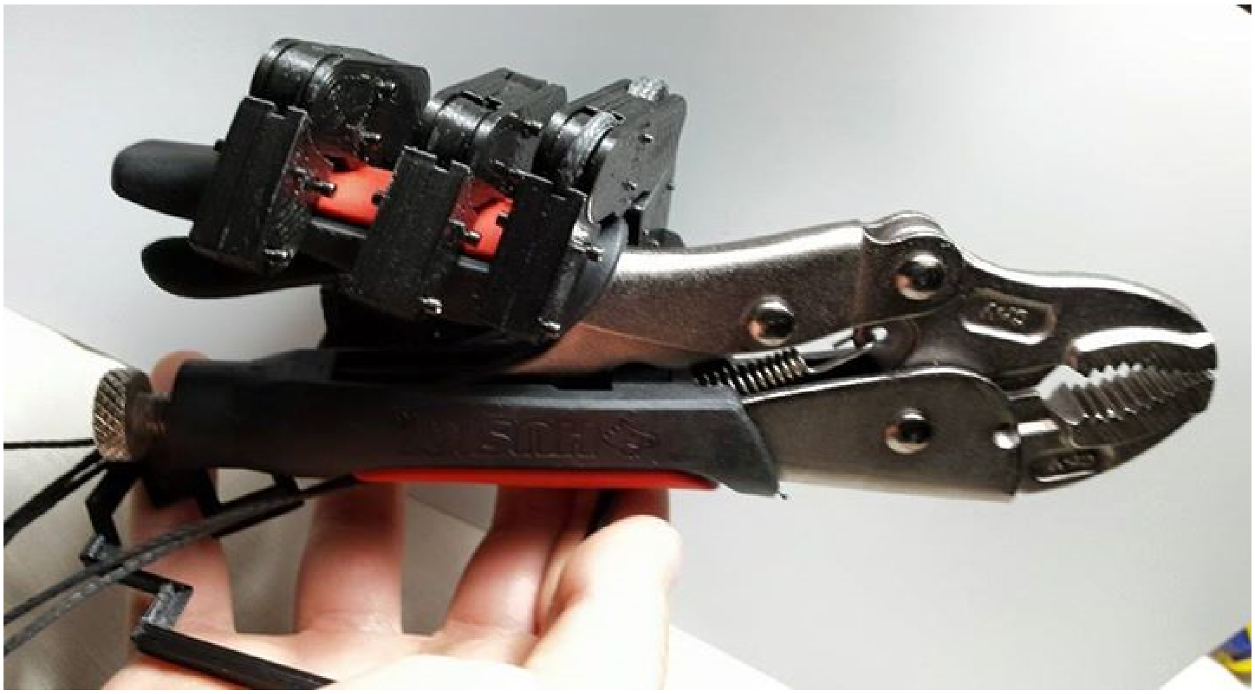
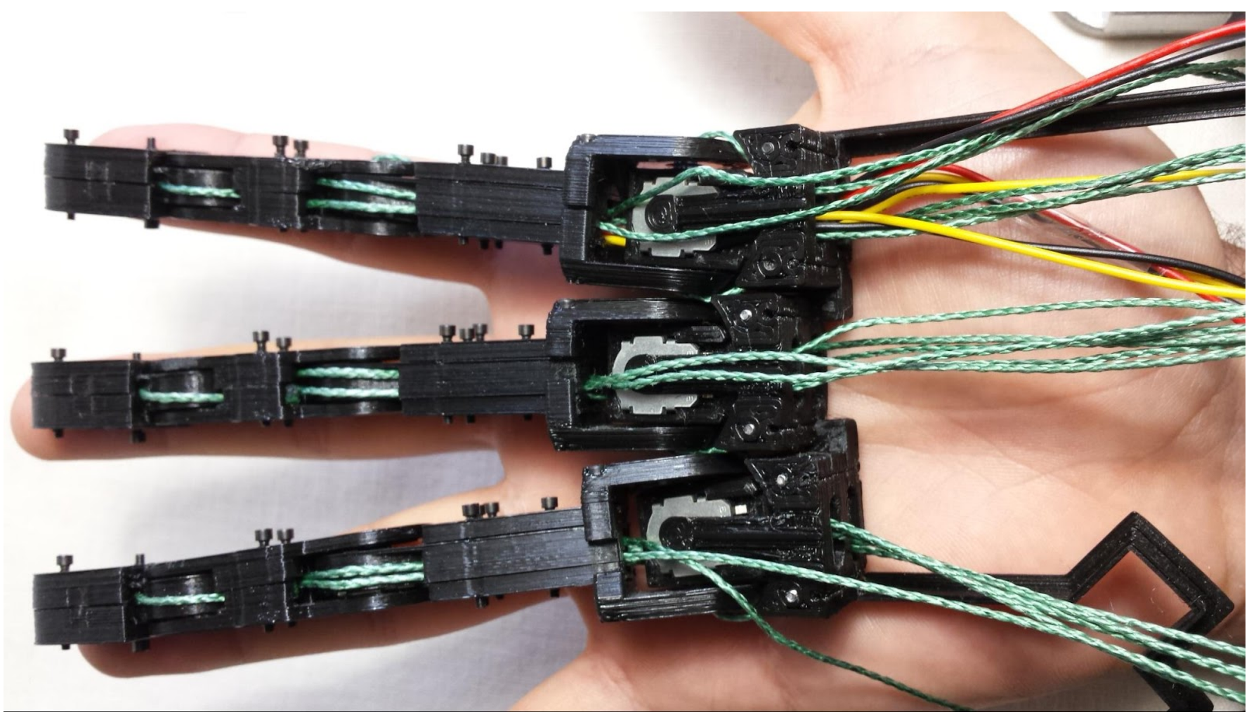
Robotic Hand Project

David Di Giorgio





1. Preface

The goal of the robotic hand project is to vastly improve my technical engineering capabilities in the field of human-like robotics and prosthetics. This ambitious personal project is a 2-year goal from the perspective of a recent Electrical Engineering graduate to research, design, fabricate, program, and document all technical aspects: mechanical, electrical, and software that goes into fabricating an inexpensive, anthropomorphic robotic hand. This also includes learning and mastering the processes and tools necessary to complete the hand and getting out of my comfort zone.

2. Overview

The robotic hand has been designed to be as cheap as possible while attempting to maintain human-like capabilities. It has 23 degrees of freedom, motor and cable driven, and angular position sensors in the joints. Designed in Solidworks, fabricated using personal PrintrBot Jr. 3D printer as well as other construction materials, and programmed in Python using a Raspberry Pi, an ARM based mini-computer using Linux. This document details the capabilities, design considerations, and materials, and tools used in the manufacturing process. The design aspects and through processes are described in three major sections: Mechanical Design, Electronics, and Programming. The final sections of this document include the supplies used including a parts, tools, and software list.

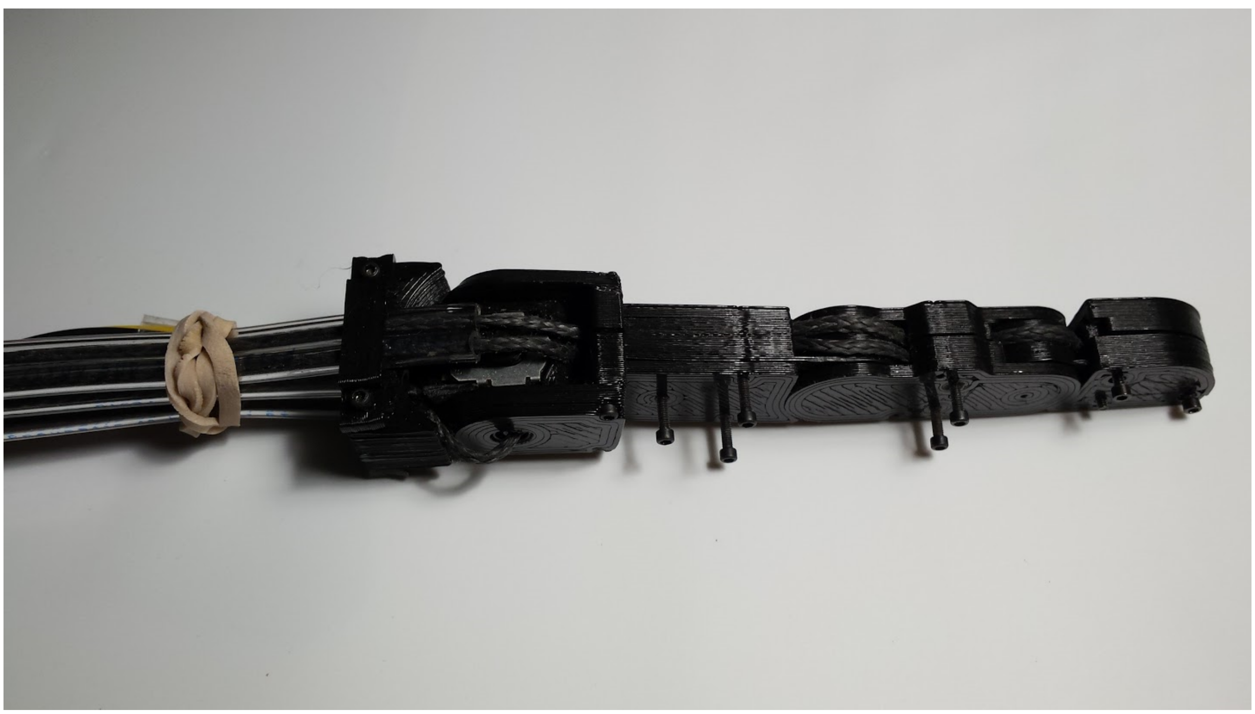
3. Mechanical Design

Most of the structural hardware is PLA plastic using a PrintrBot Jr. 3D printer. Rapid prototyping allows for Various other standard materials like screws, threaded rods, tubing, wire etc come from McMaster Carr or other suppliers.

3.1. Finger

The finger design achieves human-like movement using as few cables tendons and motors as possible. A total of eight cables are needed, of which four tendons apply flexion, extension, abduction, and adduction to the two-axis knuckle joint. Another two tendons apply flexion and extension to the middle phalanx and which also actuate the last two remaining cables coupling the middle and distal phalanges. These cables are shown as blue and red respectively in the pictures below. These cables are shown as green, purple, and orange respectively in the pictures below. Finally, two cables control left and right abduction and are shown in brown and pink in the pictures below.

The cable system is easy to install, smooth, and very strong. By using 1mm Dyneema strands with a break strength of 200 lbs the cabling is less likely to snap when large loads are applied. The Dyneema cable is tied using a buntline hitch around 0-80 screws (Distal/Middle/Flexor, Distal/Middle Extensor, and Proximal Flexor, Proximal Flexor) or rest snugly inside canals (Coupled Distal Flexor, Coupled Distal Extensor, Abductor, and Adductor). An old design used 2mm Technora with Brass crimps to properly anchor the cabling to the technora, but since the newer Dyneema is much smaller knots may be tied and fit inside the finger structure instead of crimps. Bends can negatively affect the Dyneema's breaking point so 200lbs is not a practical value, but a pull test demonstrates the finger will not break when human pull strength is applied.



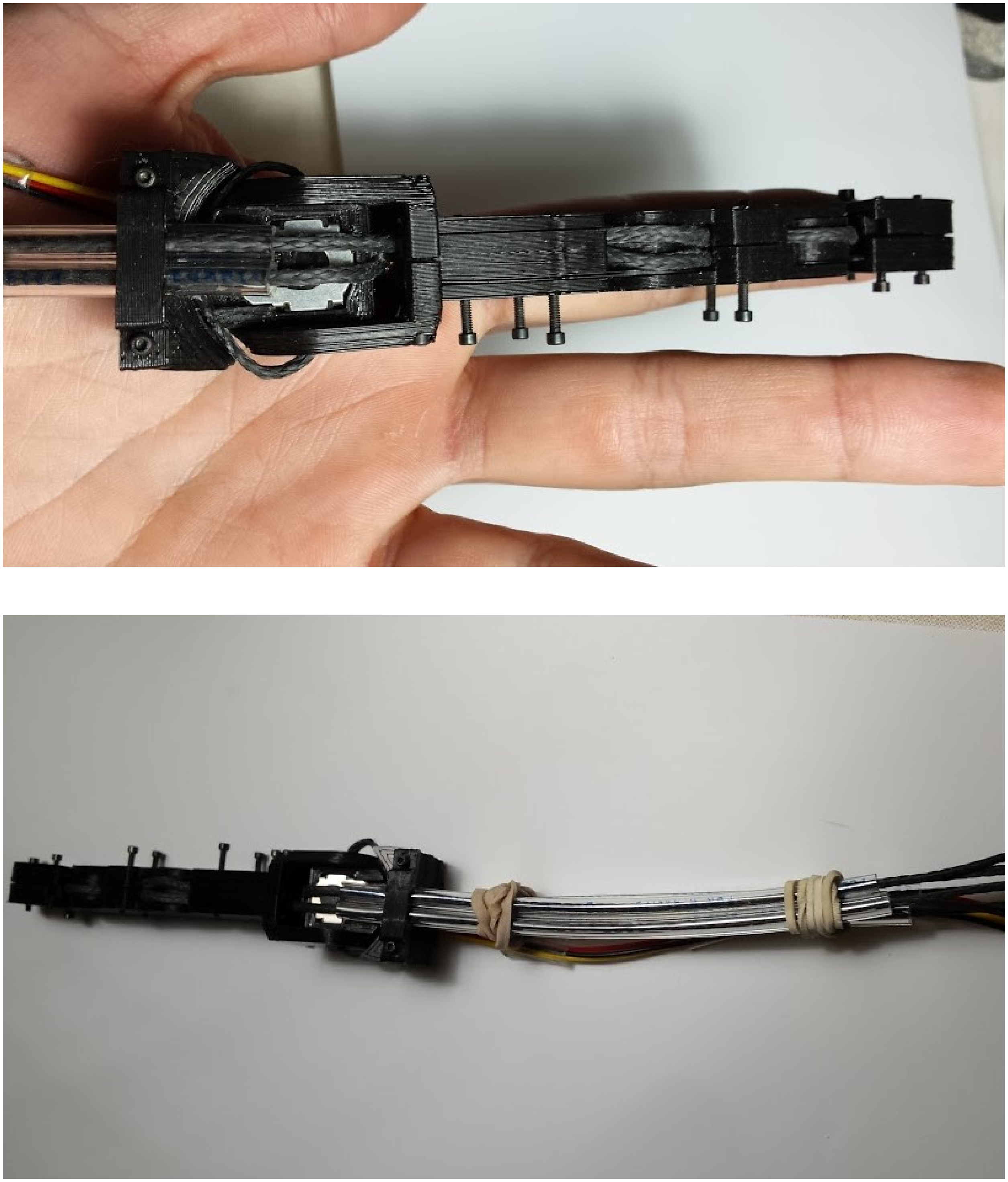


Fig 3.1: Completed Finger (with Technora cabling)

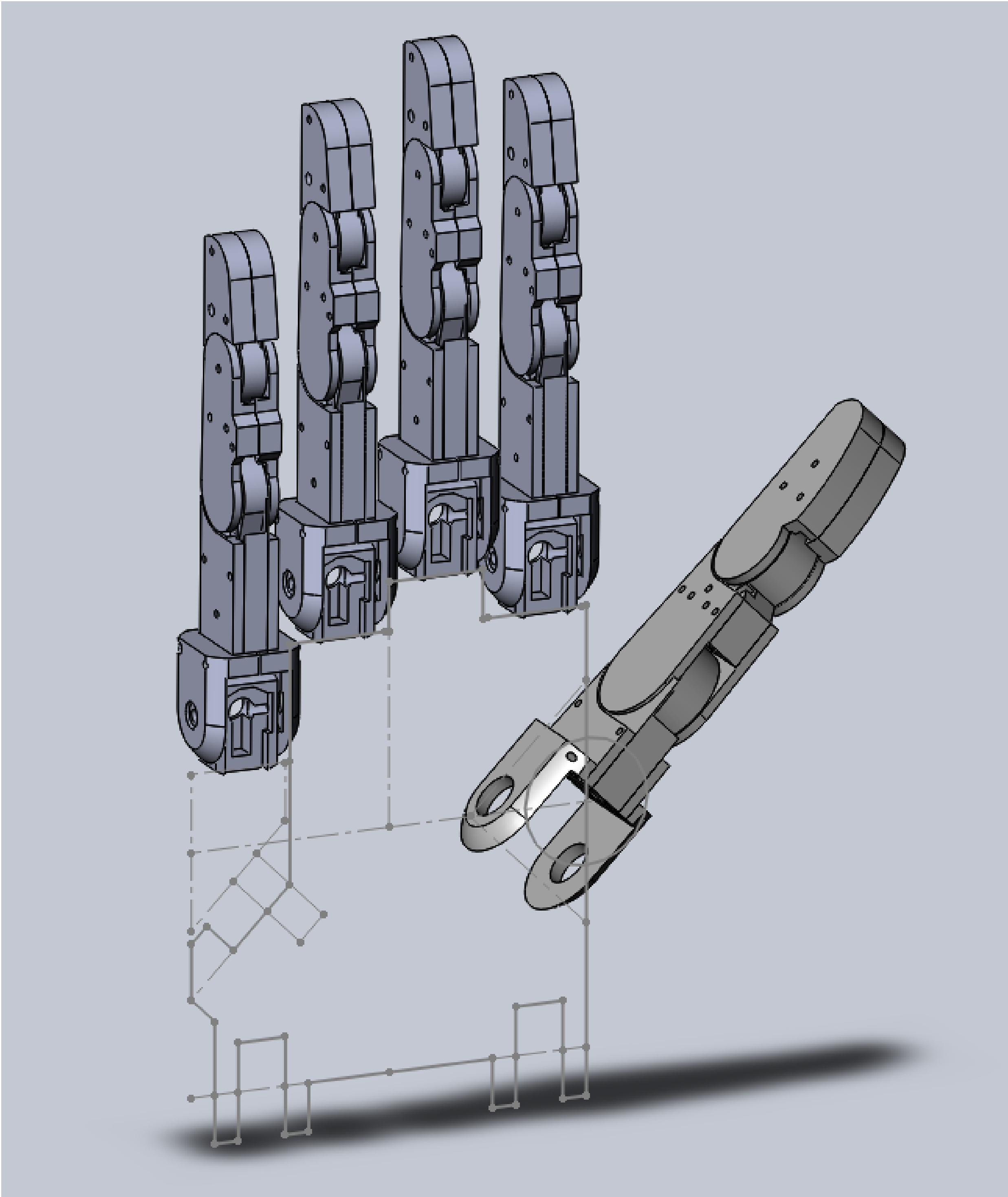


Fig 3.2: Solidworks WIP Assembly

Fig 3.3: Finger Cross Section (with Dyneema cabling)

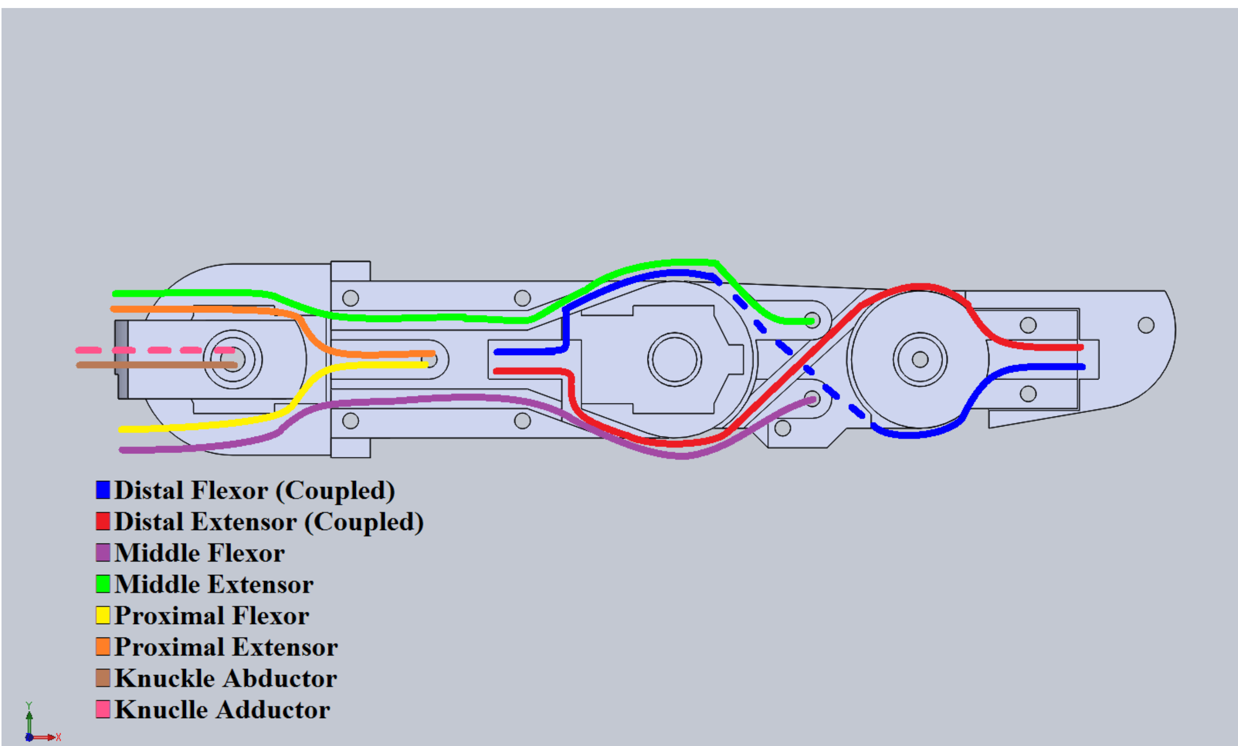


Fig 3.4: Finger Cross Section

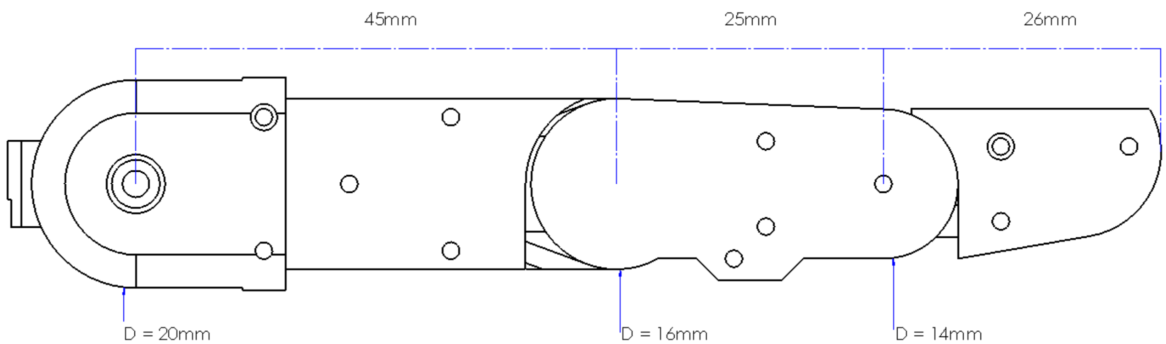


Fig 3.5: Finger Dimensions

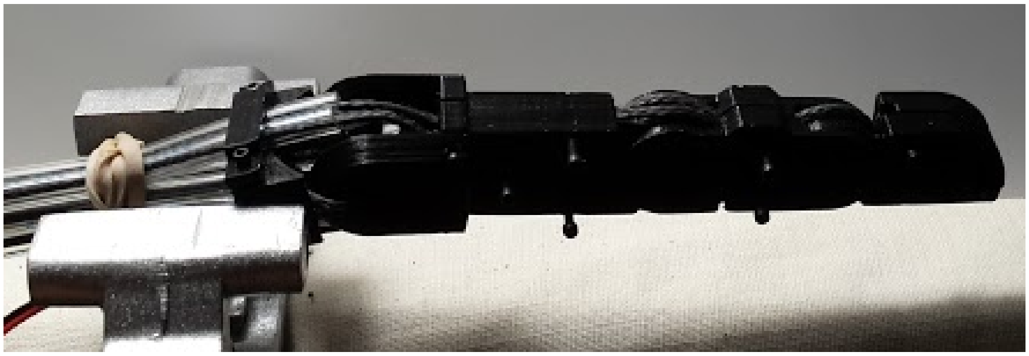
Design Considerations:

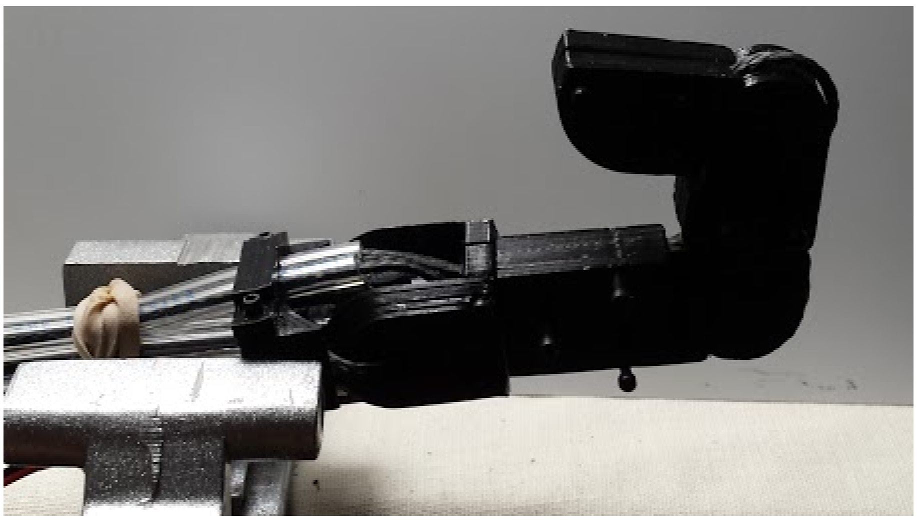
1) The only human finger-type movement the design does not support is the distal phalanx being straight while the middle phalanx is curled. Like the finger design shown above, the human hand naturally couples the distal and middle phalanx movements together. However when the human finger comes in contact with an object as it curls and the finger is provided a resistance, an individual may straighten the distal phalanx using the object's resistance. The finger design may do this to a minute degree with the Dyneema's very small stretching properties, but it does not fully replicate the human finger's capability in this regard. To achieve this somewhat trivial movement would radically change the design and require more linear actuators, more circuitry, more cabling, and thus more complexity and cost.

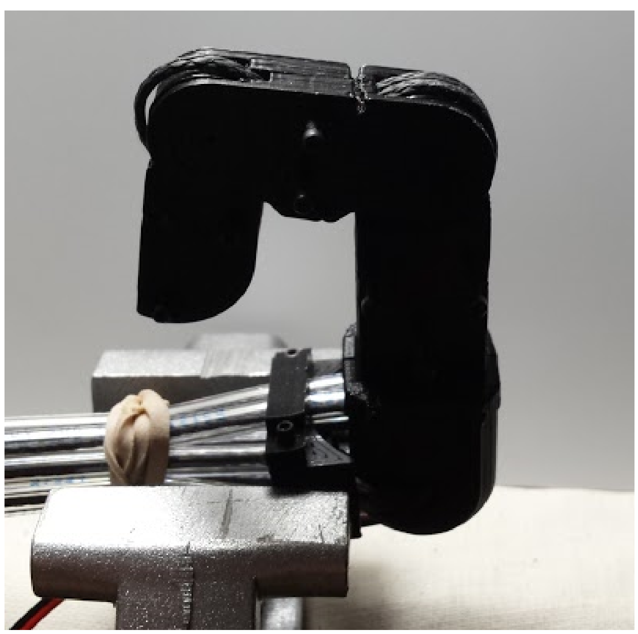
2) How parts are printed on the 3D printer is heavily considered in the design process. Structure materials are made to have very minimal post-processing and therefore can not have overhangs or areas that need drilling. Advanced printers have multiple extruder heads which print overhand supports using a water-soluble material. However, the PrintrBot Jr. does not have this capability. This is an unintended boon because parts may be made by very cheap 3D printers and cleaned up only using a simple hobby knife.

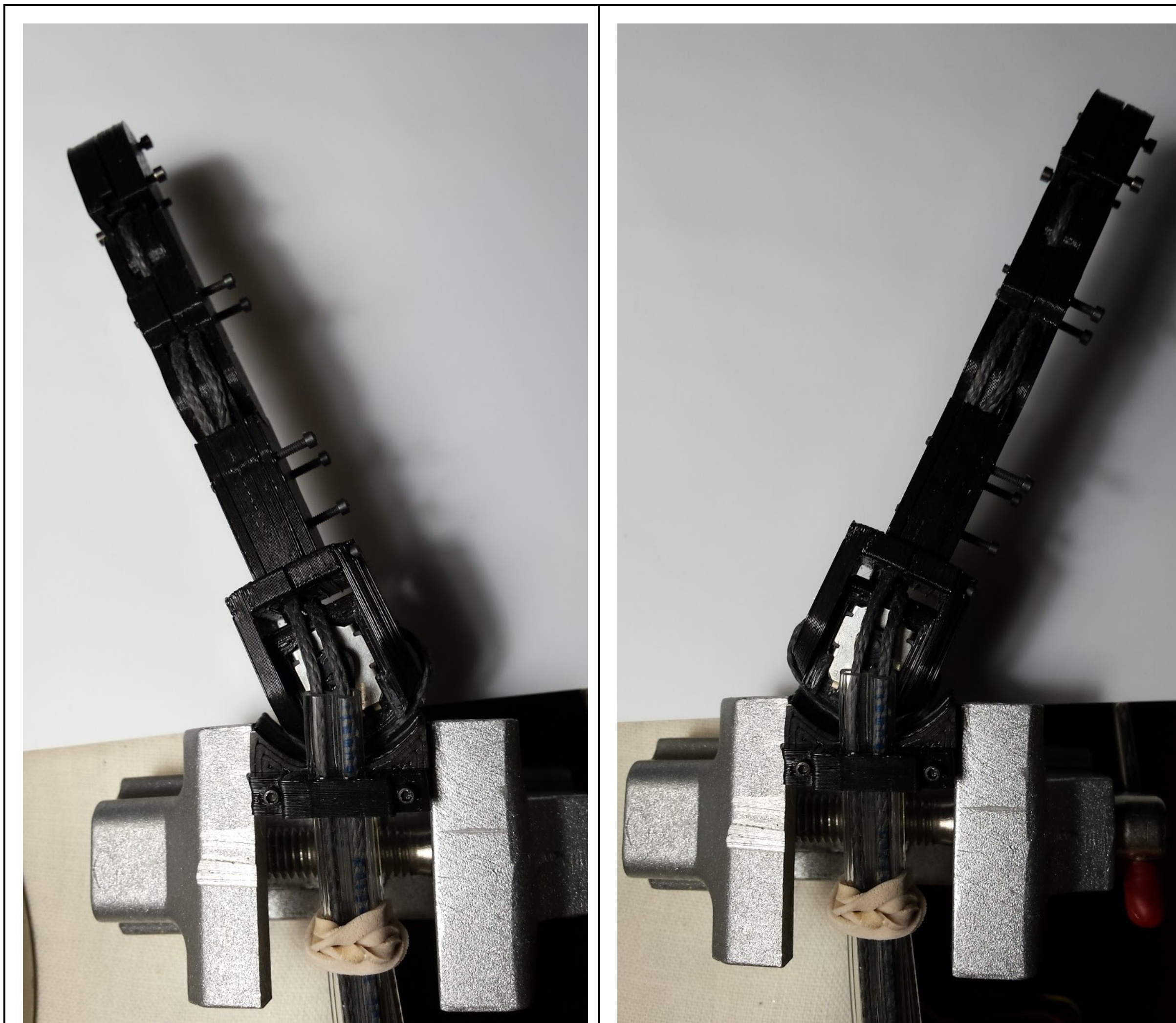
3) ?

3.1.1. Range of Motion

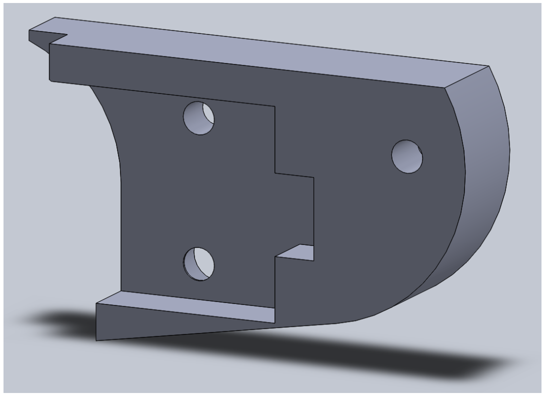


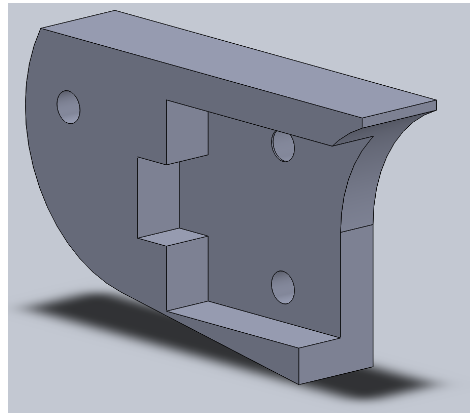


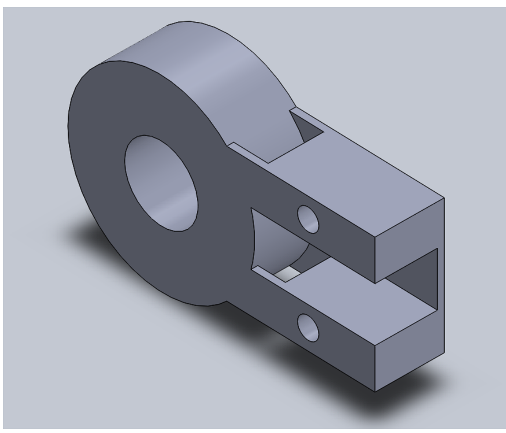


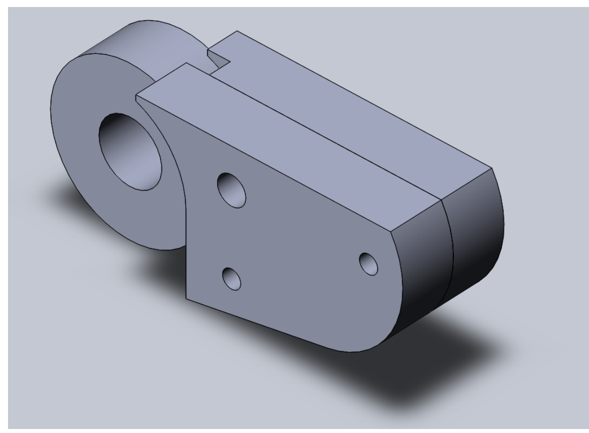


3.1.2. Distal Phalanx

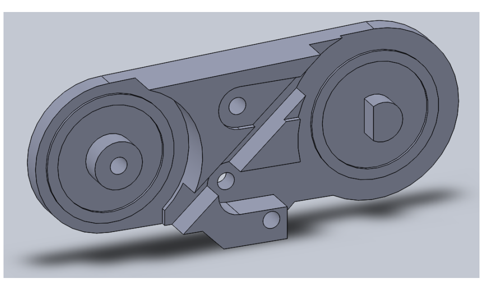


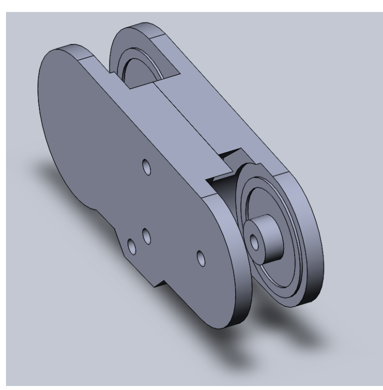


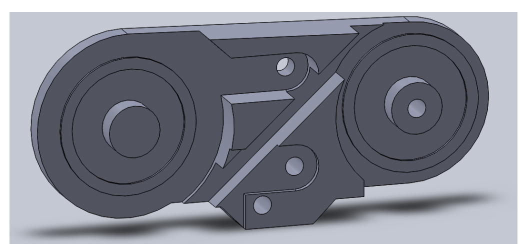




3.1.3. Middle Phalanx



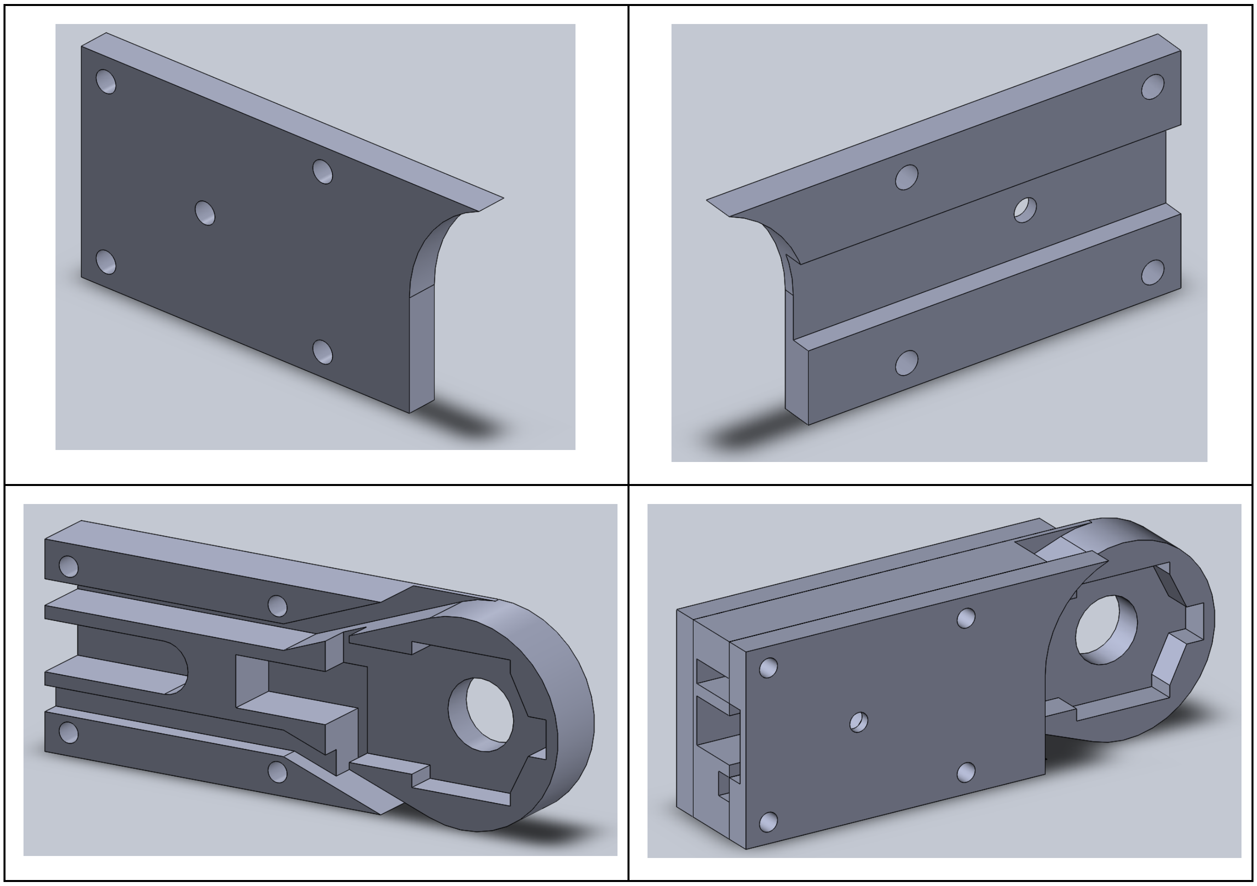




Design Considerations:

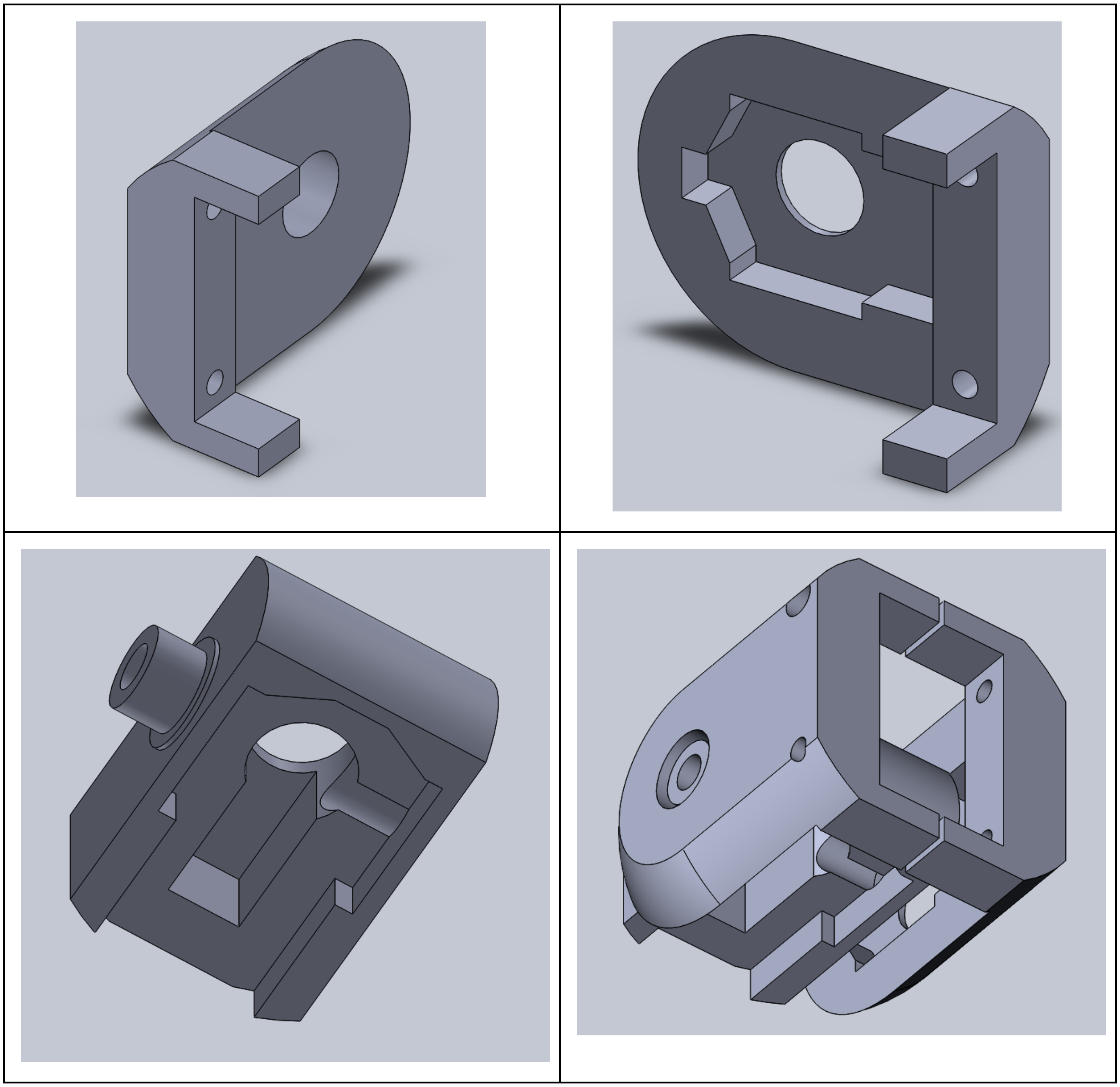
Ideally the middle phalanx should not have the extra material sticking out of the bottom of the finger because it limits the size of future cosmetic or touch sensor attachments. Because of the geometry of the cabling directing force diagonally and the limited space of the phalanx, it is difficult to support the crimp without having it break the part. Thus, for now the support material is needed to help support stress on the 0-80 screw which supports the crimp inside the phalanx.

3.1.4. Proximal Phalanx



Design Considerations:

3.1.5. Knuckle



Design Considerations:

Due to the tight tolerances of the knuckle joint area, the tolerances of the PrinterBot Jr., and routing the adduction cable through the potentiometer axle hole, the axle for the potentiometer was made by inserting 2mm inner diameter tubing into the hole. [Insert picture showing this]

3.2. Thumb

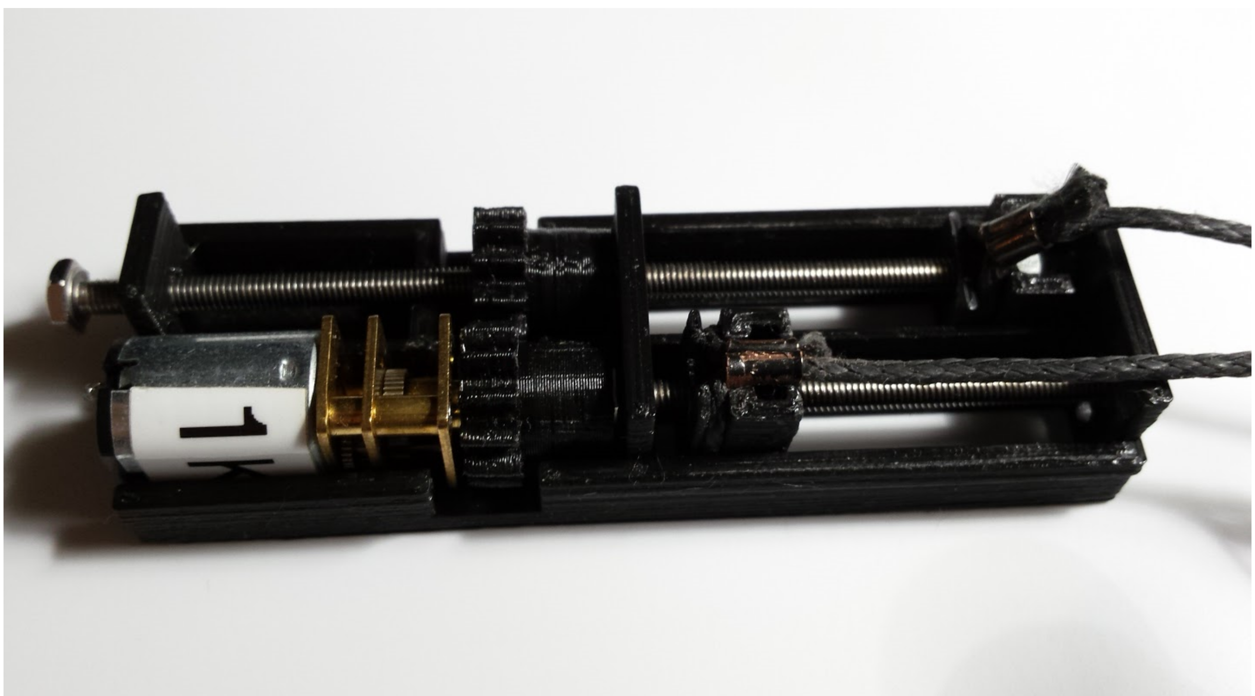
WIP

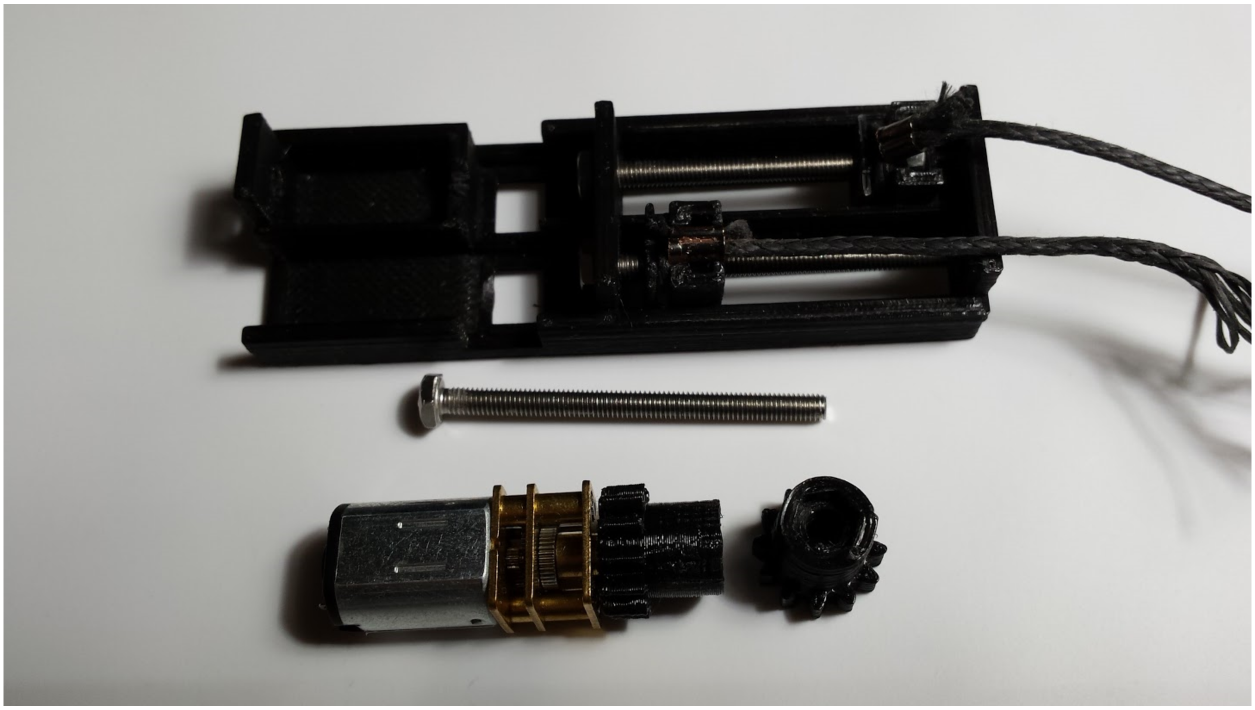
3.3. Palm

WIP

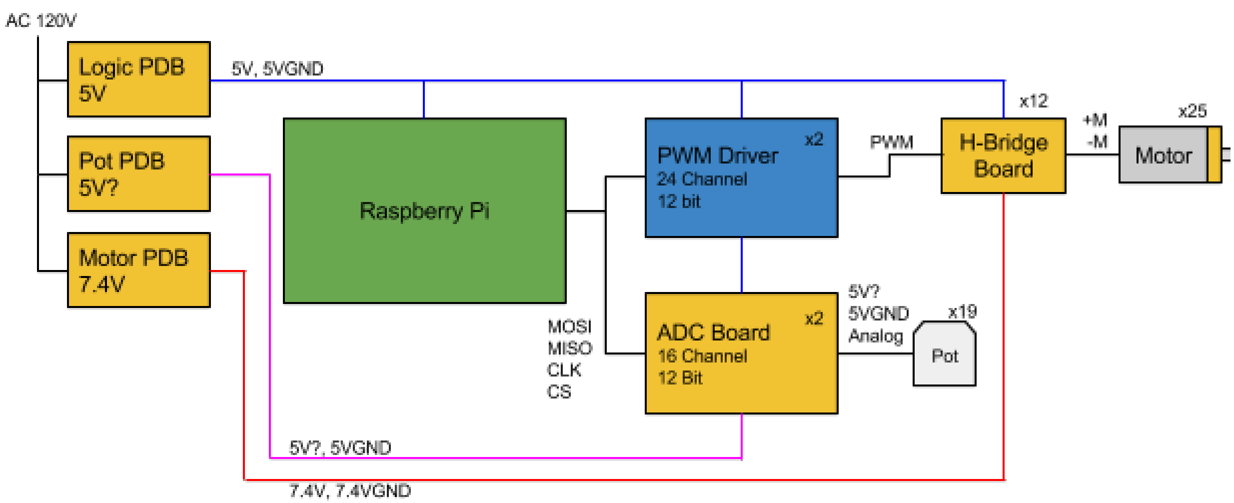
3.4. Linear Actuator

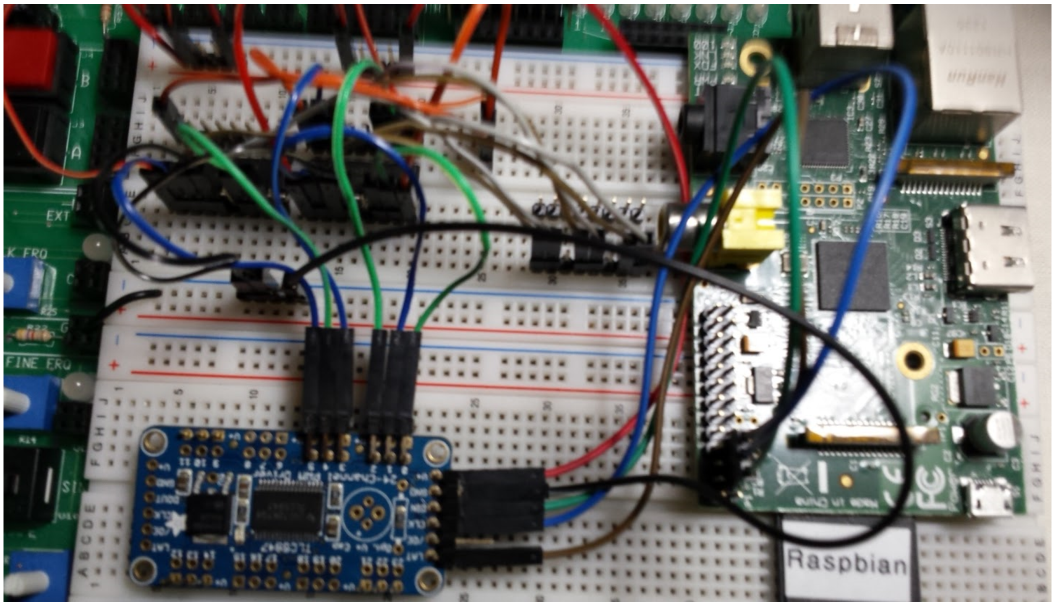
The optimal number of cables is a variable design choice because it depends on the type and capabilities of actuation being used in the design. Small spur gear DC motors are used for this project with the added flexibility of different types of actuation devices in the future: pneumatics, hydraulics, piezoelectrics, synthetic muscles, etc. Therefore, the optimal tendon number while maintaining human-like capabilities is eight because all joint movement may come in pairs when using DC motors. This has the benefit of using one motor per joint because a motor can share flexion and extension. One type of DC motor actuation is coupling lead screws by using opposing gears attached to one motor to flex and extend. Also, pulleys may be employed directly attaching the tendons in a clockwise and counter clockwise fashion. Unfortunately, doing these options on an inexpensive budget is extremely difficult because high-torque motors are required and high efficiency systems need to be employed. Further research in this area is required.

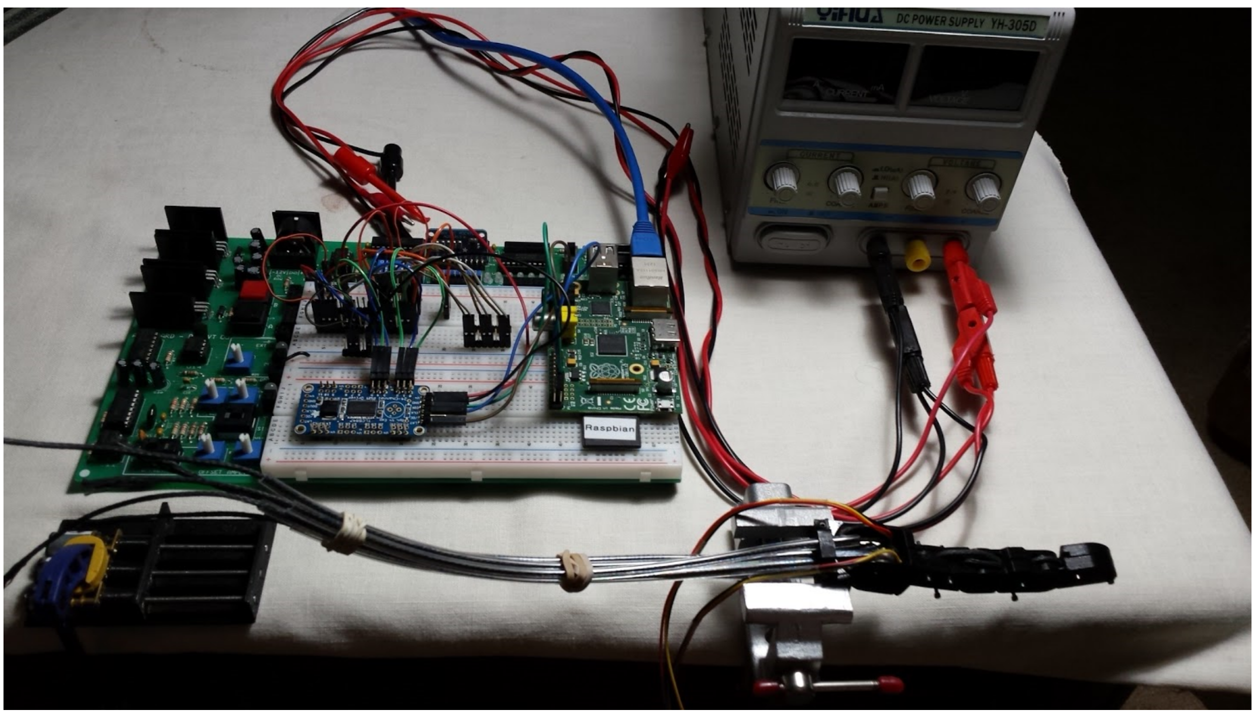




4. Electronics





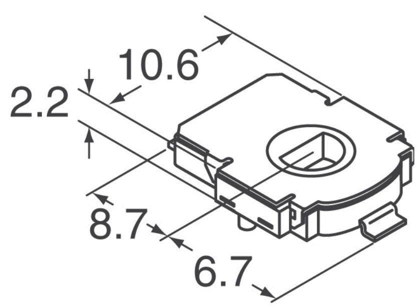


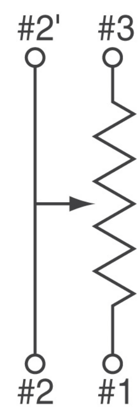
4.1. Raspberry Pi

4.2. Angular Position Sensor

A rotary position resistor senses the rotation of joints. Because the distal and middle phalanx are coupled in the fingers, the angle between the distal and middle phalanx is equal to the angle between the proximal and middle phalanx. For design simplification, a sensor between the distal and middle phalanx of each phalange is unnecessary because its equivalent is read between the proximal and middle phalanx. A breakdown of the of the sensors is as follows:

Name	Joints	Number of	Degrees	
		Position Sensors	Min	Max
Finger - Middle	FM1, FM2, FM3, FM4	4	0	90
Finger - Proximal	FP1, FP2, FP3, FP4	4	0	90
Finger - Ab(Ad)duction	FA1, FA2, FA3, FA4	4	?	?
Pinky - Palm	PP	1	0	45
Thumb - Middle	TM	1	?	?
Thumb - Proximal	TP	1	?	?
Thumb - Ab(Ad)duction	TA	1	?	?
Wrist - Flex/Extend	WFE	1	?	?
Wrist - Ab(Ad)duction	WA	1	?	?
	Total	18		





Manufacturer Part Number	EVW-AE4001B14
Rotation Angle	0° ~ 343°
Resistance	10kΩ

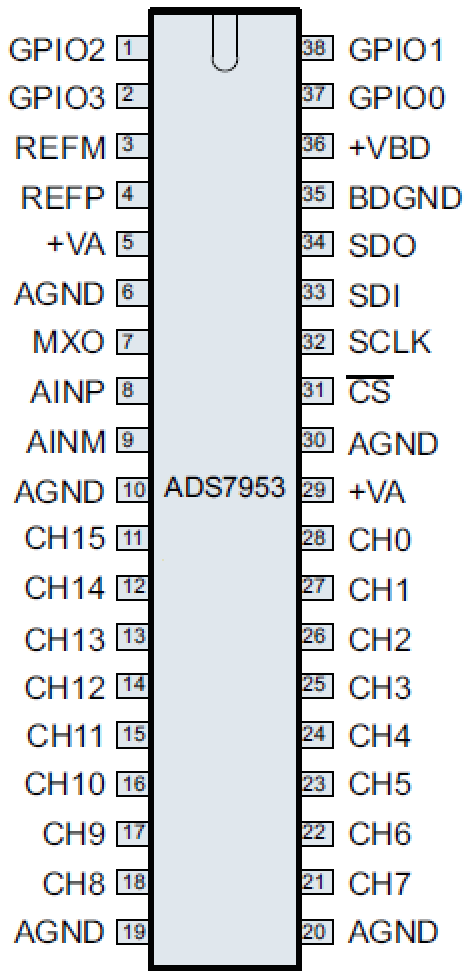
Design considerations:

A number of other robotic hand designs use rotational hall effect sensors to measure the angle. An advantage of hall effect sensors over the rotational potentiometer is the axis of rotation does not physically have to connect to the sensor itself. However, this is not an issue in the current finger design. The footprint of the potentiometer is roughly the same size as a rotational hall effect sensor microchip, so there's no advantage in space saving at this time. A big disadvantage of hall effect sensors is their cost. A relatively cheap rotational hall effect sensor on Mouser is the AS5132-HSST-500 chip which goes for $6.05 for a quantity of 1. The EVWAE4001B14 potentiometer on Mouser goes for $1.80 for a quantity of 1. To save on cost and research time, the potentiometer has been chosen as the device of choice for measuring joint angle of rotation.

4.3. ADC Board

When polled by the Raspberri Pi, the selected input channel of the Analog-to-Digital Converter boards reads the analog voltage outputted from the angular position sensors, converts it to a digital signal, and outputs the conversion back to the Raspberry Pi via SPI communication protocols.

Part Name	ADS7953
Manufacturer Part Number	ADS7953SBDBT
Pins	38 TSSOP
Sample Rate	1MHz
Serial Interface	20MHz
Channels	16
Resolution	12 Bit
Analog Supply Range	2.7V to 5.25V
I/O Supply Range	1.7V to 5.25V



4.4. PWM Driver Board

4.5. H-Bridge Motor Controller Board

4.6. Motor

Name	Number of Motors	Actuation Distance	Actuation Type
Finger Flexion - Coupled Distal and Middle	4	?	Linear
Finger Flexion - Proximal	4	?	Linear
Finger Extension	4	?	Linear
Finger Abduction	4	?	Rotational
Pinky Palm	1	?	Rotational
Thumb Flexion - Distal	1	?	Linear

Thumb Flexion - Middle	1	?	Linear
Thumb Flexion - Proximal	1	?	Linear
Thumb Extension	1	?	Linear
Thumb Abduction	1	?	Rotational
Wrist Flexion	1	?	Linear
Wrist Extension	1	?	Linear
Abduction Wrist	1	?	Rotational
Total	25		

4.7. Power Distribution Board

5. Programming

5.1. Reading ADC

5.2. Driving Motor

5.3. 3rd Order Motor Equations

5.4. Motor Interaction

6. Supplies (NEEDS UPDATE 2015-04-07)

6.1. Parts List

Type	Part	Description	Amt	Price/ Unit	Supplier
Electronics	EVW-AE4001B14	Angular Position Sensor	19	$1.50	Digikey
Electronics	Wire	28 Gauge. Red, Black, and Other Color. 25’	3	$2.82	McMaster-Carr
Electronics	Wire	DECIDE ON BIGGER GAUGE?			
Electronics	Female Pin	2.54mm. Copper.	1	$6.99	Amazon
Electronics	Female Header	2.54mm. 1x1. 100 pcs.	1	$6.99	Amazon
Electronics	Solder				
Electronics	Raspberry Pi	Model B 512MB RAM	1	$39.95	Adafruit
Electronics	PWM Driver	24 channels. 12 bit. SPI. 5-30Vpower. 5Vlogic	1	$14.95	Adafruit

Electronics	Angle Header	1x36 pin. 0.1". 10 pack.	1	$5.95	Adafruit
Electronics	Angle Header	2x36 pin. 0.1". 5 pack.	1	$5.95	Adafruit
Electronics	Motor	Add Motors			
Mechanical	PLA	1.75m, 1kg/2.2lb	1	~$20.00	Ebay
Mechanical	Screw	Add lead screw			
Mechanical	Bolt	Add lead bolt			
Mechanical	Screw	0-80 Thread. 5/16" Length. Steel. Pack of 100.	1	$7.23	McMaster-Carr
Mechanical	Screw	0-80 Thread. ½" Length. Steel. Pack of 25.	1	$6.19	McMaster-Carr
Mechanical	Screw	0-80 Thread. ¾" Length. Steel. Pack of 25.	1	$3.42	McMaster-Carr
Mechanical	Technora	Length: 100'. Diameter: 0.08". Breaking Strength: 450lbs	1	$29.99	Amazon
Mechanical	Crimp Sleeves	2.0mm Copper. Good for mono up to 350lb.	1	$8.99	Amazon

6.2. Tools List

Type	Tool	Description	Price	Supplier
Electronics	Variable DC Power Supply	30V 5A 110V Precision	$64.90	-
Electronics	Soldering Iron		~16.00	Radioshack
Electronics	Wire Stripper	10-24 AWG (works on 28 AWG)	$21.49	Amazon
Mechanical	3D Printer	Printrbot Jr. Discontinued. 150x150x150 mm^3. 0.4 mm Extruder Head.	~$750.00	Printrbot
Mechanical	Crimp Sleeve Crimpers	2.0mm setting	$22.49	Amazon

6.3. Software

Type	Software	Description	Price	Supplier
Mechanical	Solidworks	2014 Trial Version	-	-
Mechanical	Repetier	3D Printer Software	Free	
Electronics	Eagle		Free	

- VNC
- Putty

7. Useful Links

- https://www.youtube.com/watch?v=tWnfnt2rNO0
- http://graphics.cs.cmu.edu/nsp/projects/hands/hands.html
- https://www.youtube.com/watch?v=GhfP2qjczJc
- http://leisonmotor.en.made-in-china.com/product/seyQIXiEXvYt/China-6V-Low-RPM-DC-Metal-Micro-Gear-Motor.html