

# ***Humanoid Hand***

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# Design Requirements Summary

Customer Requirement	Description
CR1	Strong enough to play the piano and catch a ball
CR2	Fast enough to play the piano and catch a ball
CR3	Accurate dimensions
CR4	Accurate weight
CR5	Within budget
CR6	Many degrees of freedom
CR7	Uses standard form of power to function
CR8	Does not overheat
CR9	Has basic and functional UI
CR10	Reliable
CR11	Precision of motion

Engineering Requirement	Description
ER1	Grip force of 45-50N
ER2	Time from full extension to full closure 200-250ms
ER3	Within 1-1.5 scale of average person's hand and forearm
ER4	Approximately 3-4kg
ER5	Cost of manufacturing <\$1500
ER6	15 degrees of freedom
ER7	Operates with 1-3 120V plugs
ER8	At high operating load, no component exceeds 75°C
ER9	Can be operated by Lerner or Reza with a <10 min demo
ER10	Each joint operable near 10k motions
ER11	Able to predict finger placement within +/- 5mm based on sensor data

**QFD**

System QFD			Project Humanoid Hand																	
			Date: 10/20/2025																	
1		Grp Force	-																	
2		Time for actuation	0	0																
3		Approximate hand size	0	+	0															
4		Approximate hand weight	0	+	+	+														
5		Cost	0	+	0	+	0													
6		Degrees of freedom	0	0	+	0	0	+												
7		Standard Power	0	0	0	0	0	0	0											
8		Does not overheat	+	0	0	0	0	0	0	0										
9		Easy to operate UI	+	0	0	0	0	+	-	+	0									
10		10,000 actuations	+	+	+	-	-	-	-	0	+	0								
11		Precision of motion	+	+	+	-	-	-	+	0	0	+	+							
			Technical Requirements										Customer Opinion Survey							
			Customer Weight(1-5)	Grip Force between 45-50N	Time from full extension to full closure is 200-250ms	Approximate size of human hand(1-1.5 scale)	Apx 3-4kg	Cost of manufacturing-\$1500	apx 15 DOF	Operates with 1-3 standard 120V plugs	At room temperature under extreme load; no component exceed	Lamar and Reza give the cooperator an average of 4/5 scores	Each joint ensured up to 10k motions	Able to predict finger segment placement within +/- 5mm based sensor data	f Finger	y	B Acceptable	d	E Excellent	
Customer Needs																				
1		Strength		5	9	3	3	3	9	9	3	3	9	3			B	(C)	C	A
2		Speed		5	3	9	3	1	9	9	3	3	3	1	3			(C)	B	A
3		Accurate dimensions		2	3	3	9	9	3	9	0	0	3	0	3			A	C	B
4		Accurate weight		1	9	9	9	9	3	3	0	0	0	0	0			(C)	B	B
5		Storage		4	9	3	3	9	9	3	0	0	9	0	0	A			B	A
6		Many degrees of freedom		4	3	3	3	3	9	0	0	0	3	3	0	(C)			B	A
7		Shows stand form of power to function		5	1	1	9	9	9	1	9	3	0	0	0				AB(C)	
8		Does not overheat		5	0	0	0	0	0	1	1	9	3	9	0				AS	C
9		Max basic and functional op	4	1	1	1	3	3	3	0	9	0	1	(C)				B	A	
10		Reliable	4	3	1	0	0	0	1	0	9	3	9	0				AS	C	
11		Precision of motion	4	3	3	9	3	9	3	0	9	0	0	0				B	AC	
			Technical Requirement Units															Legend:		
			Technical Requirement Targets															Shadow Hand		
			Absolute Technical Importance															Dex Hand		
			Relative Technical Importance															Optimus Hand		

# Top Level Testing Summary

Experiment/Test	Relevant Design Requirements
T1- Static Grip Strength	CR1, ER1
T2- Actuation Speed Test	CR2, ER2
T3- Weight and Size Test	CR3, CR4, ER3, ER4
T4- Durability and Thermal Release	CR8, CR10, ER8, ER10
T5- Sensor Accuracy Calibration	CR11, ER11
T6- Power Draw Test	CR7, ER7
T7- User Interface Evaluation	CR9, ER9
T8- Functional Performance Test	CR1, CR2, CR11, ER1, ER2, ER11
T9- Degrees of Freedom and Budget Evaluation	CR5, CR6, ER5, ER6

# ***Detailed Testing Plan – Strength testing***

- Equipment: Load Cell, hanging scale, rigid mounting fixture, data logger
- Variables Measured: Applied fingertip force (N), grip force (N)
- Variables Calculated: Converted mass to force
- Procedure (Static Finger):
  - Mount the hand securely to a rigid base to prevent movement during testing
  - Zero load cell
  - Place the cell under the fingertip and command the finger to close. Record peak normal force
  - Repeat 10 times per finger
  - Inspect hand for slippage or permanent deformation after testing.
- Procedure (Hanging Scale):
  - Mount the hand securely to a rigid base to prevent movement during testing
  - Place bar connected to the scale in the hand and command full close
  - Place progressively heavier weight on scale and record heaviest weight held for 10 seconds without slippage
- Results: Fingertip force 3-5N and whole hand 45-50N

# ***Detailed Testing Plan – Actuation Speed***

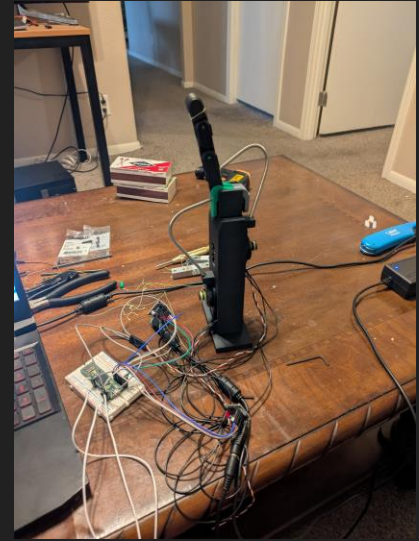
- Equipment: FSR's, microcontroller, stopwatch
- Variables Measured: Time between extension and closure (ms)
- Variables Calculated: Average actuation time
- Procedure:
  - Mount one sensor at full extension and another at full closure
  - Connect sensors to microcontroller
  - Command finger to perform 10 cycles of full open and close
  - Record time between sensor activation
  - Repeat 3 sets of 10 cycles to confirm repeatability
- Results: <250ms

# ***Detailed Testing Plan – Weight and Size***

- Equipment: Digital Scale, Calipers, Solidworks Model, Tape Measure
- Variables Measured: Hand weight (kg), dimensions (cm)
- Variables Calculated: Percent difference between average anatomical and robotic measurements
- Procedure:
  - Weight the assembled hand using a digital scale (record 3 trials)
  - Measure hand length, finger length, palm width, forearm diameter (at wrist and base) and forearm height with calipers and measuring tape
  - Compare against human averages
  - Document deviations and verify scale ratios
- Results: hand should weigh 3-4kg and measurements should be 1-1.5x average adult male. Measurements from step should be 19.4, 7.8, 9.0, 54, 90, 29 cm respectively

# Detailed Testing Plan – Durability and thermal Release

- Equipment: Motorized finger in jig, motor controller with cycle counter, laser thermometer
- Variables Measured: Cycle count, temperature (C)
- Variables Calculated: N/a
- Procedure:
  - Mounted finger to cycling rig and set actuation to 1 Hz
  - Run continuous open-close cycles recording count and taking timelapse video
  - Pause every 1000 to inspect for damage
    - Measure and record motor, driver board, and power supply temperatures
  - Continue to failure or 15k cycles
- Results: 10,000 cycles minimum and ideally survive more than 15,000, Operation Temperatures should not exceed 75°C





# ***Detailed Testing Plan – Sensor Accuracy***

- Equipment: Camera and Calibration Grid
- Variables Measured: Actual Finger Joint Angles
- Variables Calculated: Positional error
- Procedure:
  - Command fingertips to target position and take a picture of finger in final position
  - Using the photograph measure actual angles of each joint
  - Calculate the deviation between commanded and measured points
  - Repeat each target 5 times and record mean and standard deviation
- Results: error at tip should be 3-5mm with standard dev ~1mm

# ***Detailed Testing Plan – Power Draw***

- Equipment: Power analyzer, timer, data log
- Variables Measured: Power(W)
- Variables Calculated: Average Power
- Procedure:
  - Connect hand's power input to power analyzer
  - Record wattage at 1 min intervals during 2 scenarios
    - Low Load: Finger calibration and idle movements (0.3Hz)
    - High Load: Stress ball and command close all the way-1 min
  - Plot power vs time
- Results: Expected power at high load is less than 360W

# ***Detailed Testing Plan – User Interface***

- Equipment: User Feedback form
- Variables Measured: User Satisfaction scoring
- Variables Calculated: N/a
- Procedure:
  - Create qualitative feedback form
  - Have Lerner and Reza answer qualitative feedback form
  - Calculate average scoring
- Results: average score should be 4/5 or higher

# ***Detailed Testing Plan – Functional Performance***

- Equipment: Object set, (ping-pong ball, tennis ball, cup, rubics cube, plate, paper, and pencil), timer, force gauge
- Variables Measured: Time to press(ms), tip force (N), hold duration (s)
- Variables Calculated: Retention rate, average tip force
- Procedure (Piano Test):
  - Program finger to press load cell at 1/16<sup>th</sup> notes at 120 BPM
  - Record 10 trials and time stamps for presses
  - Record measured tip force for each press
- Procedure (Object Holds):
  - Grasp each test object for 30s
  - Apply small perturbations to simulate movement
  - Record whether object is retained or slips
- Results: at 120 BPM, 16th note is .125 sections. Key presses should take~.125 seconds total and tip force must be >1N. Objects must be held securely for 30s.

# ***Detailed Testing Plan – DOF and Budget Evaluation***

- Equipment: Comprehensive Material List, Final Hand
- Variables Measured: Number of DOF, Cost of final product
- Variables Calculated: N/a
- Procedure:
  - Actuate then count the number of DOF in the hand
  - Sum the value of each part in the final hand
- Results: The hand should have at least 15 DOF and final cost should be below \$1500

# Specification Sheet Preparation

Customer Requirement	CR met? (yes or no)	Client Acceptable (yes or no)
CR1- Strong enough to play and catch a ball		
CR2- Fast enough to play piano and catch a ball		
CR3- Accurate dimensions		
CR4- Accurate weight		
CR5- Within budget		
CR6- Many degrees of freedom		
CR7- Uses standard form of power		
CR8- Does not overheat		
CR9- Has a basic and functional UI		
CR10- Reliable		
CR11- Precision of motion		

# Specification Sheet Preparation

Engineering Requirement	Target	Tolerance	Measured/ Calculated Value	ER met? (yes or no)	Client Acceptable (yes or no)
ER1- Grip force	45-50N	5N			
ER2- Full extension to full closure	200-250ms	25ms			
ER3- Scale of human dimensions	1-1.5x	N/a			
ER4- Accurate weight	3-4kg	.3kg			
ER5- Within budget	<\$1500	N/a			
ER6- Degrees of Freedom	15DOF	1 DOF			
ER7- Operates with 1-3 standard 120V plugs	1-3 Plugs 360W	0 50W			
ER8- Does not overheat	<75°C	5°C			
ER9- Easy to use	➤ 4/5 Qualitative score	N/a			
ER10- Reliable use	> 10,000 joint cycles	N/a			
ER11- Accuracy of finger	Within 5mm	N/a			

# *Questions*