A Power-assisted Exoskeleton Optimized for Pinching and Grasping Motions

L.A. Martinez, O.O. Olaloye, M.V. Talarico, S.M. Shah, R.J. Arends, B.F. BuSha
The College of New Jersey
School of Engineering
Ewing, NJ 08628

Abstract— **Over 450,000 Americans suffer from degenerative muscle diseases characterized by loss of strength and dexterity in the human hand. An assistive hand exoskeleton was designed to amplify residual muscle strength and restore functionality by assisting pinching and grasping motions. The device featured three movable digits: thumb, index, and middle-ring-small (MRS) digit. Adjustable straps wrapped around the exterior of the finger links and secured the user's fingers inside the device. A microcontroller processed force sensing resistor (FSR) data and commanded articulating motors. The exoskeleton was lightweight, flexible, portable and accessible to a wide range of user finger diameters.**

I. Introduction

A combined 450,000 Americans suffer from degenerative muscular disorders, such as multiple sclerosis, muscular dystrophy and carpal tunnel syndrome, which result in the loss of strength and dexterity of the hand. The degeneration of hand muscles results in a reduction of an individual's ability to execute everyday tasks that require pinching and grasping efforts. Hand assistive exoskeletons have been designed to amplify the residual muscle strength in the hand, but most are limited to actuating either pinching or grasping motions.

The five-fingered assistive hand designed at the University of Tsukuba [1], utilized a tendon-drive mechanism that amplified grasping force; however, pinching and other crucial finger movements occurred without amplification. The powered hand exoskeleton designed by Shields et al. [2], assisted astronauts in performing tasks in which glove stiffness would fatigue their hands. Hand movement was monitored by pressure sensors located between the exoskeleton and the hand, and input from these sensors determined commands for a programmable microcontroller

The previous iteration of the device, a lightweight, non-cumbrous hand exoskeleton, featured three movable digits, Bowden cables for actuated flexion and a two-bit binary control algorithm developed using LabVIEW v8.5 [3].

The objective for this iteration was to design an orthotic assistive hand exoskeleton that was lightweight, flexible, portable and accessible to a variety of users. The device amplified the user's residual hand strength in pinching and grasping. Furthermore, a microcontroller was utilized as a digital control system in order to take advantage of the benefits of binary and variable control structures. The device utilized feedback from force sensing resistors (FSRs) to adapt motor control. The goal was to mimic the natural function of the human hand. Motors utilized an integrated controller, which eliminated the need for cumbersome motor control boards.

II. Structural design of exoskeleton

The device featured three movable digits: thumb, index, and middle-ring-small (MRS) digit. The exoskeleton of each digit consisted of an aluminum cylindrical band that enclosed the phalange. Narrow bands decreased weight and improved precision control. Cable guide channels were located within the band for both the flexion and extension mechanisms.

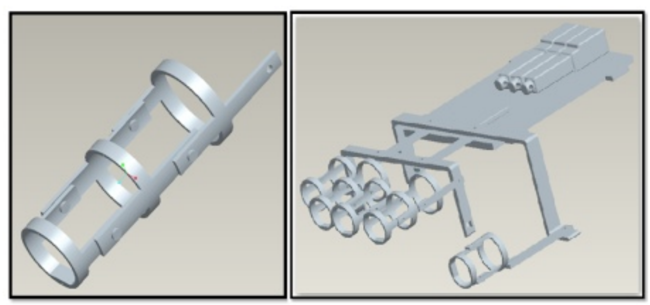

Figure 1.(a) - Linkage design for all digits (b) - Hand assembly

A tendon drive mechanism enabled both flexion and extension of the digits. The flexion mechanism consisted of linear actuators connected to a cable drive system that actuated on the palmar side of the phalanx. Linear actuators were capable of maintaining a constant force of 15N at a speed of 8mm/s which was sufficient for restoring strength and dexterity to the user. A passive spring extension mechanism returned the digits back to rest by actuating on the ventral side.

The forces exerted by the exoskeleton's motors were transferred to the device's finger links via cabling attached to both the motors and finger links. Healthy adults can exert up to 120 pounds of force during gripping [4]; therefore, a braided steel cable with tensile strength of 270 pounds was used in the construction of our device.

A. *Customizable Fitting Mechanism*

In order to fit the maximum range of hand sizes, the exoskeleton was designed to be adjustable so that it would comfortably fit users with different digit diameters. A Velcro strap (Fig. 2) was positioned inside the device's distal link at the thumb, index, and ring fingers. The strap wrapped around the exterior of the finger link, and secured the user's finger inside the device.

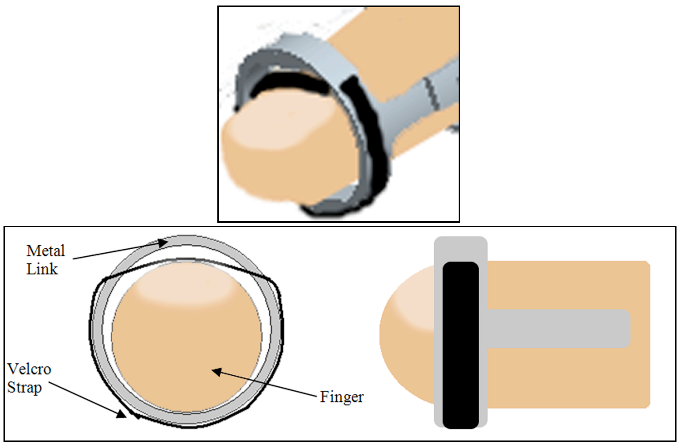

Figure 2 - Velcro strap (black) securing finger inside the device

III. Motion Control

A. *Force Sensing*

The sensors placed on the inside surfaces of the exoskeleton were FSRs. FSRs are resistive sensors in which resistance decreases as pressure is applied. The microcontroller measured the voltage across a potentiometer placed in series with the sensor and then divided the output into thresholds that translated to different levels of motor actuation.

B. *Motor Control*

Three linear actuator motors, mounted on the subject's forearm, received commands from the microcontroller. The motor interpreted the duty cycle of a 1 kHz, 5 V square wave sent from the microcontroller as a desired position and caused the actuator to extend or retract to the correct length. A feedback signal between 0.0 and 3.7 volts from the motor indicated the position of the motor arm to the microcontroller. This feature was useful as both a patient safety and device reliability measure, allowing for disabling of the motors prior to potentially damaging motions that would injure the operator, the motors, or the exoskeleton.

C. *Microcontroller*

The input to the microcontroller was provided by each of the two FSRs located on the inner surface of the thumb, index and middle digits. Higher voltages measured by the microcontroller corresponded to greater forces applied to the sensors. The A-Wit C-Stamp, selected as the microcontroller platform, utilized onboard A/D converters which processed both the input data from the FSRs and the motor position data from the motor controller to command the actuating motors. According to these inputs, the C-Stamp then interpreted what action the user was attempting and modified the output to the motor controller accordingly, actuating the appropriate motion (Fig. 3).

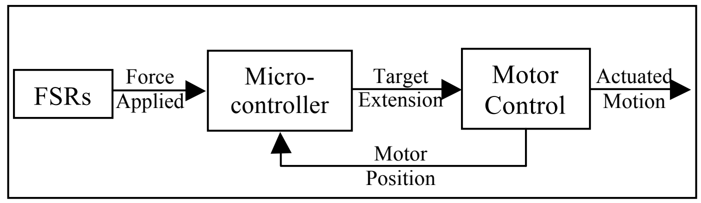

Figure 3 – Electronic Control System

IV. Conclusion

The purpose of the device was to amplify residual muscle strength to restore hand functionality through an actuated precision pinch and a power grasp. The device fit a variety of users and was able to be calibrated for each individual. A microcontroller processed data from the pressure sensors and feedback from the motors and controlled the articulating motor. The combination of the microcontroller and batteries allowed the device to be portable and more accessible to the user.

Acknowledgement

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