BIOMIMETIC PROSTHETIC HAND ACTUATED BY ARTIFICIAL MUSCLES

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INTRODUCTION

Limb loss plagues over a million individuals in the U.S. alone [1], and it is a disability that greatly affects quality of life, from an inability to perform daily routines to serious depression and other forms of mental illness. Prosthetics offer hope to many people by allowing for regained functionality with the missing limb. Unfortunately, modern prosthetics can range in price from thousands of dollars, for even a purely cosmetic replacement, to tens of thousands of dollars for fully-functional myoelectric prostheses. Fortunately, the advent of additive manufacturing through the increased availability of 3D printing has allowed for an influx of new designs of prosthetics in a market that is sorely in need of refurbishment [2].

Although some previously published papers have reported designs based on muscle wires, most of these designs do not have a humanoid appearance [3], do not have flesh material to protect the internal components and provide restoring force [4], or do not have a locking mechanism to help save electric current to the wires [5]. This paper proposes a new, innovative prosthetic hand design that features a 3D-printed plastic bone structure that closely mimics the shape of a true human hand, flexible elastic joints, a silicone “flesh” cover that protects the internal components, provides restoring force, enables better gripping capability, and appears cosmetically realistic, and a non-invasive, intuitive control system. The prosthetic is actuated by artificial shape memory alloy (SMA) muscle wires to allow multiple different gripping positions, which can then be locked into place to conserve power and increase effective grip strength. Control of the prosthetic is achieved by voice recognition software or an EEG headset that monitors brainwaves and facial expressions. Extensive research, analysis, and testing has been done to optimize the actuation and controllability of the design.

METHODS

Fig. 1 shows the CAD model of the proposed prosthetic hand. The bones and joints are 3D printed of PLA and TPU, respectively. The silicone “flesh” covering is made of Eco-Flex 00-35 which was poured in a 3D printed mold that encloses the whole internal structure. The used SMA muscle wires are Dynalloy’s 0.02” Nitinol wires.

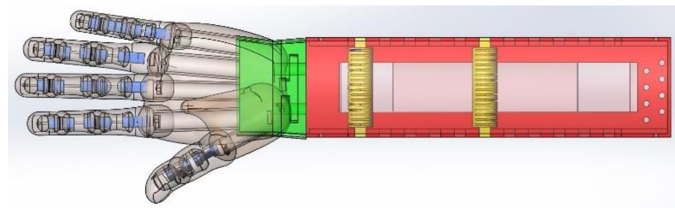

Figure 1: CAD model of the entire prosthetic

The mathematical model in [4] was used to calculate the SMA wire length required to achieve full deflection of the fingers. This model is based on the geometric parameters in Fig. 2 as well as the ratios of the PIP and DIP joint rotations to that of the MCP. All these parameters were measured for the present design. A 270° rotation of the distal phalange, as shown in Fig. 3 (left), can be achieved with 0.495 in. contraction of the wire length. Hence 12.36 in. SMA wire length is used given that the contraction is 4%.

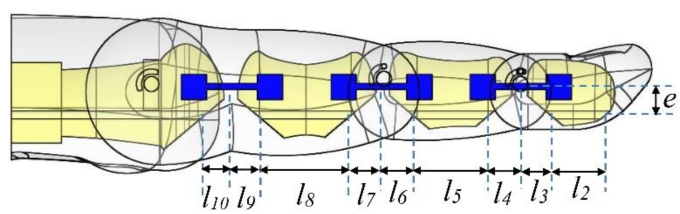

Figure 2: Geometric parameters of the analytical model

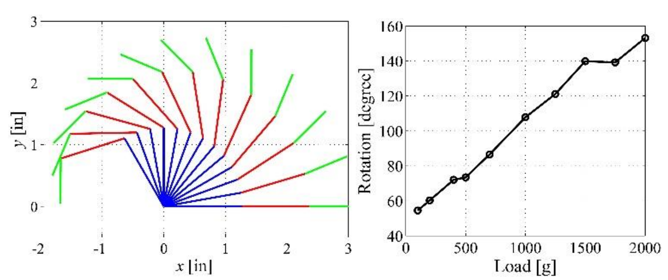

Figure 3: (left) Computational angular rotation of the three index finger phalanges, (right) Experimental total rotation versus load for index finger

The overall angle of rotation of each finger was tested by discrete, incremental loading as shown in

Fig. 4 for the index finger at loads of 100 g and 2000 g. The total angle of rotation versus load for the index finger is shown in Fig. 3 (right). A setup was created to measure the force that the finger exerts using a force sensor hanging from a 3D printed enclosure that prevents the finger deflection as shown in Fig. 5.

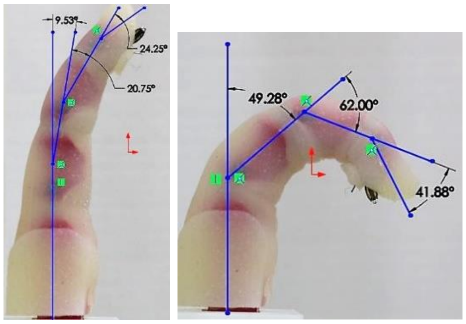

Figure 4: Deflection of the index finger under load of 100 g (left) and 2000 g (right)

Figure 5: Setup for force measurement

CFD and thermal analyses were also done in COMSOL Multiphysics finite element software to determine the optimal placement of the cooling system and the final geometry for the design by performing a parametric sweep of all potential fan, outlet and vent positions. Fig. 6 shows the temperature distribution (in Kelvin) and the velocity field inside the forearm housing in one computational iteration.

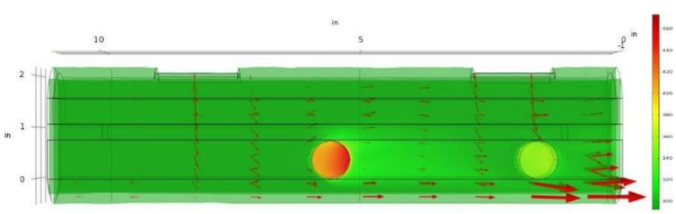

Figure 6: Temperature distribution [K] and velocity field (arrows) inside the forearm housing in one computational iteration.

This prosthetic offers two innovative options for control. The first uses a custom-made app to allow modern, commercially-available voice recognition software to fully control the prosthetic, while the second uses an EEG headset to monitor brainwaves or facial expressions. Both devices interface with the prosthetic via a custom circuit that ensures a constant 4 amps to the SMA wires.

RESULTS AND DISCUSSION

The force exerted by a single finger was found to be 15.26 ± 0.12 N. As this design features five fingers, this allows for a total overall applied force of 76.3 ± 0.60 N, or 7.77 kg of grip strength. Note that the average *maximum* grip strength is 47.3 kg for men and 28.5 kg for women [6]. Similarly, the total angular deflection of the fingers can be seen in Fig. 3 (right). Note that the theoretical maximum angular deflection of a human finger is 270°, achieved when making a fist with nothing grasped. However, typical daily use does not see a "fist" grip, but rather a grip around an object.

CONCLUSIONS

The proposed prosthetic hand design allows for a grip strength comparable to that employed by a human when picking up objects. Additionally, the locking mechanism allows it to maintain this grip indefinitely with no expenditure of power. Similarly, it can achieve a total angular deflection that easily allows it to grip most common, household objects. These qualities far exceed those of modern, additively manufactured prosthetics, which have no protection for their internal structures, do not have the semblance of a human hand, and have poor grip functionality. Finally, the dual, optional control systems offer better control and functionality than any other 3D printed prosthetic on the market.

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