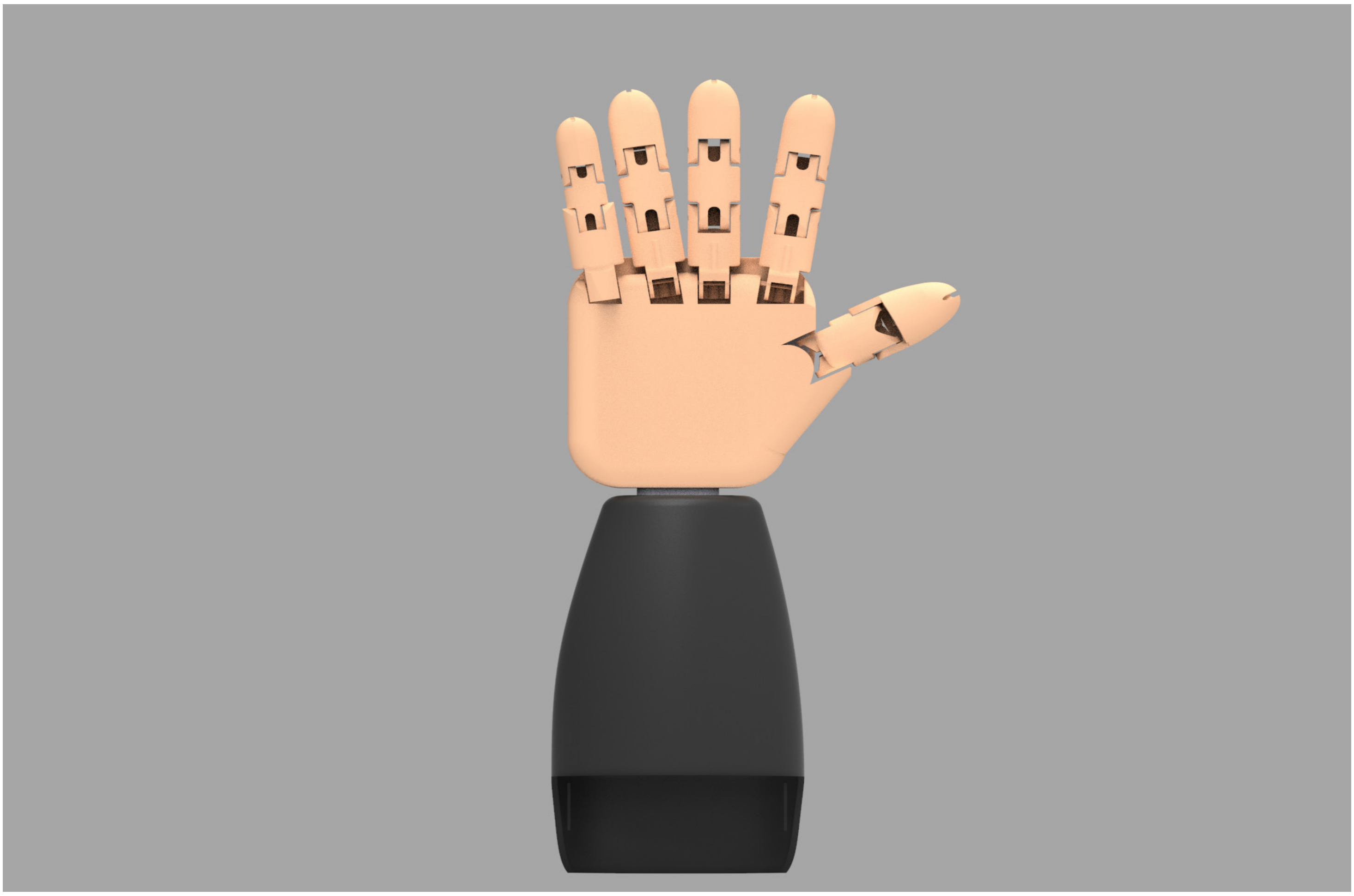


DIY REPORT

A-TEAM, DSCE, BANGALORE

small is BIG

Affordable Modular Myoelectric Prosthetic Arm

Ashutosh Pandey & Ravi Maurya

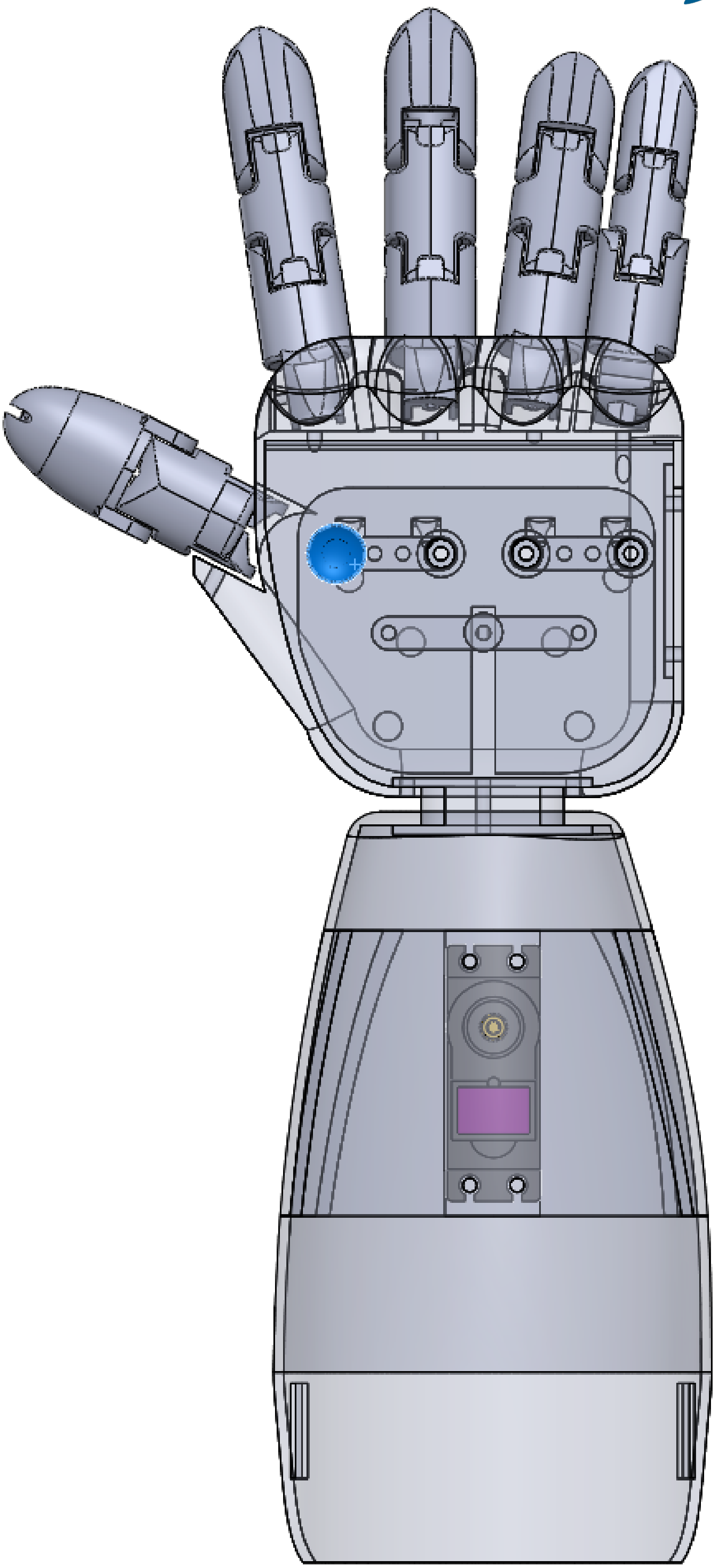


Table of Contents

Problem Statement

- A multifunctional, modular, myoelectric prosthesis.

50 lakh
amputees in India.

₹1.5 L
Cost for a semi functional prosthesis.

400 g
Average weight of a human hand.

50%
people don't wear their prosthesis regularly.

27
Degrees of Freedom in the human hand.

Prosthesis

Prosthetics are artificial limbs that can be used by people who have lost their limbs, or are born with natural deformities. While the foot prosthesis has made remarkable strides in functionality and affordability with the Jaipur leg costing as little as $40, there is no such equivalent for the upper body prosthesis. Moreover, the alternatives that do exist have severe shortcomings when it comes to pinch force, grip strength and mass.

One major reason for this lack of development in upper body prosthesis is due to the complexity of the human hand itself - It has 27 degrees of freedom and it is both strong and dexterous. A need exists for an upper body prosthesis that is cheap, functional, easy to use and lightweight.

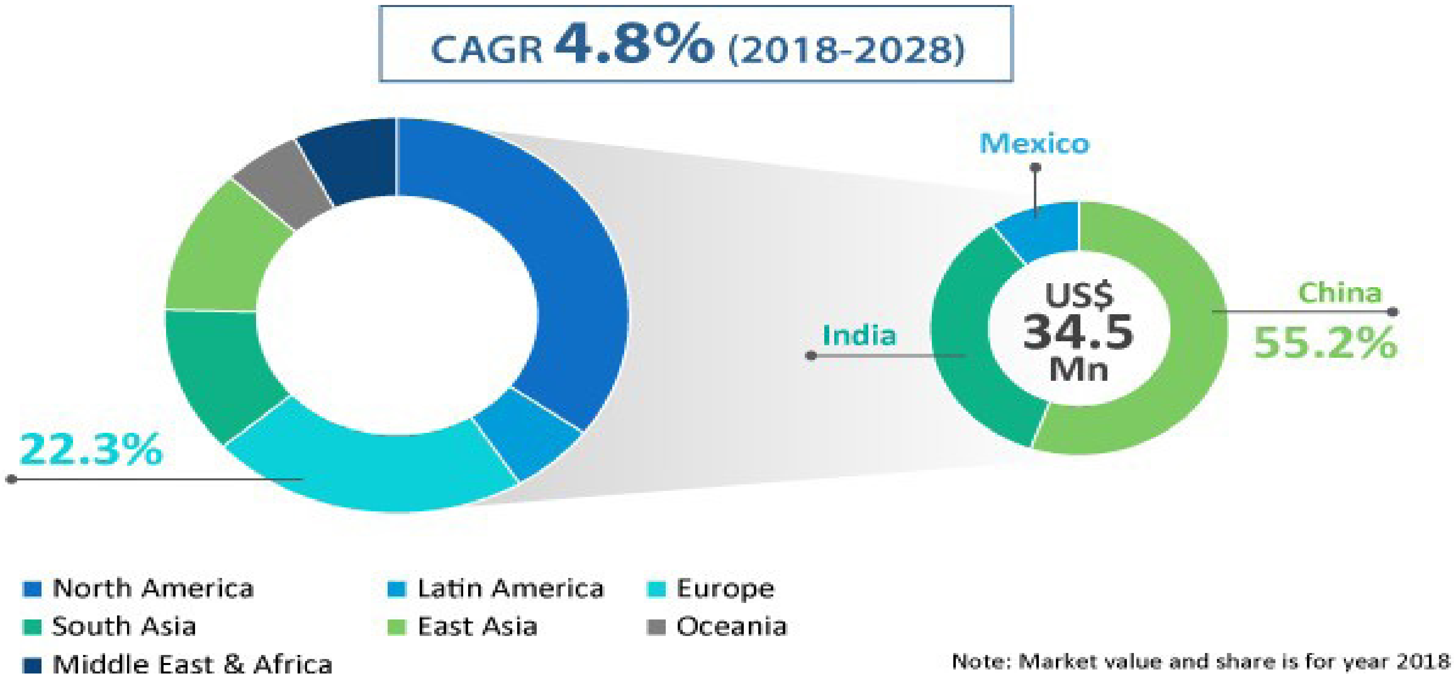
Types of Prosthesis

There are primarily three types of upper body prosthesis in the market today:

1. **Cosmetic Prosthesis**: these prosthesis do not offer any functionality. They are very cheap.
2. **Body Powered**: these are manipulated by hooks and cables attached to the body. While they are also inexpensive, they require a lot of power from the user to move successfully. They also offer very little grip force and pinch strength. They are limited to opening and closing motions of the palm.
3. **Myoelectric**: these are controlled by electrical signals from the arm stump. They do not require any force to be exerted by the user, can replicate a variety of movements but are extremely expensive ($15,000 and up).

Market Analysis

- A global 1.2 billion USD market for prosthesis exists.



The Global Prosthesis Market

According to a survey by Future Market Insights (FMI), upper body prosthesis are predicted to grow at a **Compounded Annual Growth Rate (CAGR) of 4.8 %**. The market is primarily dominated by 4 companies: Ottobock, Ossur, Fillauer and Blatchford.

North America and Europe account for 55% of the sales, while India makes up less than 10% of the current **$330 million upper body prosthesis market**. This despite India having over 50 lakh amputees, and adding over 24,000 new amputees every year, shows that the uptake of upper arm prosthesis in India has been very slow.

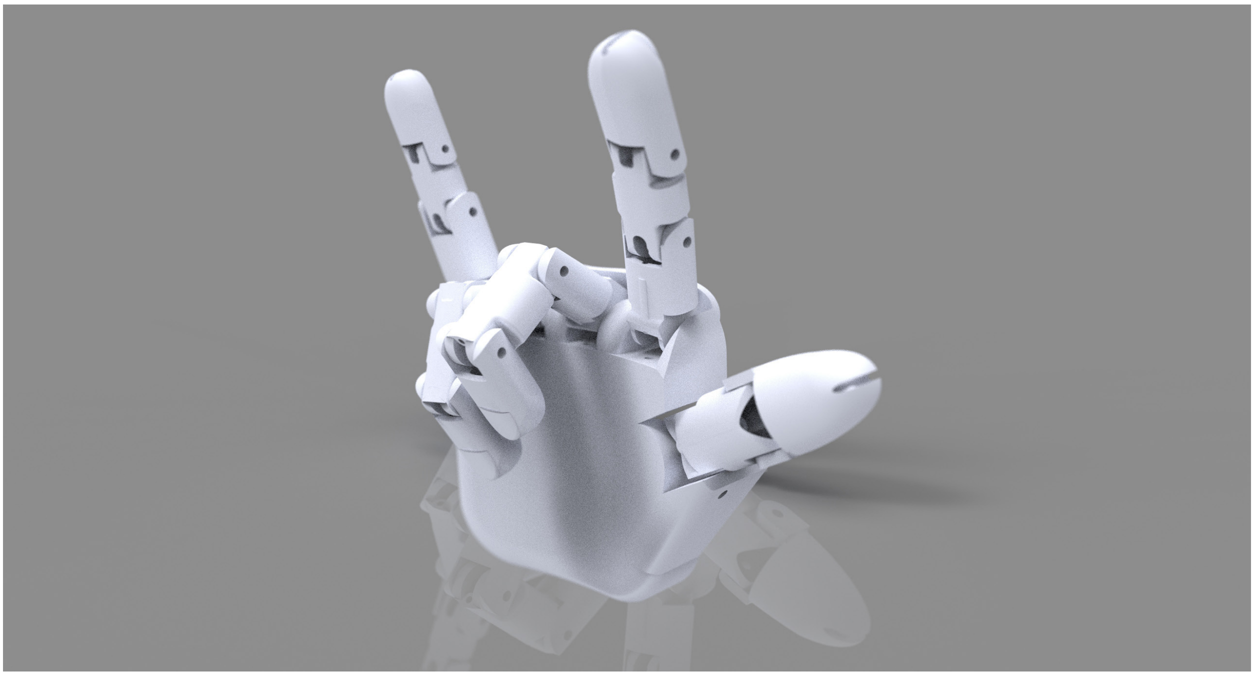
The current offerings in the market are prohibitively expensive, In USA a part of the prosthesis cost is borne by the Insurance companies, despite this the costs go from $15,000 to over $90,000. The cheapest Indian alternatives also cost over ₹1.5 Lakh, putting them out of reach of economically disadvantaged individuals who lose out on their livelihoods due to their disabilities.

25% of the demand is for below the elbow prosthesis, while the demand for myoelectric prosthesis is 40%.

In India a few popular options are the Ottobock Body powered arm that uses hooks and cables and costs ₹1.5 lakh, the Myofacil Myoelectric arm that costs ₹2,36,000 and can perform a few movements after training, and the upper segment has the Bebionic prosthetic arm, which costs over ₹10,00,000 and can replicate lots of movements.

Shortcomings

- In the current market offerings



An average hand can exert upto 95 N of force in a precision grip. For a prosthesis to be functional, it has to be able to manage atleast 50% of that grip strength, which almost all prosthesis fail to do. There has been very little progress in upper arm prosthesis research in 40 years.

- Study by TU Delft.

Modern day prosthesis are plagued by a whole host of problems apart from the cost, we shed some light on these shortcomings below:

Pinch Force and Grip Strength: a person needs to be able to lift objects with their prosthetic arm. Studies recommend a bare minimum of 45N of grip force, with 65N being the optimum.

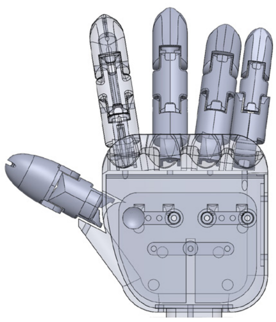
Weight: The average human hand weighs 400 grams. Myoelectric prosthesis can weigh upto 1.5Kg, which makes them too uncomfortable to use and wear for extended periods of time.

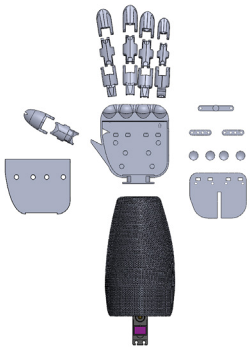
Cost: Unlike the ubiquitous Saathi and Jaipur leg, there is no cheap upper arm prosthesis in India. The most common type of prosthetics used by Indians are the cosmetic ones, which help with the social stigma but do not objectively improve the quality of life.

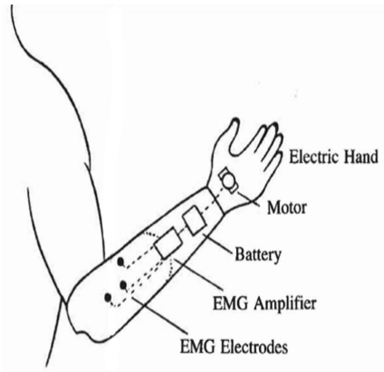
Non Modular: Upper arm prosthesis tend to wear out in 5 years. This makes them an expensive, recurring investment. The tips of the fingers are particularly prone to wear and tear, and currently the entire prosthesis must be replaced in such a case. Moreover, children often outgrow their prosthesis and have to buy new ones.

Our Solution

- A multifunctional, modular, myoelectric arm.







32 distinct combinations

Our whiffletree mechanism allows our arm to have 32 distinct combinations of positions.

Modularity

Our arm consists of distinct modules which can be easily swapped out.

Myoelectric control

We use myoelectric control powered by an inexpensive sensor to make the product easy to use.

> *Our product costs less than ₹15,000 to manufacture using 3D printing technology which is fast becoming ubiquitious in India. It is lightweight - weighing in at only 372 grams. This is made possible by the use of generative design in the fixtures. We use cheap, off the shelf myoelectric sensors and make the design modular to be able to easily replace worn out parts.*

Our Product

We studied the various prosthesis in the market, referred to research papers by leading universities and medical journals, and finally chose to use **3D printing technology** for our prototype because it allows us to quickly test out variations of the design.

Keeping the Indian weather conditions in mind, **ABS** was chosen as the material because of its greater tolerance to heat and higher strength.

The **Whiffletree** is a mechanism to distribute force evenly through linkages. In our prosthesis, it allows us to make different positions and combinations using only 1 servo and that is the reason it was chosen.

Keeping the weight low was important to making the product more useable and to reduce cost. We used **generative design** in the servo fixtures to reduce the weight.

Body powered prosthesis require a lot of hooks and cables, and ultimately provide a worse user experience because they require so much force to operate. Keeping this in mind, we decided to opt for **myoelectric control** over making a purely mechanical design. We used commercially available components to bring down the cost and reduce the time to market.

Design Details

We use a bottom-up design methodology

4	1	1
Fingers	Thumb	Palm

The Fingers

are the basic unit of articulation.

The Thumb

Humans have opposable thumbs.

The Palm

Houses the selectively lockable differential mechanism.

Fingers

One single finger was the starting point for the entire design process. The human hand consists of four similar fingers and one thumb, it was logical to conclude that the finger design could potentially be replicated four times. The finger design process began with determining what motion was required for each finger. The human hand was simply viewed gripping various household objects such as a cup and marker commonly found in a person's daily routine. The location of the various joints were measured and translated to drawings.

The human finger is an amazing piece of engineering consisting of three individual pivot joints which can almost be individually actuated through muscular tendons.

The Thumb

The thumb has also been designed in a similar fashion. Most commercial and research prosthetic hands aim to provide at least three degrees of freedom in the thumb.

This thumb however only provides a two degrees of freedom – it can only open/close in a single way. Guide holes have been incorporated into the design of the fingers and thumb to optimise tendon orientation and prevent the tendon lines from getting caught on a sharp edge.

The Palm

Each finger connects to the palm by pins. The palm accommodate:

1) the finger base frames,

2) the selectively lockable differential mechanism

The design of the proposed differential mechanism is motivated by the fact that humans develop over their lives a tremendous ability to select the most appropriate grasping strategy for a given task. A well known differential mechanism is the whiffletree , which is typically used to interconnect the index, middle, ring and pinky fingers of underactuated, multifingered robot hands.

Product Development Cycle

A few questions that we asked ourselves

Identify the problem

Our product design cycle starts with research into the problem statement.

Effectiveness

How effective are the solutions in the market? Do they adress the need of the users? is there scope for improvement?

Market Value

Is there an untapped market for the product? How much is the industry worth currently? Is the product going to increase in demand?

Responsibility

Does the product help improve the quality of life for its users? Can it be sold ethically without short changing the consumer?

Different Approaches

What are the different design philosophies that can be used? Different manufacturing processes?

Scalability

How labour intensive is the manufacturing process? Can it be mass produced easily?

Upgradeability

Can the product be easily upgraded? Can it be done in a cost effective manner?

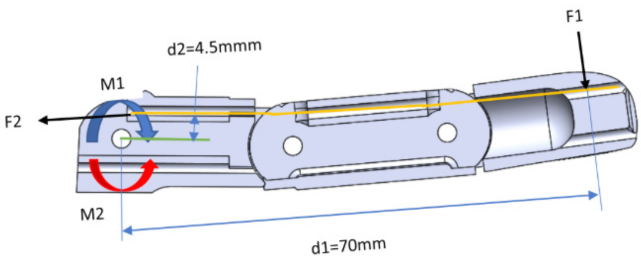
Profit

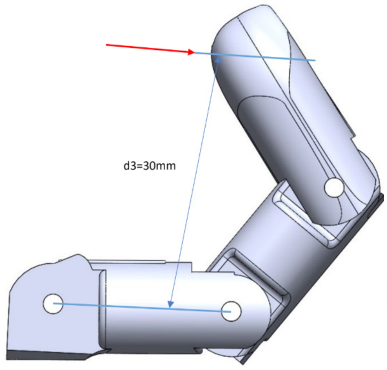
Can the product be sold for a sustainable profit? Does the revenue model account for losses?

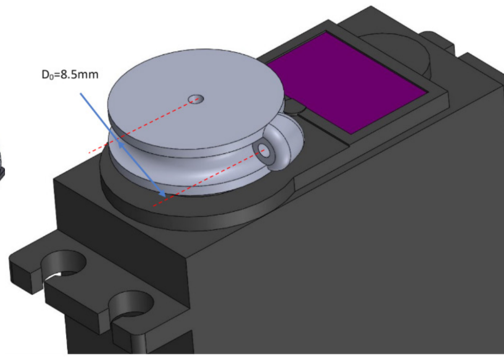
The prototype went through iterations where it was tested, upgraded and independently analysed critically. This helped us make the end product lighter, more efficient and easier to use and maintain.

Calculations

The weight that could be supported by the fingers was calculated.







> *135 grams is the mass that each finger can lift when it is fully extended. When the fist is closed, the force applied to the index finger acts normal to it, and each finger can lift a total of 320 grams for a lifting capacity of 1280 grams.*

*When the finger is **fully extended**, force is applied at the tip (distal) end of the finger. The movement is given by the expression:* $Moment = Force * Perpendicular\ distance$

$$M = F * D$$

The given torque of the servo we use: $Torque = 9Kg - cm = 176.58\ N - mm$

*Tendon creates a moment about each joint in the finger. Since knuckle joint is the furthest from the applied force the moment about it will be the greatest. At maximum lift M1=M2. The stall torque (maximum turning force) of the OC Servo A091 is 9Kg-cm at 6v. This **stall torque** will be transferred equally in all 5 fingers.*

$$F2 = \frac{176.58\ N - mm}{8.5\ mm} \qquad F2 = 20.77\ N$$

$$Also,\ F1D1 = F2D2 \qquad F1 = \frac{F2D2}{D1}$$

$$F1 = \frac{20.77N * 4.5mm}{70mm} \qquad F1 = 1.33N$$

$$mass = 135\ grams$$

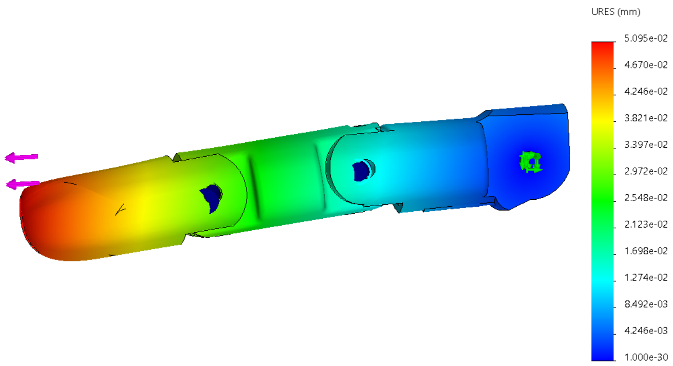
135 grams is the mass that each finger can lift when it is fully extended. When the fist is closed, the force applied to the index finger acts normal to it, and each finger can lift a total of 320 grams for a lifting capacity of 1280 grams.

Analysis

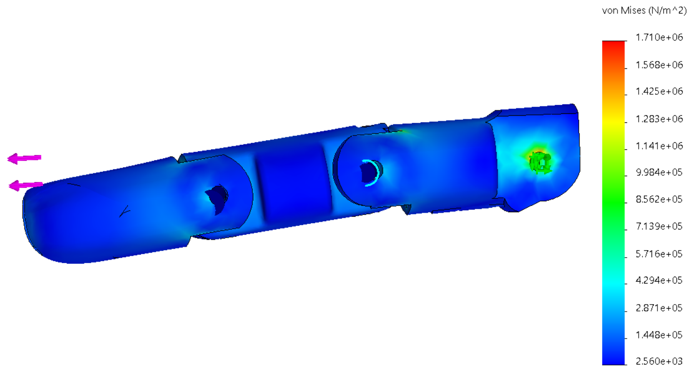
- We confirmed our hand calculations with analysis.

1

Displacement for 1kg load ABS

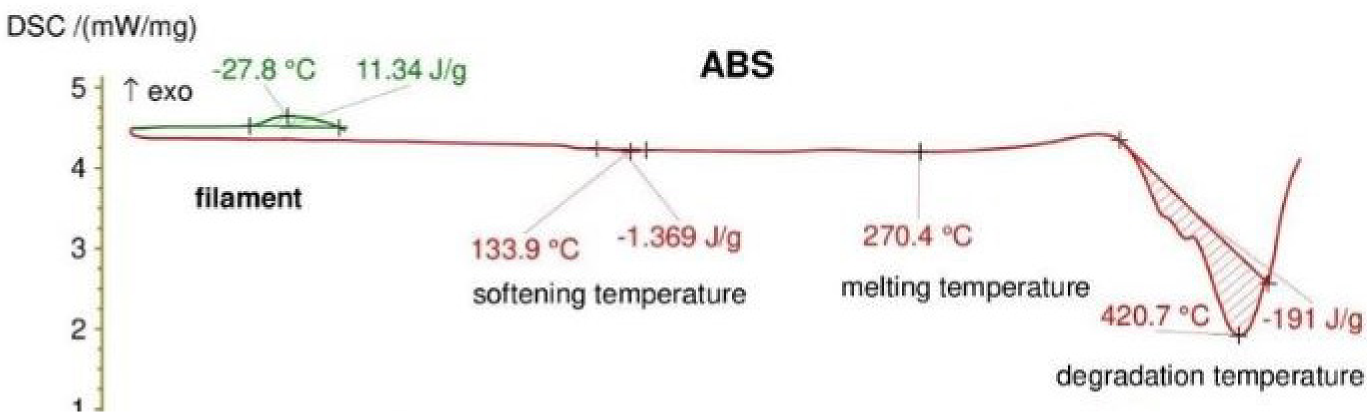


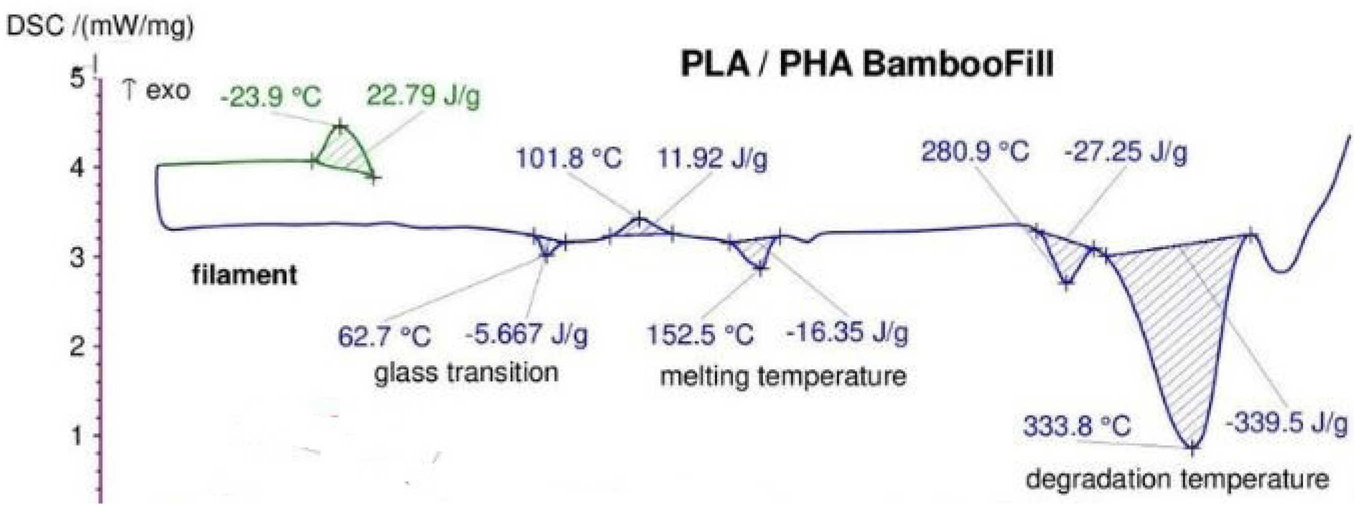
Stress for 1kg load ABS



2

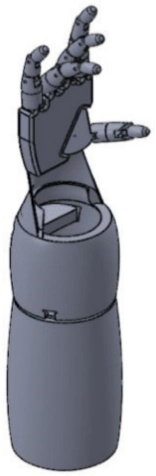
PLA is prone to softening with heat. This can affect reliability





Design Iterations

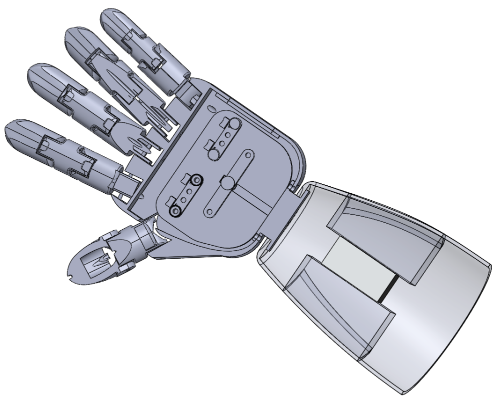
- 3 prototypes were made in total



The First Prototype

The first prototype was made for the initial concept submission phase. This prototype had the following shortcomings/features:

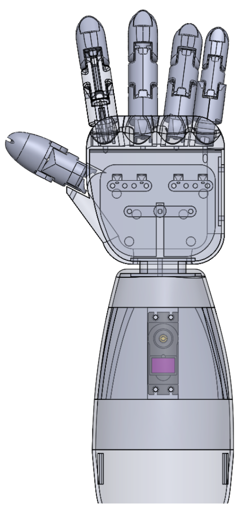
- The prototype could only open/close the fist.
- There were no buttons or whiffletree mechanism.
- The 5 fingers were directly connected to different servos.
- It was rather heavy 725 grams.



The Second Prototype

The second prototype was made for the zonal round in Chennai. This prototype featured improvements:

- The whiffletree mechanism was chosen to reduce the complexity of the electronics.
- TPU material was chosen for the joints to act as tendons, because of its elasticity and durability.
- During manufacturing it was found that the fingers needed repositioning and tolerances were needed.



The Third Prototype

The third prototype was made for the finals of Aakruti 2019. This features a number of improvements over the second version:

- The fingers were repositioned to make them move more freely.
- Tolerances were considered during 3D printing to make manufacturing easier.
- The thumb was redesigned to have means to connect to a second servo, as the human thumb is opposable and free to move and thus, operates independently of the rest of the hand.

Raw Materials

- After much experimentation, we chose these

ABS - Acrylonitrile Butadiene Styrene

- High Strength
- High Glass Transition temperature
- Smooth Finish and can be 3D print

TPU - Thermo Plastic Polyurethane

- Used as an artificial tendon
- Flexibility and elasticity
- Durability- lasts a long time

Nylon Thread

- To transfer force from the servo to fingers
- Resistant to heat
- Durable

Acetone

- Is used to work the ABS to a smooth finish.

Cyanoacrylate Glue

- To glue together different components,
- Cures fast.
- Strong bond.

Bill of Materials

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	INDEX FINGER DISTAL		1
2	INDEX FINGER MIDDLE		1
3	INDEX FINGER BOTTOM PROXIMAL		1
4	RING FINGER MIDDLE		1
5	RING FINGER DISTAL		1
6	RING FINGER BOTTOM PROXIMAL		1
7	MIDDLE FINGER MIDDLE		1
8	MIDDLE FINGER DISTAL		1
9	MIDDLE FINGER BOTTOM PROXIMAL		1
10	PINKY FINGER PROXIMAL		1
11	PINKY FINGER MIDDLE		1
12	PINKY FINGER DISTAL		1
13	THUMB PROXIMAL		1
14	THUMB TIP		1
15	PALM FRAME BODY	PALM FRAME BODY	1
16	STANDARD SERVO		1
17	FOREARM LOWER JOINT		1
18	LOCK SCREW		4
19	PALM FRAME BODY	PALM COVER PLATE	1
20	FOREARM UPPER JOINT		1
21	PALM FRAME BODY	COONECTOR A	1
22	PALM FRAME BODY	CONNECTOR B	1
23	PALM FRAME BODY	CONNECTOR C	1
24	PALM FRAME BODY	WHIFFLETREE BASE PLATE	1
25	BATTERY		1
26	ARDUINO		1
27	EMG SENSOR		1

SolidWorks Costing Report

Date and time of report:	01-10-2019 11:52:02 PM
Manufacturing Method:	**3D Printing**
Material:	ABS
Stock weight:	372 gm
Structural Material Cost:	22.8 USD
Wall Thickness:	1.2 mm
Material cost/weight:	0.21 USD/gm
Shop Rate:	N/A

Quantity to Produce

Total number of parts:	100
Lot size:	100

Estimated cost per part: 152 USD

Costing template used:	machiningtemplate_default(englishstandard).sldct m
Costing mode used:	Manufacturing Process Recognition

Cost Breakdown

Material:	22.80 USD	15%
Manufacturing:	129.2 USD	85%
Markup:	0.00 USD	0%
Mold:	0.00 USD	0%

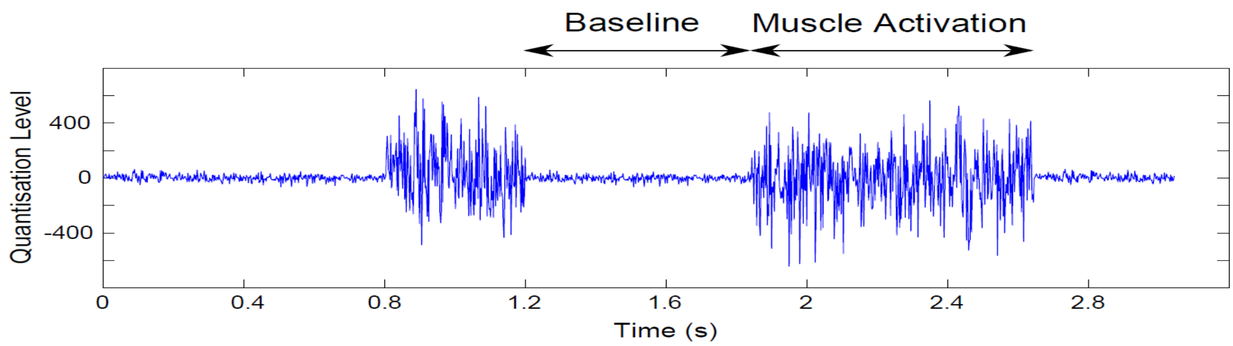
Estimated time per part: 18:51:39

Setups:	00:05:12
Operations:	18:46:27

EMG

Electromyography is used to read signals from the arm.

Electromyography is an electrodiagnostic medicine technique for evaluating and recording the electrical activity produced by skeletal muscles. In our prototype, we use EMG Sensors attached to the stump of the arm and measure the change in potential with contraction of muscle fibers, and use this signal to control our prosthetic hand.



All animals have muscles that contract by means of electrical activity - it is well known that the brain sends electrical impulses to the motor neurons in the arm which causes muscle fibers to contract. It is easy to measure this contraction of muscle fibers from surface electrodes, this is known as electromyography.

Procedure

For the purpose of the prototype, we use a Myoware sensor which costs $37. The sensor has a pair of snap on electrodes attached to it. Currently these electrodes are one time use only - we are undertaking research on how to use reusable electrically conductive cloth.

The electrodes are placed at specific spots above the stump of the arm. There are three electrodes - Two electrodes at the ends of a muscle fiber, and one reference electrode which is normally attached to the underside of the arm.

When the consumer flexes their arm, it generates an electrical signal that is picked up by the sensor.

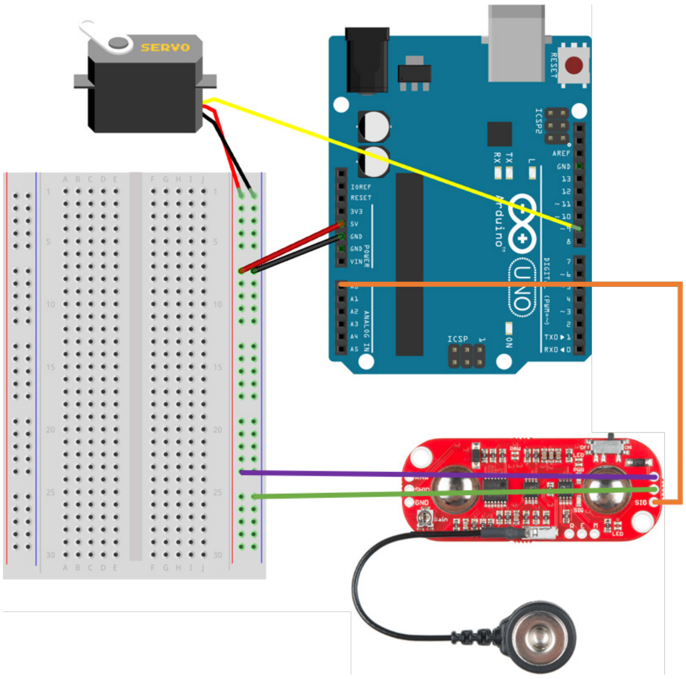
The sensor is connected to a microcontroller, which processes the signal and controls a servo. Practically any microcontroller can be used for this, although we use an ATMEGA328P as it is common, cheap and fast enough to do the job real time.

The servo we use is a high torque 9kg-cm servo that provides the prosthesis a lifting capacity of upto 1.3 kg, this is no mean feat as n0rmal prosthesis are able to lift nowhere near this amount.

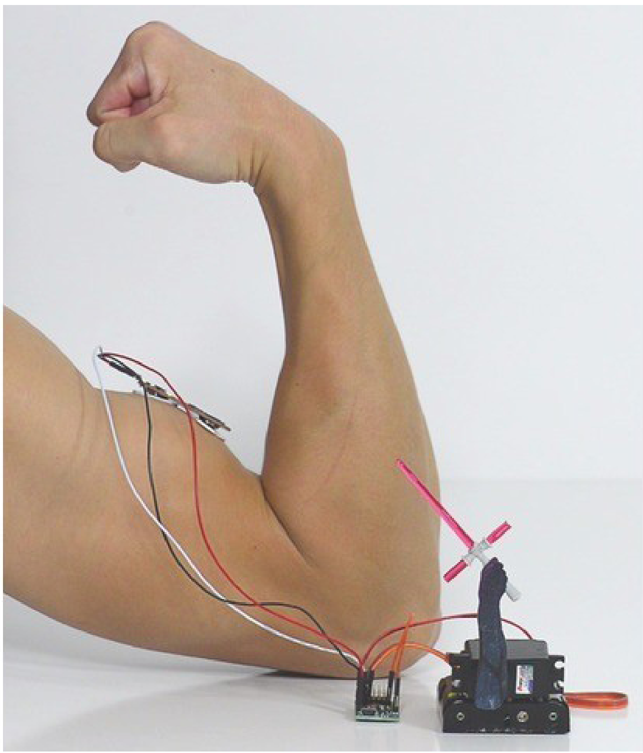
The whole setup is powered by a battery, at full load the system can last around 8 hours of use on a 2200 mAh battery. The battery can be recharged at night when the prosthesis is disengaged.

Circuit Diagram

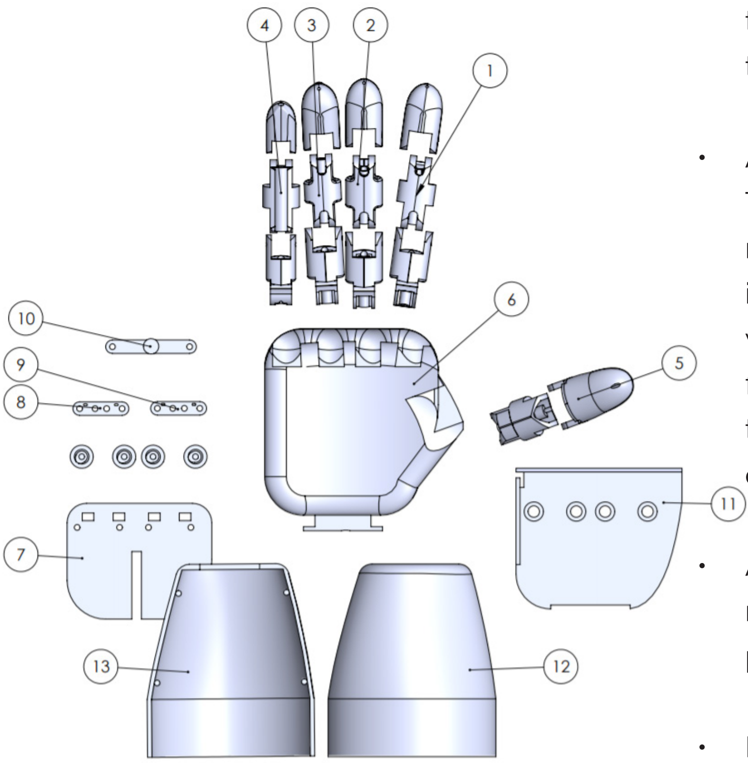
The following circuit diagram is made on fritzing.



A picture of the setup and the arm.



Assembly



- Each finger consists of three individual printed parts connected by polypropylene pins. all the 4 fingers along with thumb are connected in the same way.

- Artificial tendon loops of TPU and nylon thread runs through channels inside the finger which when pulled rotational forces are applied to all the joints and fingers curls up.

- All the fingers are connected to the palm by polypropylene/abs pins.

- Palm accommodates the differential mechanism (Whiffletree mechanism) Which consists of the component such as bar A(8) and bar B (9).

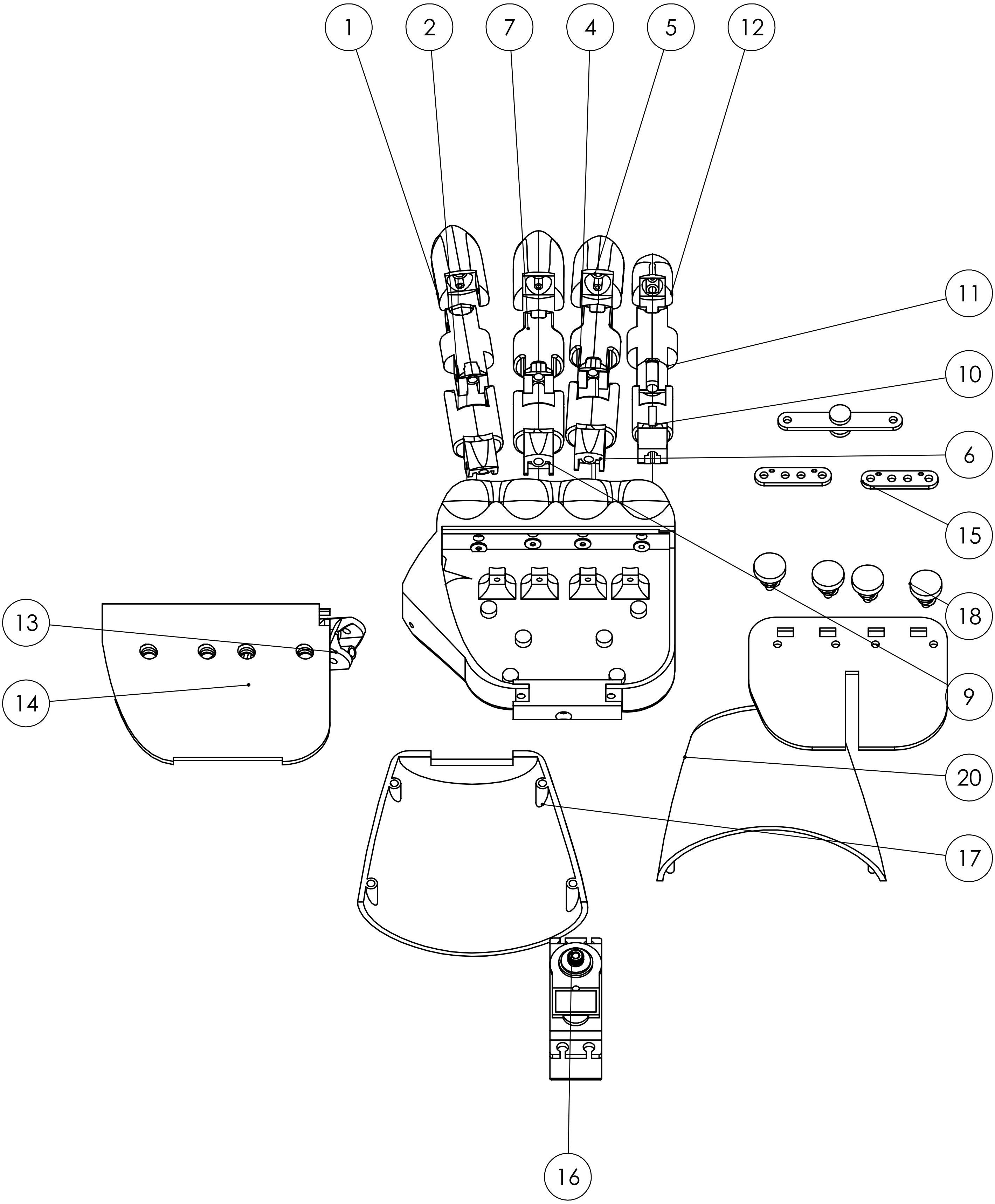
- Bar A connects index and middle finger whereas bar B concepts ring and pinky.

-

- The top two bars of our whiffletree have appropriately designed holes and the palm accommodates a set of buttons that upon pressing are elongated.

- When a button is pressed the elongated part fills the corresponding finger hole and the motion of this particular finger is constrained.

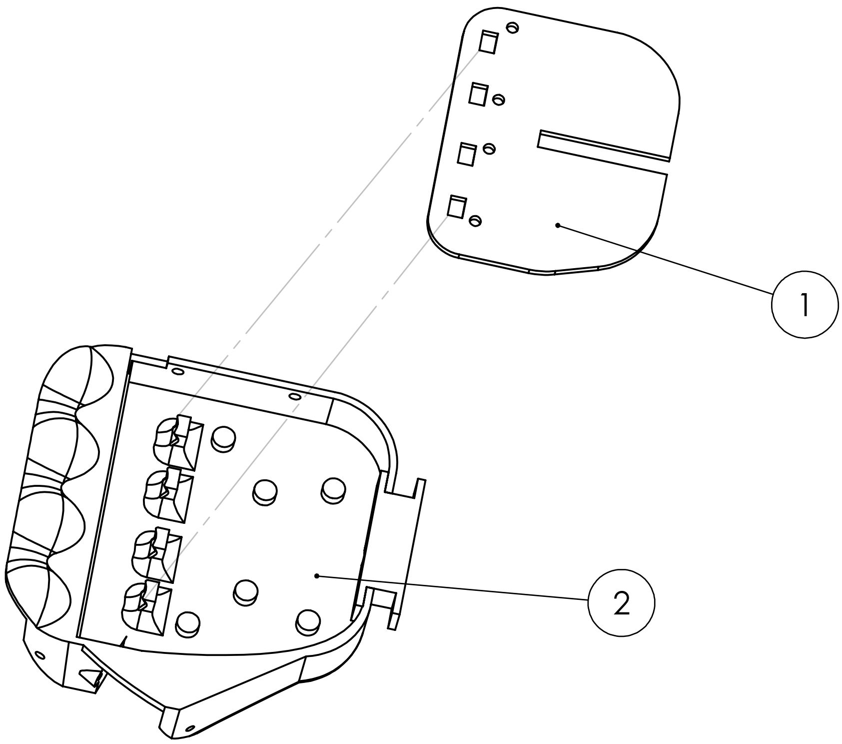
Manufacturing Drawings



Manufacturing Drawings

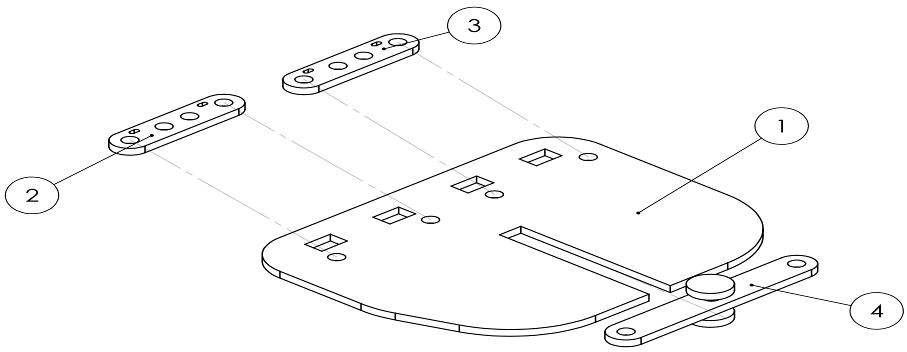
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	INDEX FINGER DISTAL		1
2	INDEX FINGER MIDDLE		1
3	INDEX FINGER BOTTOM PROXIMAL		1
4	RING FINGER MIDDLE		1
5	RING FINGER DISTAL		1
6	RING FINGER BOTTOM PROXIMAL		1
7	MIDDLE FINGER MIDDLE		1
8	MIDDLE FINGER DISTAL		1
9	MIDDLE FINGER BOTTOM PROXIMAL		1
10	PINKY FINGER PROXIMAL		1
11	PINKY FINGER MIDDLE		1
12	PINKY FINGER DISTAL		1
13	THUMB PROXIMAL		1
14	THUMB TIP		1
15	PALM FRAME BODY	PALM FRAME BODY	1
16	STANDARD SERVO		1
17	FOREARM LOWER JOINT		1
18	LOCK SCREW		4
19	PALM FRAME BODY	PALM COVER PLATE	1
20	FOREARM UPPER JOINT		1
21	PALM FRAME BODY	COONECTOR A	1
22	PALM FRAME BODY	CONNECTOR B	1
23	PALM FRAME BODY	CONNECTOR C	1
24	PALM FRAME BODY	WHIFFLETREE BASE PLATE	1
25	BATTERY		1
26	ARDUINO	`	1

Manufacturing Drawings



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	PALM FRAME BODY	WHIFFLETREE BASE PLATE	1
2	PALM FRAME BODY	PALM FRAME BODY	1

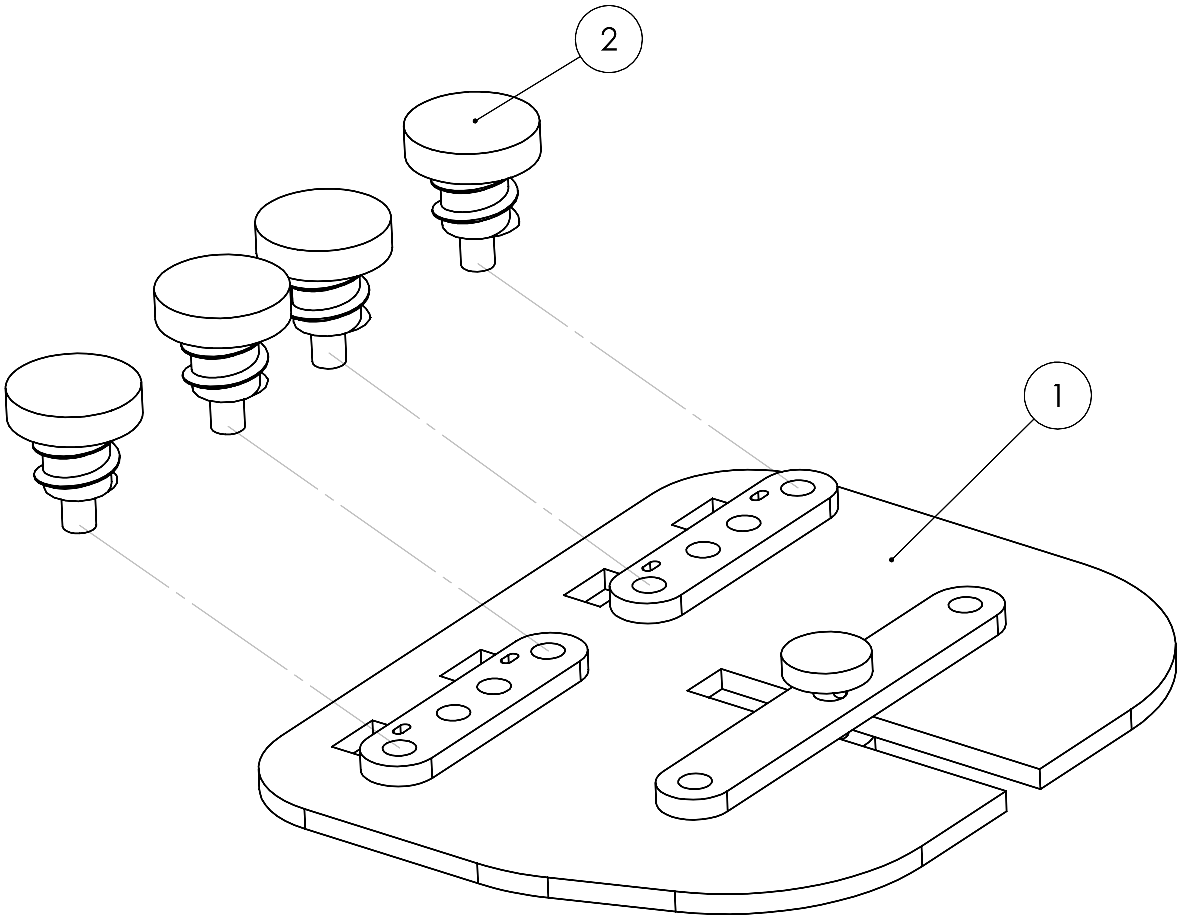
Manufacturing Drawings



SOLIDWORKS Educational Product. For Instructional Use Only.

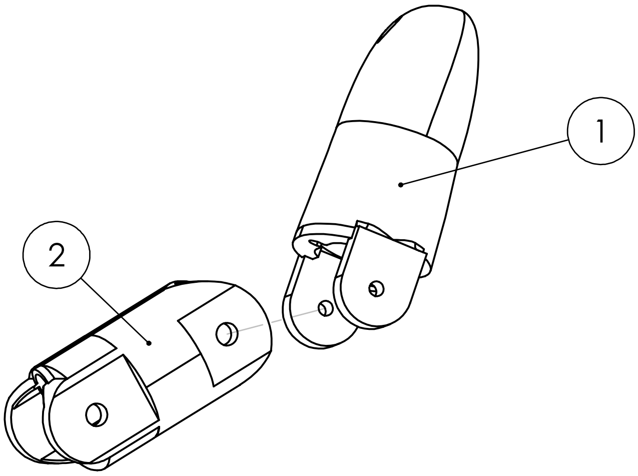
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	PALM FRAME BODY	WHIFFLETREE BASE PLATE	1
2	COONECTOR A		1
3	CONNECTOR B		1
4	CONNECTOR C		1

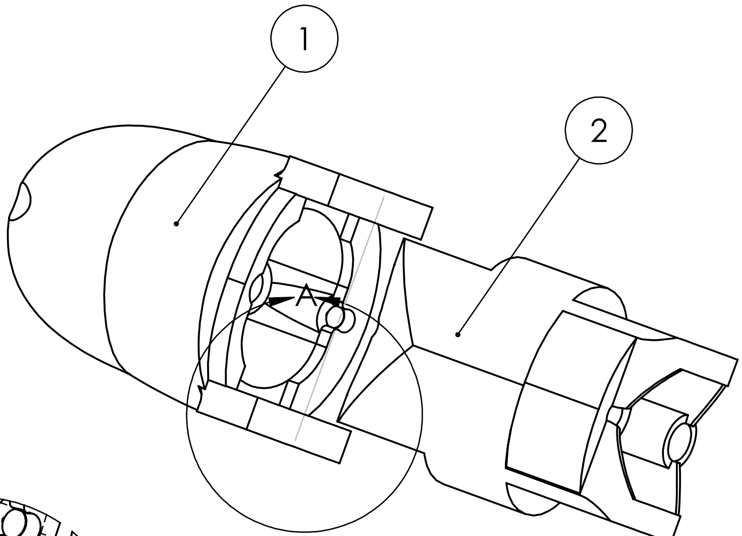
Manufacturing Drawings

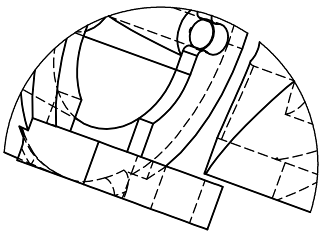


ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	PALM FRAME BODY	WHIFFLETREE BASE PLATE	1
2	LOCK SCREW		4

Manufacturing Drawings



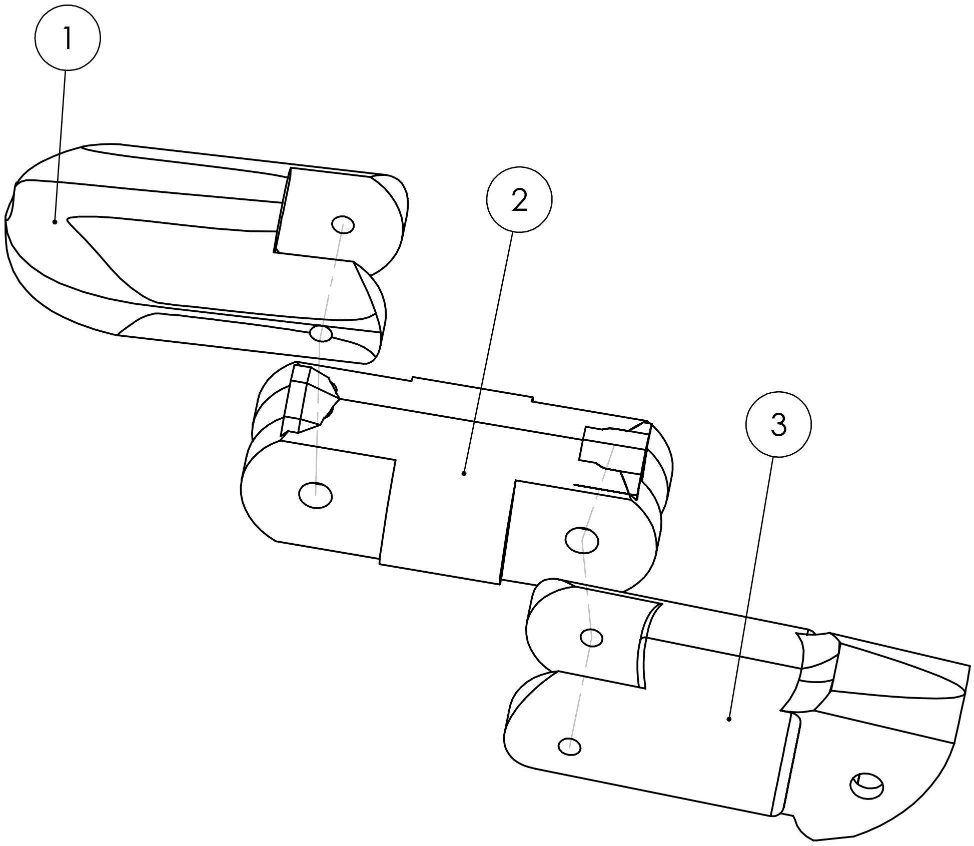




DETAIL A
SCALE 2 : 1

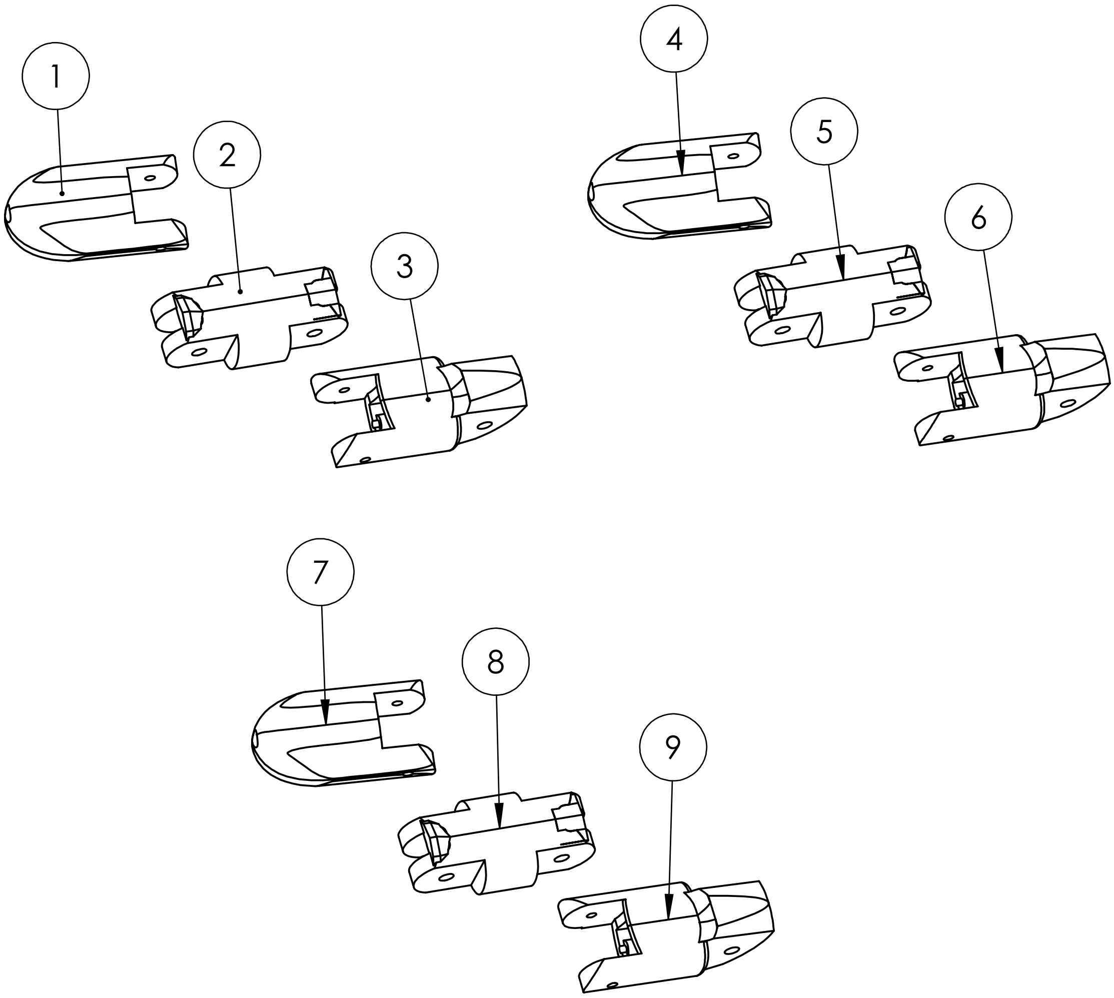
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	THUMB TIP		1
2	THUMB PROXIMAL		1

Manufacturing Drawings



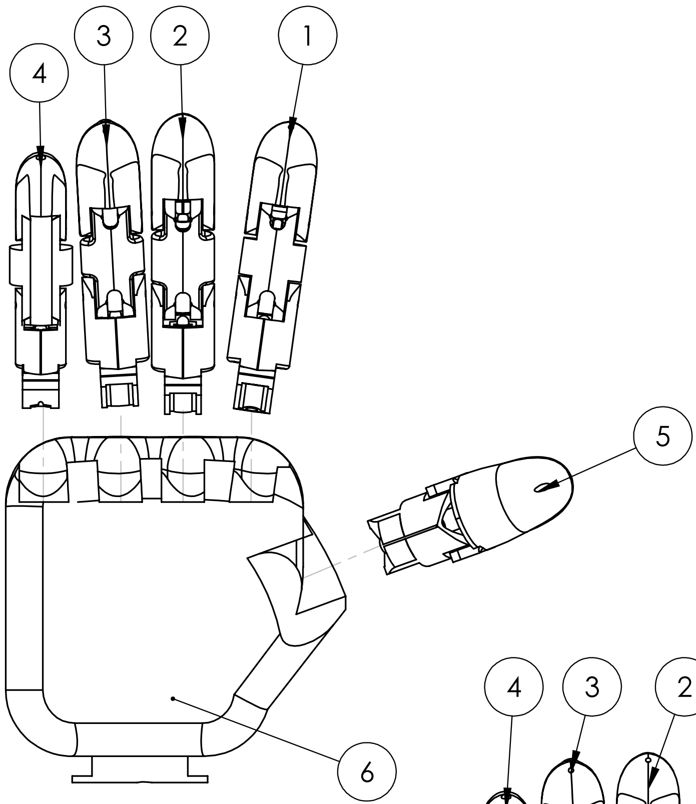
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	INDEX FINGER DISTAL		1
2	INDEX FINGER MIDDLE		1
3	INDEX FINGER PROXIMAL		1

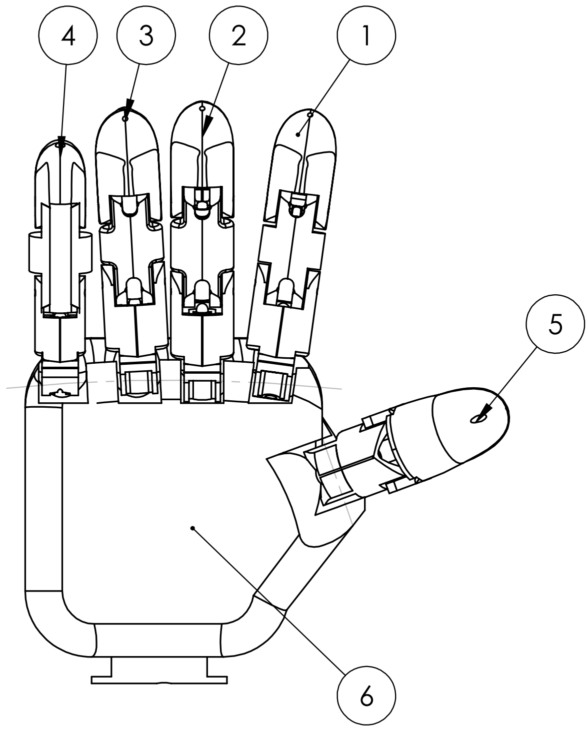
Manufacturing Drawings



ITEM NO.	PART NUMBER	QTY.
1	MIDDLE FINGER DISTAL	1
2	MIDDLE FINGER MIDDLE	1
3	MIDDLE FINGER PROXIMAL	1
4	RING FINGER DISTAL	1
5	RING FINGER MIDDLE	1
6	RING FINGER PROXIMAL	1
7	PINKY FINGER DISTAL	1
8	PINKY FINGER MIDDLE	1
9	PINKY FINGER PROXIMAL	1

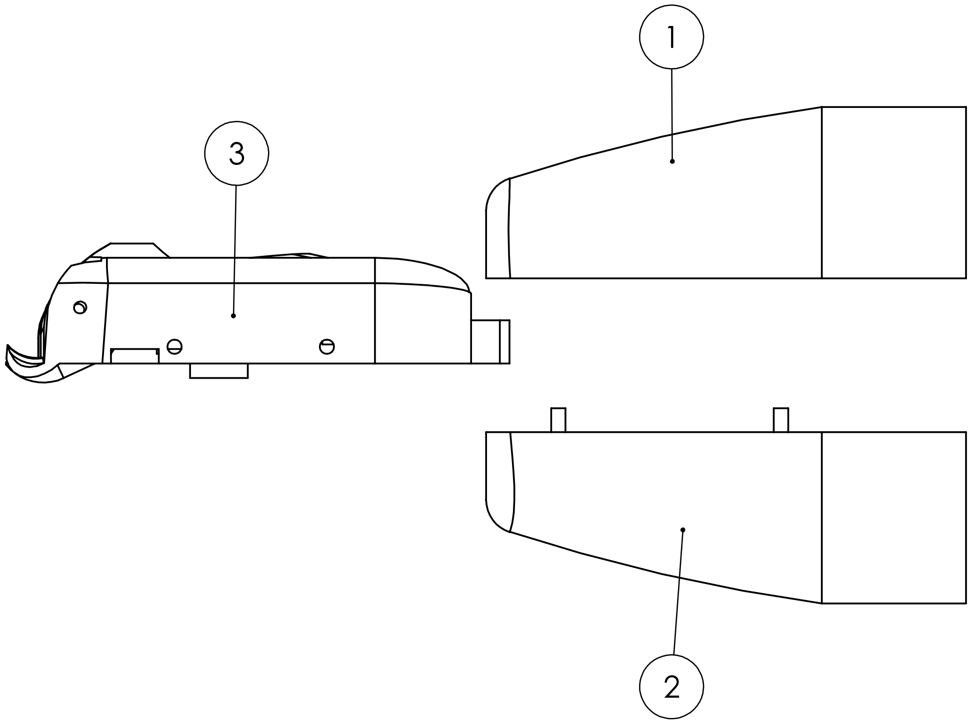
Manufacturing Drawings





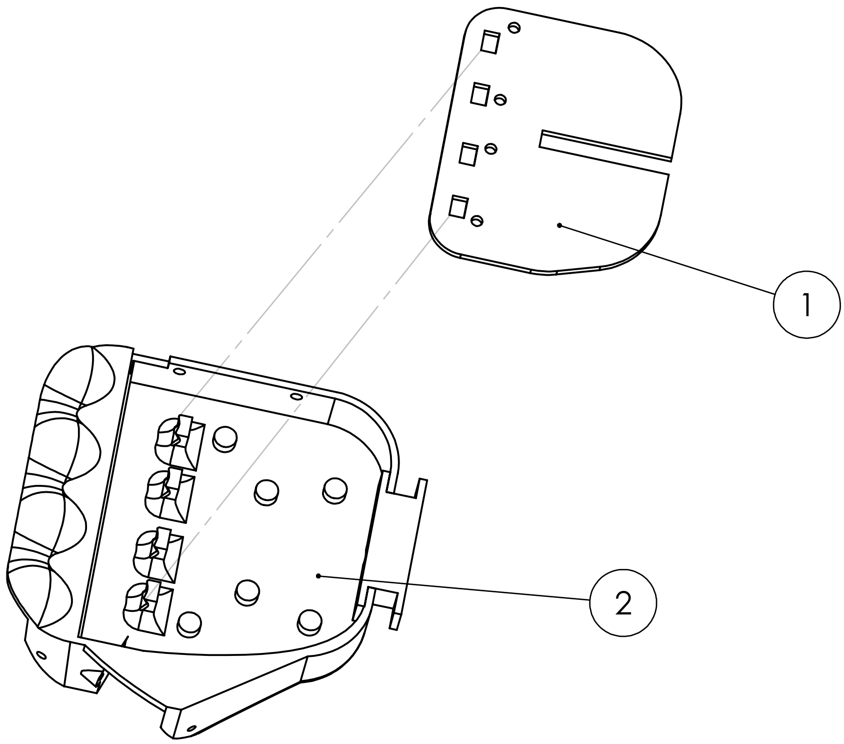
ITEM NO.	PART NUMBER	QTY.
1	INDEX	1
2	MIDDLE	1
3	RING	1
4	PINKY	1
5	THUMB	1
15	PALM FRAME BODY	1

Manufacturing Drawings



ITEM NO.	PART NUMBER	QTY.
3	PALM FRAME BODY	1
1	UPPER FOREARM	1
2	LOWER FOREARM	1

Manufacturing Drawings



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	PALM FRAME BODY	WHIFFLETREE BASE PLATE	1
2	PALM FRAME BODY	PALM FRAME BODY	1

References

https://www.ottobock.in/prosthetics/upper-limb/solution-overview/myofacil-prosthesis-system/

https://singularityhub.com/2010/06/30/how-much-is-the-newest-advanced-artificial-hand-11000-usd-video/

https://www.livestrong.com/article/468905-hand-grip-strength-test/

https://biology.stackexchange.com/questions/30857/does-the-human-hand-have-27-degrees-of-freedom

https://www.hindustantimes.com/delhi-news/customised-high-end-prosthetics-that-don-t-burn-a-hole-in-your-pocket/story-a6p6VtyVzuXjwPriSrOhNO.html

https://www.amrita.edu/news/research-paper-amrita-prosthetic-hand-elsevier-journal

https://www.rehab.research.va.gov/jour/2012/494/pdf/smit494.pdf

http://www.oandplibrary.org/al/1957_01_004.asp

https://jneuroengrehab.biomedcentral.com/articles/10.1186/s12984-018-0417-4

https://link.springer.com/article/10.1016%2FS1672-6529%2816%2960377-3

https://www.sciencedirect.com/science/article/pii/S1672652916603773

http://wcms.inf.ed.ac.uk/ipab/slmc/research/undergraduate-and-msc-projects/improving-robotic-prosthetic-hand-performance-through-grasp-preshaping/KyranouThesis.pdf

https://www.researchgate.net/publication/51759015_Bionic_prosthetic_hands_A_review_of_present_technology_and_future_aspirations

file:///C:/Users/Ashutosh%20Pandey/Downloads/Bionic_prosthetic_hands_A_review_of_present_techno.pdf

https://en.wikipedia.org/wiki/Prosthesis