Fully Automated Prosthetic Thumb Design

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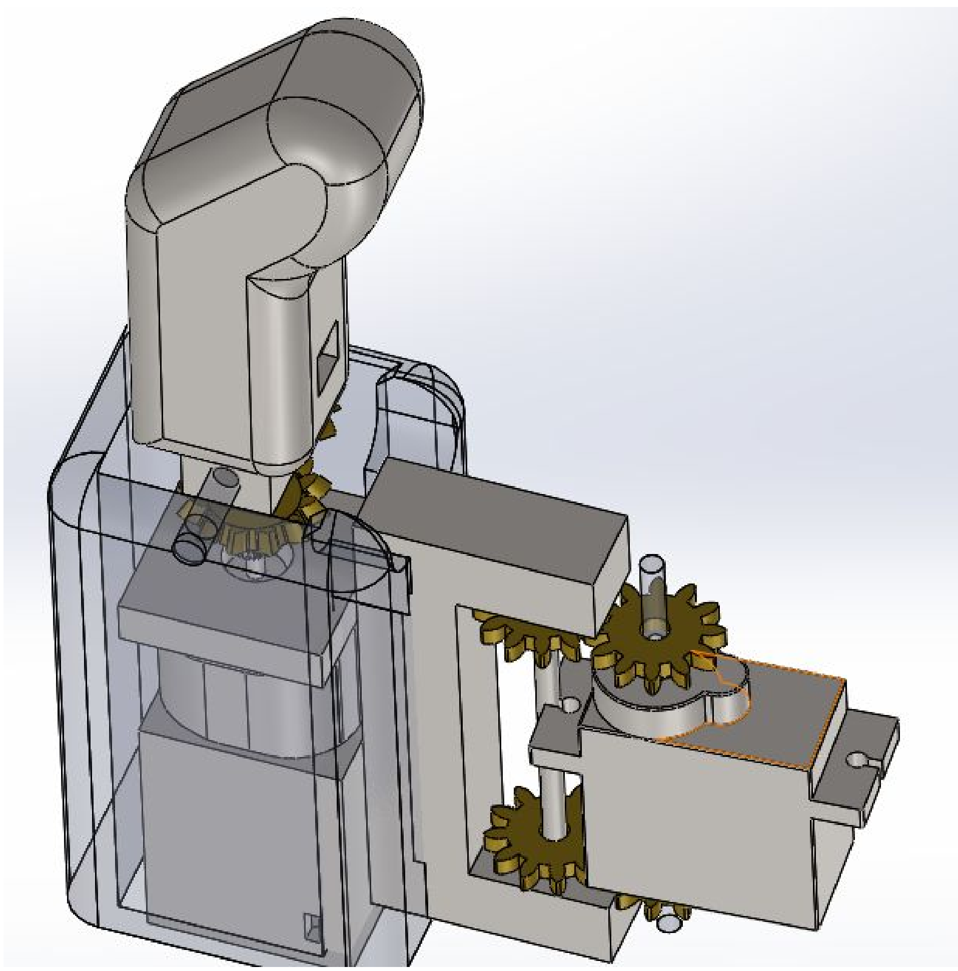

Animations of Thumb Motion:
https://youtu.be/YOoa44TtWTE and https://youtu.be/KsRCgnkUBZc

Design Background

In impoverished countries that have suffered from war, residual landmines, or other conflicts, many people have lost arms, hands, and other limbs that are useful in daily functions. Amputations are prevalent, specifically in upper limbs. Prosthetic technology is becoming increasingly affordable and practical to help individuals with amputation in these developing countries. However, in such scenarios there are clear limits on materials and cost. Thus prosthesis hand design targeted toward impoverished areas should ideally be lightweight, cheap and also easy to maintain, while still providing a range of motion and other functionality close to that of more expensive hands. In this report, a design for such a suitable prosthesis thumb will be introduced.

Design Overview:

The minimum criteria for the thumb is a two degree of freedom design (for flexion and adduction), that maintains power when the prosthetic hand is in a gripping position. In order to control motion in each degree of freedom, the thumb has two servo motors. The motor housed directly under the thumb is used for grasping motion, and uses two bevel gears. The second motor embedded in the base, or palm, of the prosthetic, rotates the thumb around the palm to provide a wider range of possible functions. Four gears in total are used for this second motor, with two identical sets on each end of rotating rods. On each end, one gear connects with the motor which is in turn fixed to the palm, while the other gear is connected to the thumb body. Thus the rotation of these gears allow the thumb to move while this motor and its housing stay fixed. The two motors will be powered by battery. Most parts of this design are 3-D printed, making the thumb easy to manufacture as well as cheap as seen below in Table 1. Furthermore, with mass production, the price of the thumb could be even lower.

Use of the gears ensures the reliability of the thumb compared with a belt or cable design. Both of these options will likely be less durable than gears. The 3-D printed parts can also easily be replaced. No special tools or techniques are required to assemble the thumb.

Our current thumb design is relatively cheap and light as compared to the other designs in Table 2. However, there are of course many improvements that could be made to this thumb. One of the important design choices that we would have made differently if we were working towards a full prosthetic hand design is that we would have only included a single thumb motor to manage the rotational motion. The grasping motion we would have somehow linked to the grasping motion of the whole hand. Two motors for just the thumb adds a lot of bulk and weight as well as increases the cost. But while we admit that this design choice has some unwanted consequences, it does allow for a range of motion that is nicely automated.

Our thumb design is somewhat detached from the mechanism that actuates the motors. The most common choice of triggering mechanism is to use myoelectric sensors attached to the patients remaining forearm/upper arm. However, the low end price of a full myoelectric sensor setup is roughly $100-$150 [2]. This cost may be prohibitive in impoverished areas. Signals are often sent from the motion of other body parts equipped with cheaper sensors that are less fine tuned, however it is difficult to find suitable body motions that go reliably unused. Other alternatives that are often used especially in low cost products are mechanical body powered prosthetics, however these designs are often uncomfortable and/or lack a wide range of motion.

Table 1: Parts List

ITEM NO.	PART Name	MASS per part*	QTY.	COST**	SOURCE
1	Motor Case/Connector Piece	38.1g	1	$ 5.70	3D print
2	Fixed Servo Connector	10.4g	1	$ 1.56	3D print
3	Bevel Gears	.44g	2	$ 0.13	3D print
4	Connector Rod	1.34g	1	$ 0.21	3D print
5	Connector Gears	.26g	4	$ 0.16	3D print
6	Motor	15g?	1	$ 0.50	Aliexpress.com
7	Servo Motor	10g	1	$ 2.50	Amazon.com
8	Thumb Body	25.4g	1	$ 3.81	3D print
9	Thumb Rod	1.31g	1	$ 0.20	3D print
Total	**N/A**	**102.3g**	**13**	**$14.80**	**N/A**

* mass computed assuming ABS PC plastic
** cost of 3D printed parts computed using $0.15 per gram of ABS plastic

<u>Table 2: Performance Comparison</u>

	Goal	Tact [1]	Hero Arm [2]	FIU Prosthetic [3]	Our Design
Cost	Affordable for developing country: ~$200 for hand ~$20 for thumb	$250 ~$15 for thumb* +	$3500 ~$400 for thumb* -	$1100 ~$200 for thumb* -	$14.80 for thumb +
Ease of manufacturing	Easy to assemble and maintain No special tool or knowledge required	14 hours to print, 29 printed parts, 5 other parts, no special tools needed for assembly +	40 hours to print, no special team to install arm 0	Moderate, 93 separate components both 3D printed and ordered commercially -	Primarily 3D printed, 13 parts in total. Easy assembly +
Functionality	Works like a healthy human hand, smooth and quiet Can easily learn how to use	First phalange of thumb can move to help grabbing small items, cooperating with other fingers can perform several different grasps. +	Opposable thumb that can flex and extend, haptic sensors, and the ability to control all fingers independently +	Allows a variety of grasps and simple pinching. +	Thumb moves in 2 basic DOF's, able to maintain power via servo motor during a grip +
Aesthetics	Durable Good looking	Pure ABS plastic exterior, exposure of main component -	Futuristic design, intuitive interface, and durable design, but does not look like a real human arm +	Simple exterior mix of plastic and metal 0	Bulky, parts look unnatural, real-looking thumb component 0

*It was difficult to obtain reliable estimates for individual component pricing such as just the parts that comprise the thumb. Thus estimates may be very inaccurate. Comparison in general was difficult because we were comparing a thumb design to that of a whole prosthetic hand.

Remarks:

As shown in Table 2, our thumb design is quite cheap. The only hand with comparable cost is Tact, another 3D printed design. In fact the design of Tact inspired our thumb's design to a large extent. One key advantage of our hand is the gear design. The gears we use are likely much more durable and reliable than the cable pulley system that Tact uses for grasping, and also these gears can be entirely on the interior of the hand.

We briefly looked at different exterior options for the hand design. Designs that use soft contact to achieve more precise grasping capabilities are a promising route for future research. A soft exterior similar to that of a human hand allows for the grasping force to be exerted more uniformly on the body of the object. One recent design, X-Limb, looks at using unique 3D printed materials that are naturally soft and light [5]. Other design options include coating the 3D printed PLA or ABS hand with a type of rubber or other soft polymer material.

Overall our thumb design is competitive with the lowest prices of current prosthetics, while also allowing an effective range of functionality with two DOF. While there are still many improvements that can be made to the thumb, and while of course the rest of the hand is still left to be designed, this gear based prosthetic thumb is a promising start.

Appendix

[1]Patrick S , 2014, “Tact: Low-cost, Advanced Prosthetic Hand”, from https://www.instructables.com/id/Tact-Low-cost-Advanced-Prosthetic-Hand/

[2]Hero Arm, from https://openbionics.com/hero-arm/

[3]Nasser S, Rincon D and Rodriguez, 2006, “Design of a Low Cost, Highly Functional, Multi-fingered Hand Prosthesis”, from https://www.researchgate.net/publication/265988890_Design_of_a_Low_Cost_Highly_Functional_Multi-fingered_Hand_Prosthesis

[4] Ciocarlie, Matei, Claire Lackner, and Peter Allen. "Soft finger model with adaptive contact geometry for grasping and manipulation tasks." Second Joint EuroHaptics Conference and Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems (WHC'07). IEEE, 2007.

[5] Mohammadi, Alireza, et al. "A practical 3D-printed soft robotic prosthetic hand with multi-articulating capabilities." *Plos one* 15.5 (2020): e0232766.