Designing an exoskeleton hand to improve grip strength

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Introduction

In nature, insects use exoskeletons for protection and strength. Humans are adopting these naturally occurring features to address deficiencies and enhance the function of extremities. Recently, the use of hand exoskeletons for assistance has become increasingly widespread (Esposito et al., 2022). Exoskeletons are being used to enhance grip strength in the growing population of elderly people and individuals with diseases that cause them to lack grip strength.

Certain exoskeletons, such as the one described in this project, are linkage-based. This allows the fingers to move in unison, and perform the same movement together (Sarac et al., 2016). By moving all fingers at the same time, only one input of force is required to control the device, decreasing the cost of the model.

The goal of this project was to design a cost-efficient (under 350 dollars) hand exoskeleton that augments grip strength by at least 4.5 pounds. Exoskeletons typically cost thousands of dollars. This project would provide an affordable option to those in need of increased grip strength.

Materials and Methods

To create the virtual model of an exoskeleton hand, Fusion 360 was used, as seen in Figure 1. The movement of the model was tested using joints and motion links. The model was printed using the Flashforge Creator Pro in rigid PLA and TPU (a flexible filament). Flexible filament was used so the model could adapt to the movement of the hand while the rigid filament was used to hold the actuator securely in place. The exoskeleton was then epoxied to a glove so that it would be functionally attached to a hand (Figure 2).

The model was powered by a pneumatic actuator which converted the force of compressed air into mechanical motion. The system, seen in Figure 3, provided the actuator with pressurized air between 40 and 60 psi.

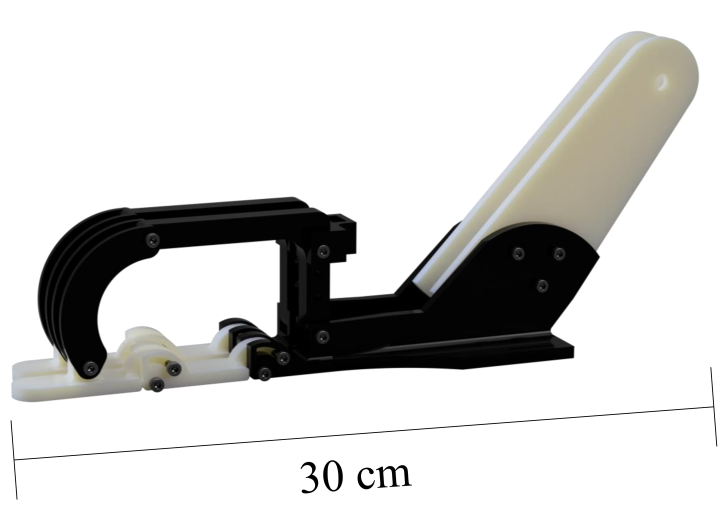


Figure 1 (left): A rendering of the exoskeleton model. Two degrees of freedom were created for each finger. One joint was located at the metacarpophalangeal joint (knuckles) and the other was located at the proximal interphalangeal joint (middle knuckle of the finger). Each of the joints had constraints to prevent injury. The lengths of the phalanges for the middle and fourth fingers were modeled from a physical right hand. The actuator was attached to the model (Figure 2).

Materials and Methods (continued)

Figure 2 (left): An image of the exoskeleton being tested with the hand dynamometer. The component protruding upwards is where the pneumatic actuator was secured. It was attached to the levers of the exoskeleton fingers. When it fired, the linear motion of the actuator caused the lever to push forwards which bent the fingers.

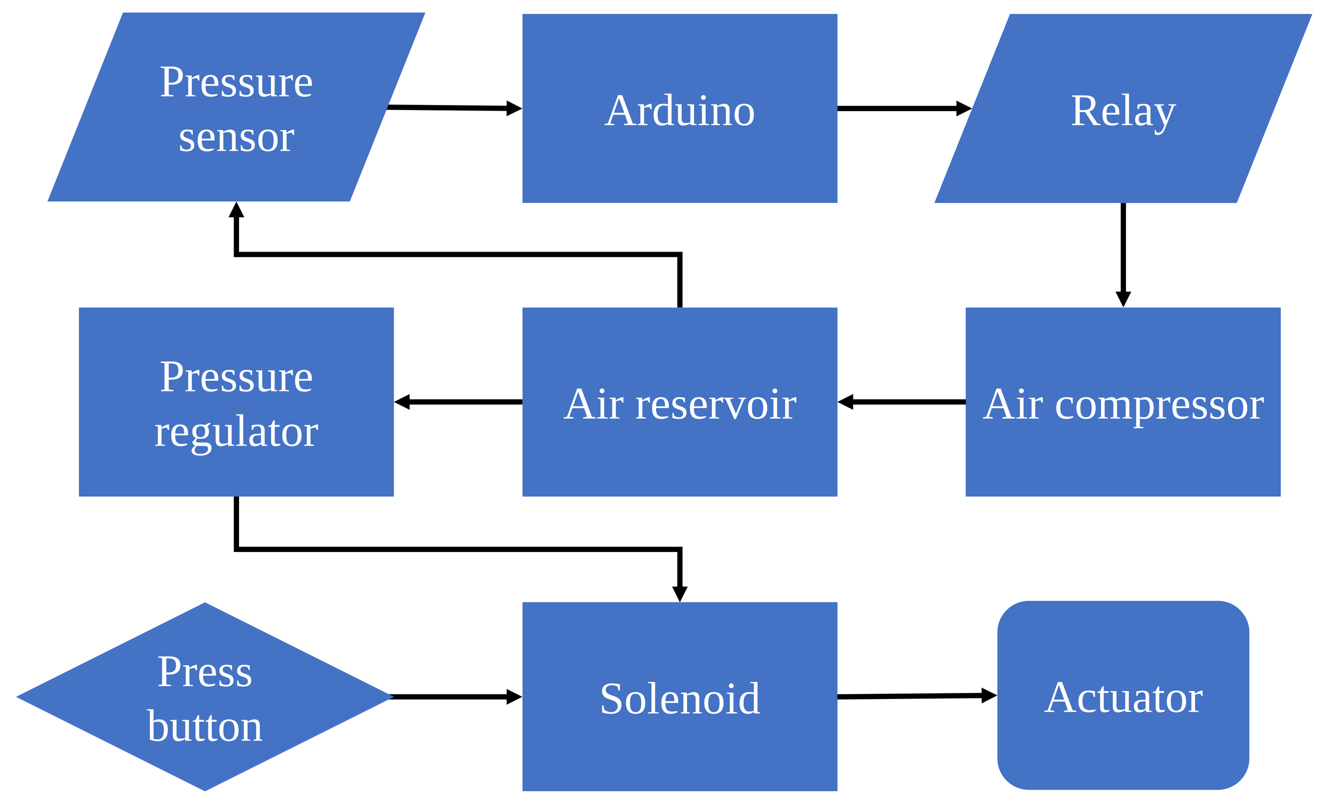


Figure 3 (above): An image of the pneumatic system. A 12-volt tool battery powered the circuit. The pressure sensor sent the pressure of the reservoir of air to the Arduino. Once the Arduino detected a pressure lower than 40 psi or greater than 60 psi, it activated the relay which either turned on the air compressor or turned it off. The air compressor then sent pressurized air to the air reservoir. The pressure regulator controlled the compressed air so that the actuator received air that was no more than 50 psi. The solenoid was essentially an on/off button that controlled when the actuator fired.

The exoskeleton model was tested on 21 subjects. Original grip strengths were recorded using a hand dynamometer. The subjects then put on the exoskeleton and recorded grip strength again. The difference in grip strength with and without the exoskeleton was analyzed.

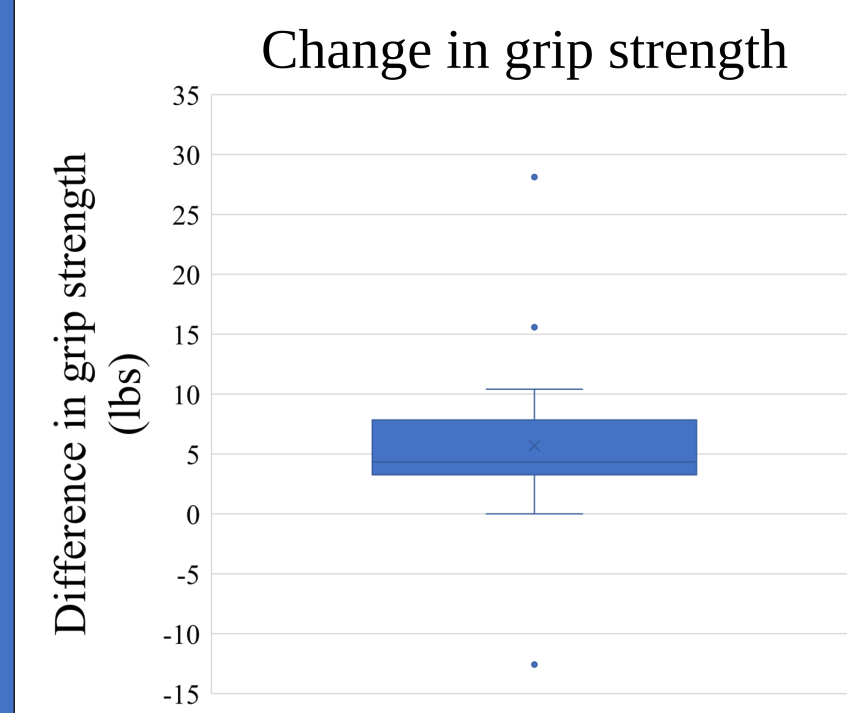
Results

A paired *t*-test was used to analyze the difference in the 21 subjects' grip strength with and without the exoskeleton in pounds (Graph 1). The alternate hypothesis was that the average grip strength with a hand exoskeleton is greater than without it. The cost of the design is broken down in Table 1.

Table 1 (right): A table of the cost of each item used in the model.

Item	Air compressor	Actuator	Arduino	Electrical components
Cost (dollars)	250	20	15	30

Results (continued)



Graph 1 (left): This box plot shows the difference in grip strength when the exoskeleton was utilized. There was an average increase of 6.0 pounds of force exerted with the addition of the exoskeleton. There was a significant difference found in mean grip strength with the exoskeleton (M = 36.2, SD = 14.6) and without the exoskeleton (M = 30.2, SD = 13.1), $t(21) = 3.76$, $p < .001$. This supported the alternative hypothesis.

Discussion

The goal of this project, to create a cost-efficient exoskeleton that improved grip strength, was accomplished. The exoskeleton increased grip strength by an average of 6.0 pounds which was greater than the goal of 4.5 pounds. Cost efficiency was accomplished with the total cost of the parts being under $350.

The exoskeleton designed in this project could be used to increase the grip strength of the elderly. Another practical use would be in the rehabilitation of individuals who suffered injuries, have neuromuscular degenerative disorders, or experienced strength deficits secondary to strokes. The exoskeleton would facilitate the movement of digits in a grasping motion. Over time, this would allow for improvement in grip strength and range of motion.

Future design improvements would explore the use of electromyography (EMG) sensors to control the exoskeleton. When the sensors detect the muscles on the forearm flexing, a signal would be sent to the Arduino which would engage the actuator. This, combined with a portable power source, would allow for greater usability in daily activities for individuals with disabilities or those who wish to augment their strength.

References

Esposito, D., Centracchio, J., Andreozzi, E., Savino, S., Gargiulo, G. D., Naik, G. R., & Bifulco, P. (2022). Design of a 3D-printed hand exoskeleton based on force-myography control for assistance and rehabilitation. *Machines*, *10*(1), 57. https://doi.org/10.3390/machines10010057

Sarac, M., Solazzi, M., Sotgiu, E., Bergamasco, M., & Frisoli, A. (2016). Design and kinematic optimization of a novel underactuated robotic hand exoskeleton. *Meccanica*, *52*(3), 749–761. https://doi.org/10.1007/s11012-016-0530-z