Units	Estimated Total Price	Actual Total Price
1	Motors	iPower GM2804 Gimbal Motor with AS5048A Encoder	3/20/2025		$42.97	8	$343.76	
2	Motors	INJORA INJS035 35KG	3/20/2025		$16.99	6	$101.94	
3	Filament	PLA Prototyping Filament	3/20/2025		$14.99	1	$14.99	
5	Filament	Onyx Filament	3/20/2025		$209	1	$209	
6	Filament	50cc Carbon Fiber Spool	3/20/2025		$150	1	$150	
7	Computation	Arduino Mega	3/20/2025		$49.65	1	$49.65	
8	Actuation	Dyneema Cord	3/20/2025		$32.99	1	$32.99	
9	Actuation	Bearings	3/20/2025		$12.99	1	$12.99	
	Estimated Remaining Budget							$1,084.68
	Actual Remaining budget							$2,000

Bill of Materials

Part	Quantity	Price	Total Price	Link
Motor				
iPower GM2804 Gimbal Motor w/ AS5048A Encoder	8	42.97	343.76	link
INJORA INJS035 35KG	6	16.99	101.94	link
3D Printed Parts				
PLA Prototyping Filament	1	14.99	14.99	link
Onyx Filament	1	209.00	209.00	link
50cc Carbon Fiber Spool	1	150.00	150.00	link
Hardware - Computation				
Raspberry Pi	1	0.00	0.00	link
Arduino Mega	1	49.65	49.65	link
Hardware - Actuation				
Dyneema Cord	1	32.99	32.99	link
Bearings	1	12.99	12.99	link
ESTIMATED PRICE	$		902.33	

Thank You

References

[1] “Average Hand Size: For Adults, Children, Athletes, and More,” Healthline, Aug. 07, 2019. https://www.healthline.com/health/average-hand-size#worlds-largest-hands

[2] J. N. Ingram, K. P. Körding, I. S. Howard, and D. M. Wolpert, “The statistics of natural hand movements,” Experimental Brain Research, vol. 188, no. 2, pp. 223–236, Mar. 2008, doi: https://doi.org/10.1007/s00221-008-1355-3.

[3] G. I. Bain, N. Polites, B. G. Higgs, R. J. Heptinstall, and A. M. McGrath, “The functional range of motion of the finger joints,” Journal of Hand Surgery (European Volume), vol. 40, no. 4, pp. 406–411, May 2014, doi: https://doi.org/10.1177/1753193414533754.

[4] S. Horibe, S. L. Woo, J. J. Spiegelman, J. P. Marcin, and R. H. Gelberman, “Excursion of the flexor digitorum profundus tendon: A kinematic study of the human and canine digits,” *Journal of Orthopaedic Research*, vol. 8, no. 2, pp. 167–174, Mar. 1990. doi:10.1002/jor.1100080203