Designing and Creating an Electro-mechanical Prosthetic Hand

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The Big Idea

Through my project, I hope to bridge the gap between low-cost 3D printed prosthetics and current high-end custom prosthetics, which can cost upwards of $30,000-$50,000, by combining simple electronics into a 3D printed chassis. From this project, I hope to vastly improve my 3D design skills and gain experience in creating a consumer product.

Introduction

Modern prosthetics cost tens of thousands of dollars, making them prohibitively expensive for many individuals [1]. Children, who quickly grow out of any prosthetic, have an especially hard time affording these life-changing products. 3D printing has proven to be an exceptional solution to youth prosthetics as the cost of replacement is relatively cheap and the devices can be easily customized on an individual basis and printed at home. Most current mechanisms rely solely on mechanical power to move fingers, but these devices could benefit from a modular electronic system that could move between prosthetics as children grow. This hybrid system could provide functional benefits for these prosthetics and the modularity would allow swapping of electronics between prosthetics to lower ongoing costs.

The US alone has almost 2 million amputees and 1 in 30,000 new births suffer from Symbrachydactyly or the absence of fingers in a hand [1] [2]. A low-cost and effective prosthetic could make a significant impact on many lives around the globe. The increased functionality of 3D printed prosthetics could give people with disabilities increased control and make it easier to live a regular life. Furthermore, a hybrid electro-mechanical 3D-printed system could provide expanded functionally with a built-in microcontroller. 3D printing and modern manufacturing techniques are set to completely revolutionize the prosthetics field so staying on the forefront of these techniques will give numerous new opportunities to help others.

Design

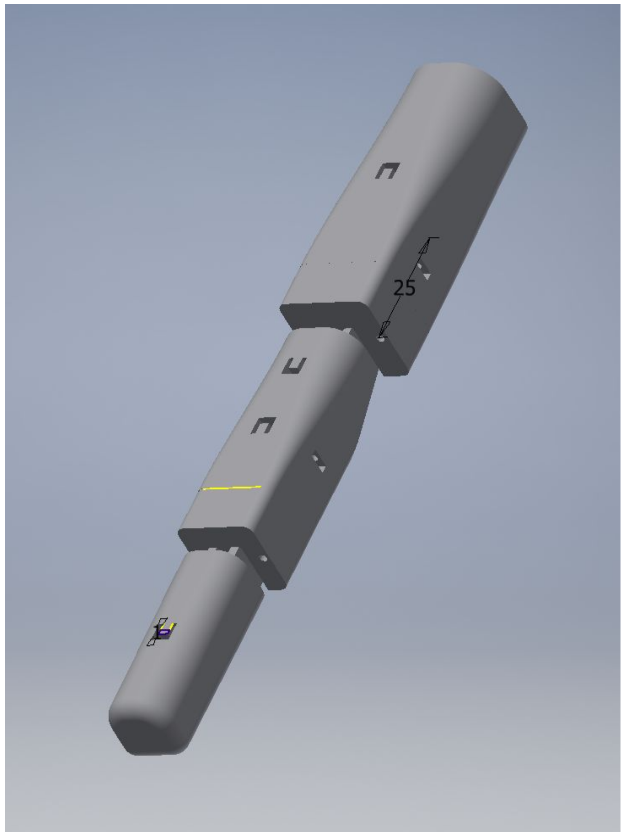
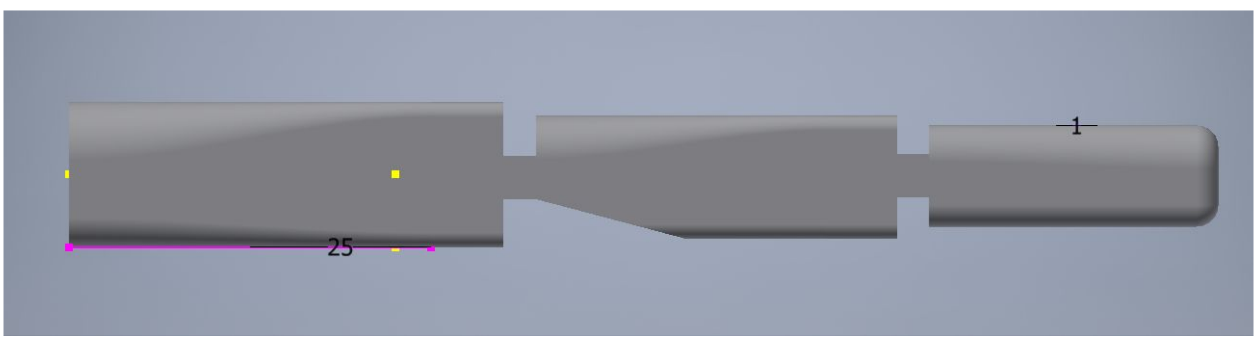


Figure 1A - Finger Fully Extended



Finger 1B - Finger Fully Extended From Side

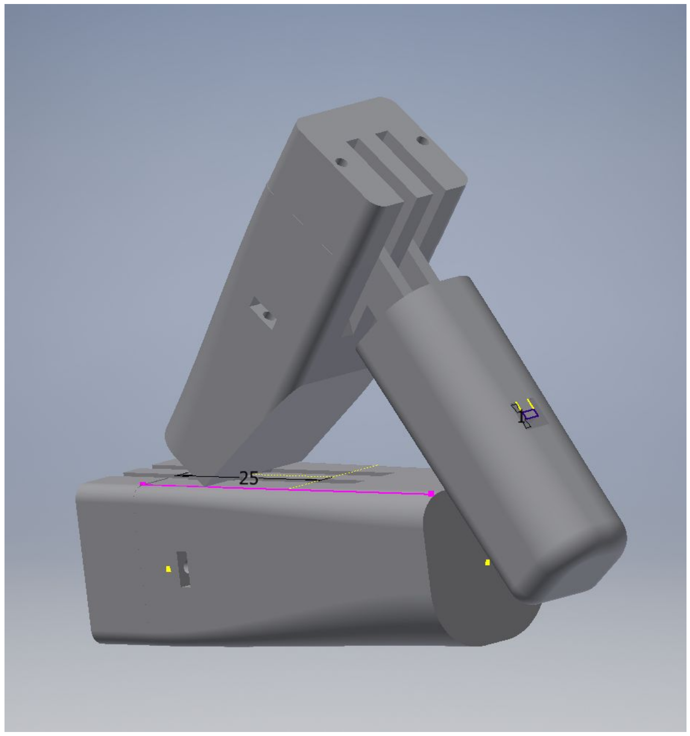


Figure 1C - Finger Folded

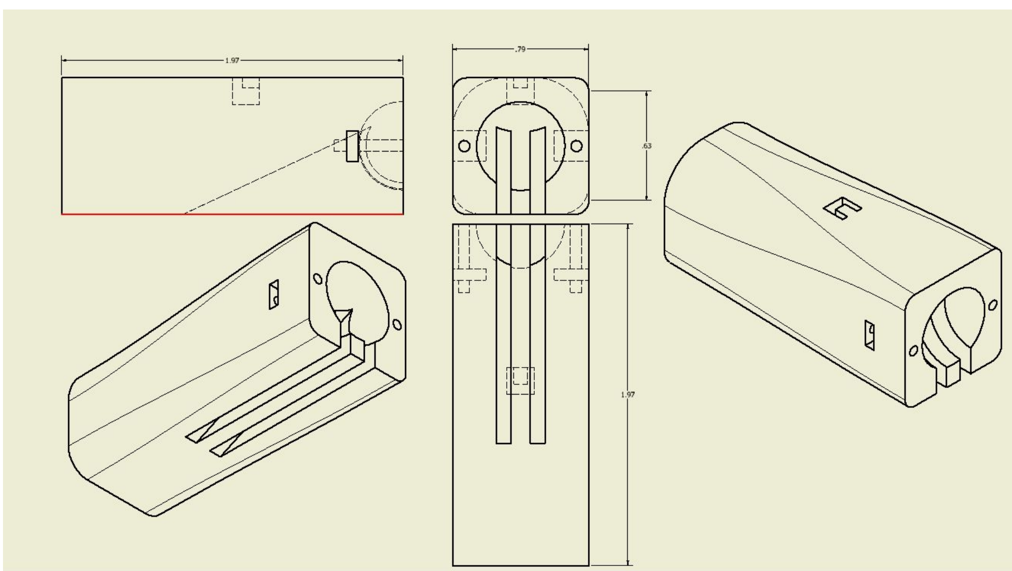


Figure 2A - Finger Proximal Phalanx (Inches)

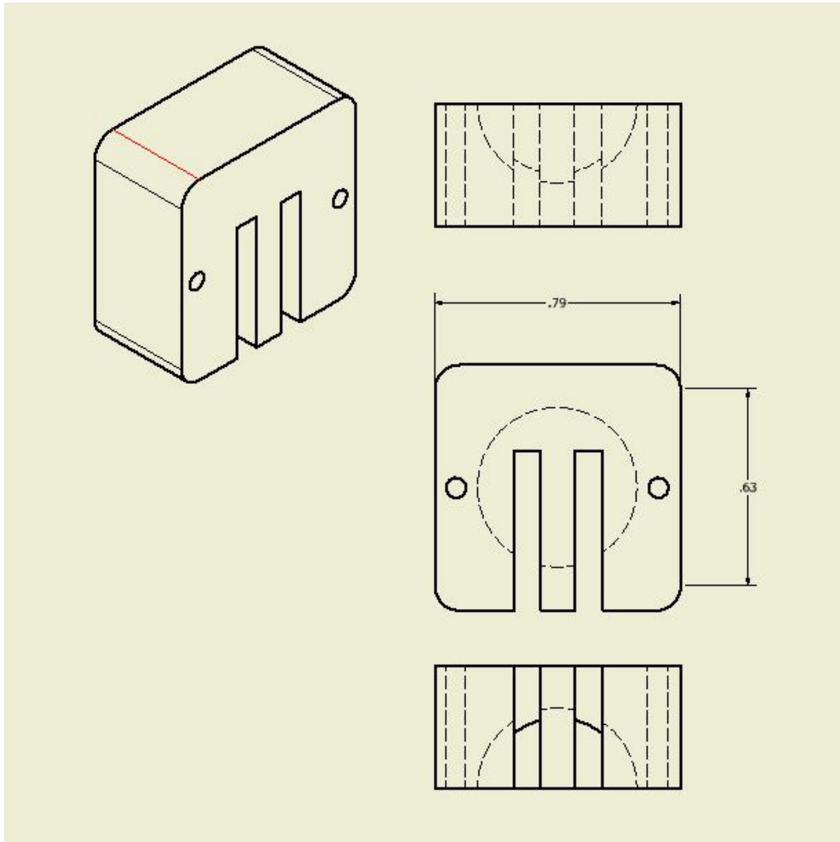


Figure 2B - Finger Proximal Joint (Inches)

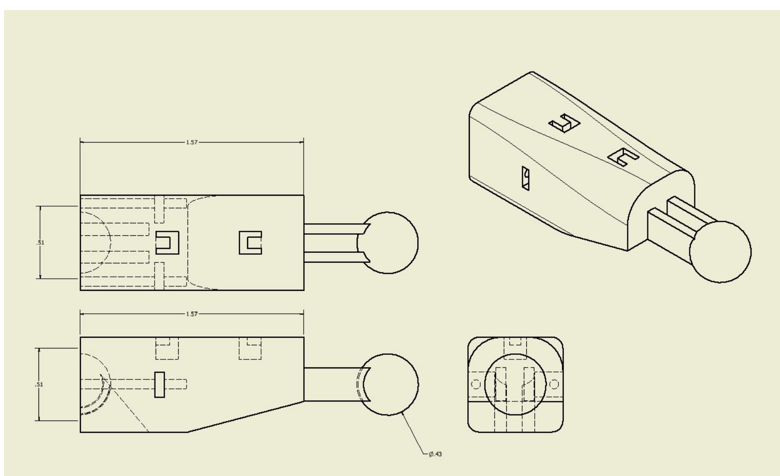


Figure 2C - Finger Middle Phalanx (Inches)

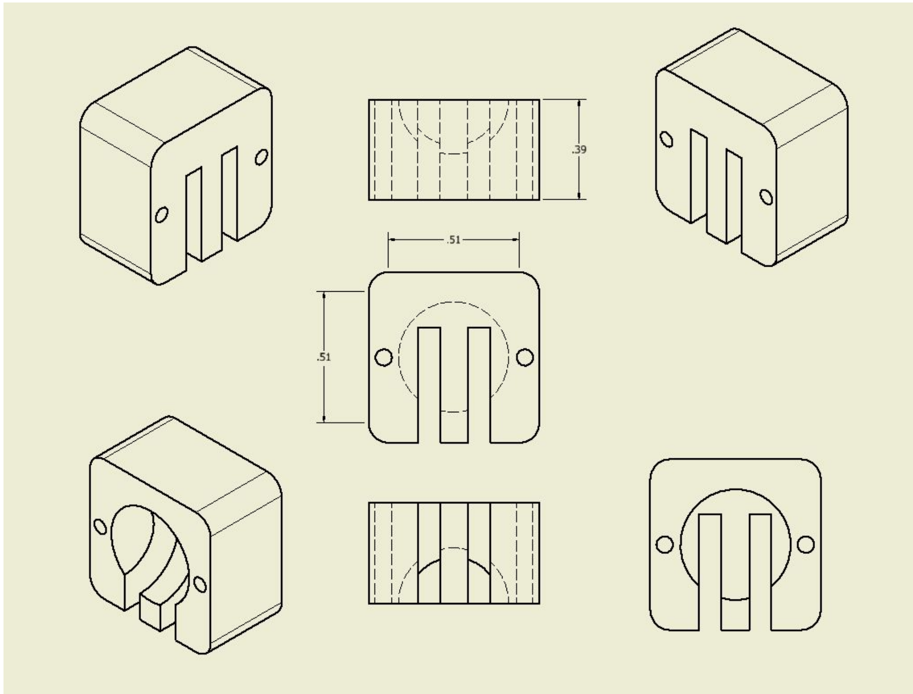


Figure 2D - Finger Middle Joint

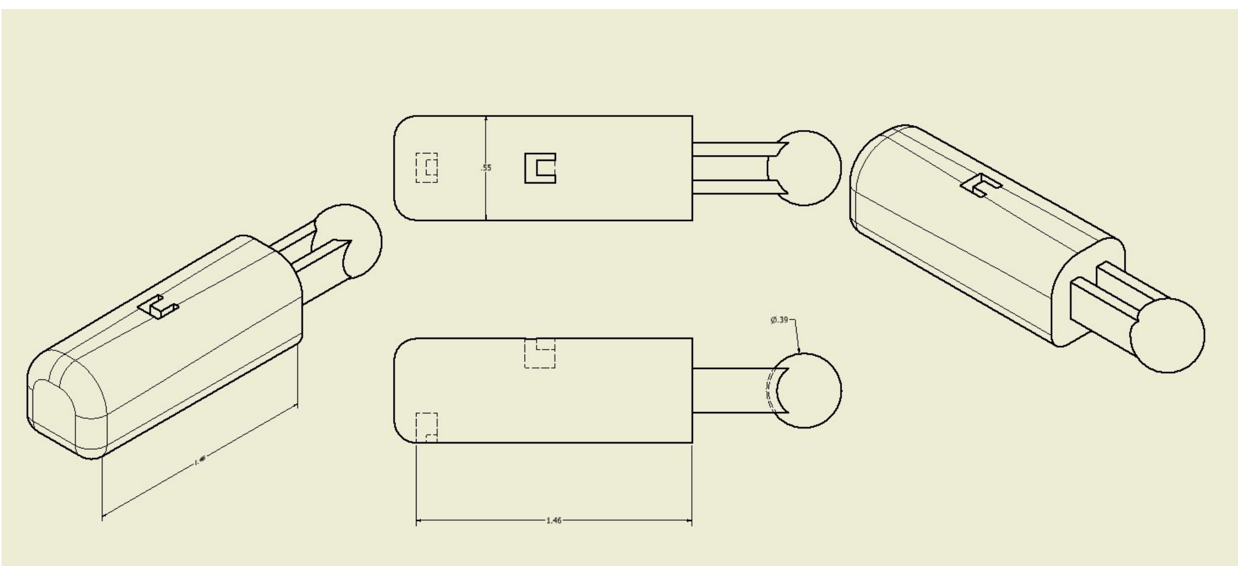


Figure 2E - Finger Distal Phalanx

The long-term goal of the project is to build a full electro-mechanical prosthetic hand. Currently, only a single index finger is designed, but the current model is easily scalable to four fingers and the general design principles could be extended to a thumb as well. Each finger consists of five individually printed parts, which comprise three distinct finger sections when assembled (see Figures 1+2 and Appendix B). The solely 3D printed features are able to move freely without any electrical components as the joints are 3D printed ball joints that require no electronics. Each single joint consists of three individually printed parts (see Figure 2A-C), which are held together with two bolts. While the bolts add complexity to the part and require a notch to be inserted for the nut, the bolt design is preferable to a snap-in design as it allows for better servicing of the hand. The serviceability of the hand is a major overall design goal as any product used daily will see eventual wearing and breaking of parts so being able to easily maintain the hand will be crucial to its longevity.

The current dual rectangular design that bridged the gap between the ball and the main finger component (see figure 2C) was chosen because the previous cylindrical design allowed the finger the spin in the socket, which would've detrimental to the functioning of the finger. The new design, however, has proved to be extremely fragile and prone to breaking so these slots will need to be combined or widened for better structural integrity. Further tests should also be conducted to compare the strength of different resin filaments for printing. Each finger will need to be able to sustain significant force without failure.

The finger is capable of extending and bending purely from mechanical movement. Rubbers bands are slotted into the inserts at the top of each finger section, which pulls the finger back to the fully extended position seen in figure 1A. A string is attached offset center to the distal phalanx, which when pulled on causes the finger to bend as seen in figure 1C. As the tension on the string is released, the rubber bands pull the finger back to the extended position. To allow for precise positioning, the system will need to be carefully calibrated, which could lead to issues if the rubber bands or strings eventually stretch. To deal with this issue, the string will eventually be replaced with stronger metal wire and the rubber bands should be replaced often. The rubber band and string system is the best system considered so far as it allows the servos, batteries, and microcontroller to be on board another device on the forearm, which otherwise would cause the actual hand to be overly bulky.

The hand will be controlled by a small device on the forearm that connects mechanically to the hand through the strings mentioned above. At first, the box will only contain a battery, an arduino mini and micro servos to pull on the string; however, in the long term, force and IR sensors will be added to the fingers to provide feedback to the controller. The current design (Figure 3), relies only on three micro servos to save on space and weight. The thumb and index finger are both individually controlled by their own servo, while the middle, ring, and pinky are all controlled by a single servo. In theory, this system will cover the majority of uses of the hand — gripping/holding and pinching — but later testing may reveal that individual control of the fingers better suits the needs of users.

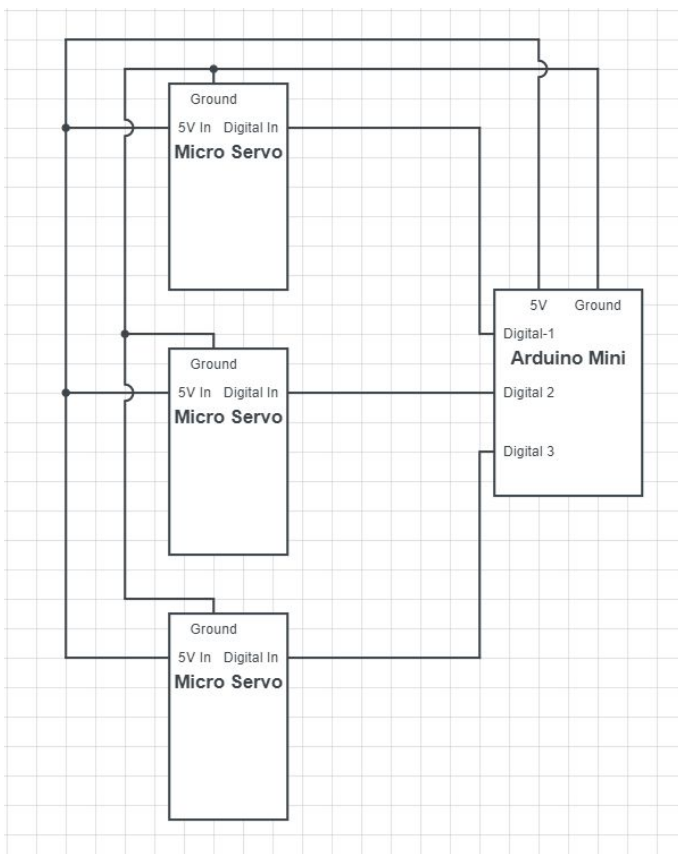


Figure 3 - Electrical design

Next Steps

The current finger design works as intended, but mostly exists as a proof of concept and needs to be extended upon. The fingers are currently very boxy and each individual finger components' length needs to be optimized for holding objects — basing these designs off of the human hand will be useful. Another important factor that needs to be considered is the surface material/structure of the hand for maximizing grip. Currently, the surface of each finger is smooth, which doesn't provide nearly as much grip as an actual hand. Eventually, surface bumps need to be added to improve upon this issue. Once optimized, the single finger design will be expanded to four fingers and a thumb. Further refinements of the current hand include adding slots for the rubber bands to run through, adding a slot for the tension wire to run through, and testing different strings such as guitar string for better durability.

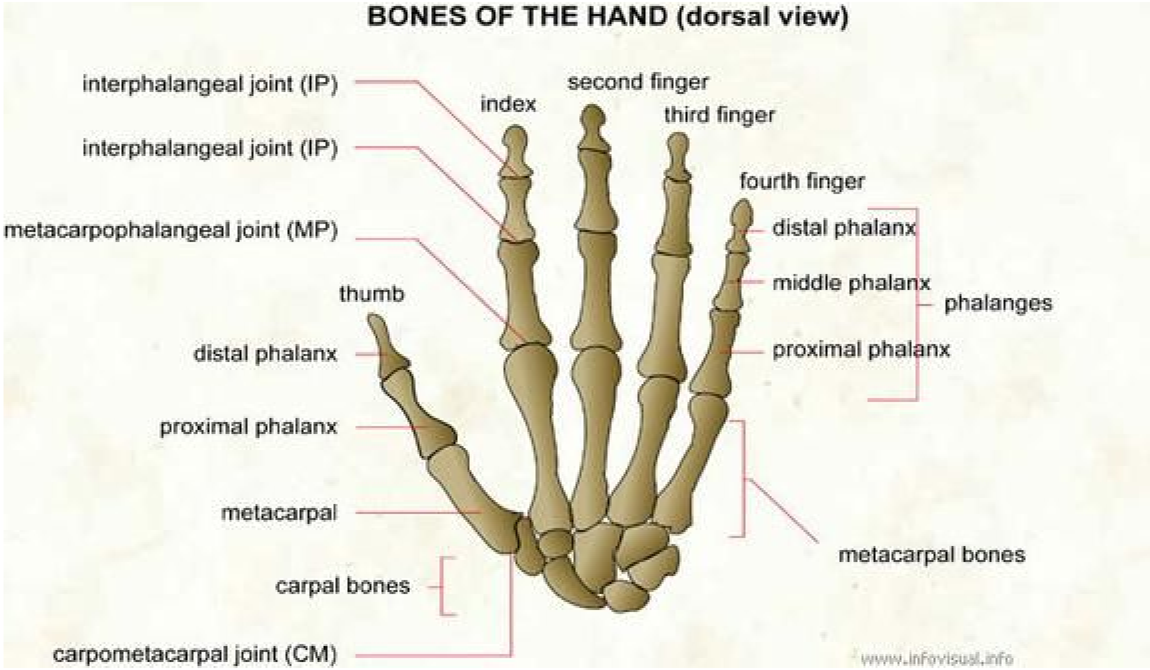
The next significant step in the project will be adding the electrical components to control the hand. A controller, which will lay on the forearm, needs to be created and will house the battery, microcontroller, and micro servos. This device, will need to be comfortable to wear, light, and durable. As this device will be worn all day, numerous trade-offs will need to be made. Primarily the size and weight vs torque for the micro servos will need to be considered and the optimal battery size and device battery life needs to be tested.

The last stage of the project will be to include sensors in the physical hand which can provide feedback to the servos to balance grip between the fingers. Furthermore, IR sensors will be added to assist patients in gripping objects.

Appendix A - Parts list

Part Description	What It's Needed For	Cost	Where was it purchased
6 thousands of inch nuts and bolts	Combining finger components	$20	McMaster Hill
Rubber Bands + guitar wire	Finger movement system	$15	Amazon
Battery, arduino, micro servos	Finger movement system	"$0"	Lab
Force/IR Sensors	Grip management	~$25	Amazon

Appendix B - Hand Anatomy



Source: https://faithanatomy.wikispaces.com/file/view/hand.jpg/32061795/579x333/hand.jpg

Citations

[1] https://www.disabled-world.com/assistivedevices/prostheses/prosthetics-costs.php

[2] https://en.wikipedia.org/wiki/Symbrachydactyly