DEVELOPMENT OF NEW SHAPE MEMORY ALLOY-BASED BIOMIMETIC PROSTHETIC HAND

[1]Julian Rodriguez, [1]Bret Raquipiso, [1]M. Justin Borreta, [1]Thomas Gay, [1]Timothy J. Alejandro, [1]Emily Molen, [1]Kevin Mauricio & [1]Peter L. Bishay

[1]California State University, Northridge, Northridge, USA
email: smartprosthetics@gmail.com; peter.bishay@csun.edu web: http://www.csun.edu/~pbishay/

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. The increased availability of 3D printing has allowed for an influx of new prosthetic designs [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 work proposes a new innovative prosthetic hand design that features a 3D-printed plastic bone structure that mimics the shape of human finger bones; 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 shape memory alloy (SMA) muscle wires to allow multiple 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.

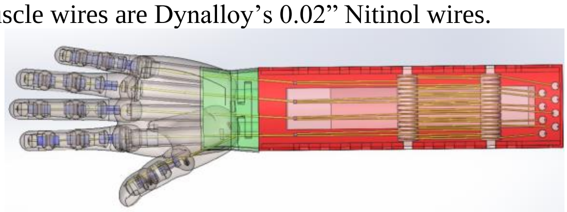

Figure 1: CAD model of the entire prosthetic

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, which were all measured for the present design. It was found that 270º rotation of the distal phalange can be achieved with 1.26 cm contraction of the wire length. Hence 31.39 cm. SMA wire length is used given that the contraction is 4%. The overall angle of rotation of each finger was tested by discrete incremental loading as shown in Fig. 3 for the index finger. A setup was created to measure the force that the finger exerts using a force sensor hanging from an enclosure that prevents finger deflection. The index finger endured loads of up to 2 Kg.

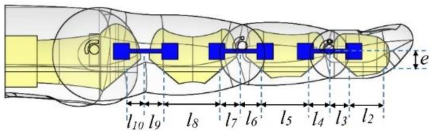

Figure 2: Geometric parameters of the analytical model

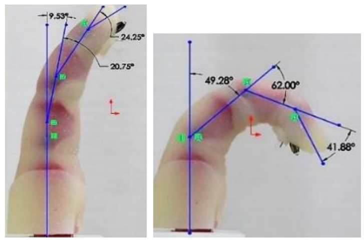

Figure 3: Index finger deflection with 0.1 and 2 Kg loads

CFD and thermal analyses were 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 analysis of all potential fan, outlet and vent positions.

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. 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.

ACKNOWLEDGMENT

The following members from CSUN’s “Smart Prosthetics” senior design project are acknowledged: Jonathan Fontana, Laura-Ashley Maeda, Cindy Saldana, Brian Richter, Sean Houston, Jennifer Fernandez, Chelsey Fryer, Bethany Enos, Utsavkumar Swami, Abdullah Baig, and Ayden Hairabedian. The authors acknowledge the Instructionally-Related Activities (IRA) and Associated Students-Student Travel and Academic Research (AS-STAR) grants.

REFERENCES

1. Jin Y, *et al. Procedia CIRP*, **36**, 199-204, 2015.
2. Zuniga J, *et al. BMC Research Notes*, **8**, 10, 1-8, 2015.
3. Kim H, *et al. Composites Part B*, **105**, 138-148, 2016.
4. Wu L, *et al. Bioinsp. Biomim.* **12**, 2, 026004, 2017.
5. Engeberg E, *et al. Bioinsp. Biomim.* **10**, 5, 056002, 2015.