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Bowden-line Foot-controlled Finger Exoskeleton Device Driven by Pneumatic Muscles

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Abstract: *With the world being increasingly reliant on computers, hand disorders have become prevalent amongst the general population. To help patients with hand disorders better recover while still allowing them to live their normal lives, glove-like wearable robotic de-vices were developed. Most of those robotic devices, however, generate motion through electric motors, which is heavy and inconvenient. Soft body robots are popular nowadays because they are versatile, safe, low in cost, and comfortable to wear. Thus, a pneumatic muscle hand device is presented in this paper to provide aid to those with impaired hands in their daily lives. This system features 10 pneumatic muscles connected with strings attached to the inner and outer sides of every finger powered by an air valve which allows the retraction of the patient's fingers. The patient is introduced to 5 pressure sensors able to be controlled by foot. To enable the patient to use the device on their own, the system is designed in a back-pack-like style.*

Keywords: *Pneumatic muscle, Hand device, String driven*

1. Introduction

Repetitive hand motion is the leading cause for carpal tunnel, the most common hand disorder. Patients with carpal tunnel struggle to perform simple tasks with their hands, such as tying their shoelaces or opening a bottle. A solution to this problem would be a device that allows the patient to function independently during their early stages of re-habilitation.

This paper introduces a device that assists the flexion and extension of the fingers as well as providing a transportable solution to the issue. The aim of this device is to pro-vide an intuitive, portable device to help the patient in their rehabilitation process. To allow easier control, a foam insole with 5 pressure sensors is placed in the patient's shoe. However, this device lacks the feature to assist in wrist movement, which in some cases is needed for the patient[1-2].

The SAFE glove is a noncommercial rehabilitation device that is currently in its development process which includes joints that extend to the back of each finger which can assist each finger in motions such as flexion, extension, adduction, abduction. It includes an AI which learns the optimal ways for motion for the hand. Like the device discussed in this paper, it is fairly light which prevents stress on the hand, as shown in Figure 1.

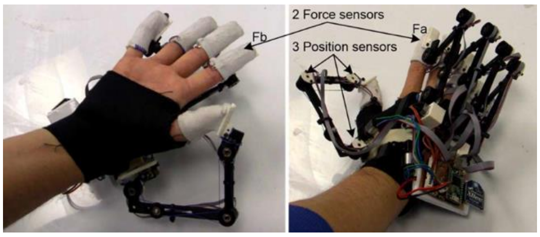

Figure 1: SAFE Glove prototype worn on a hand.

2. Structural design

2.1. Cotton Glove

This is used as the foundation of the device. The 3D printed rings were put on the glove to act as guides for the fishing line to go through, and the movement of the glove will influence the patient's hand

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to move, as shown in Figure 2.

Figure 2: Cotton Glove.

2.2. 3D printer

This was used to print all the small parts of the device such as the rings of the gloves, the connectors used to pump air into the balloons, and the base that holds the air pumps. All of the parts were created on Fusion 360, as shown in Figure 3 and Figure 4.

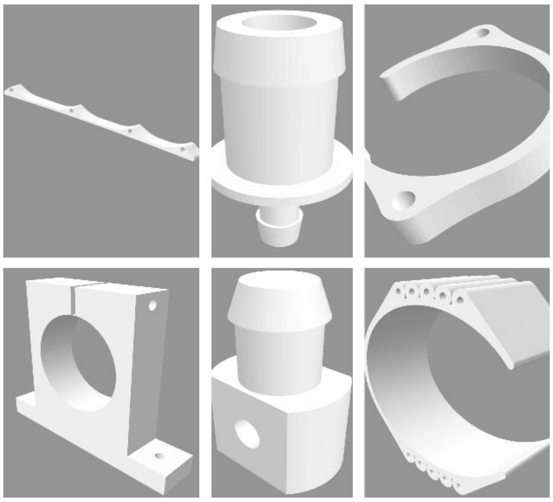

Figure 3: 3D printed parts.

Figure 4: 3D printed parts installed in gloves.

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2.3. Laser Cutter

This was used to create the bigger parts of the device such as the exoskeleton of the backpack. Using AutoCAD, the design for the box was created to hold all of the pneumatic muscles and the air pumps, as shown in Figure 5.

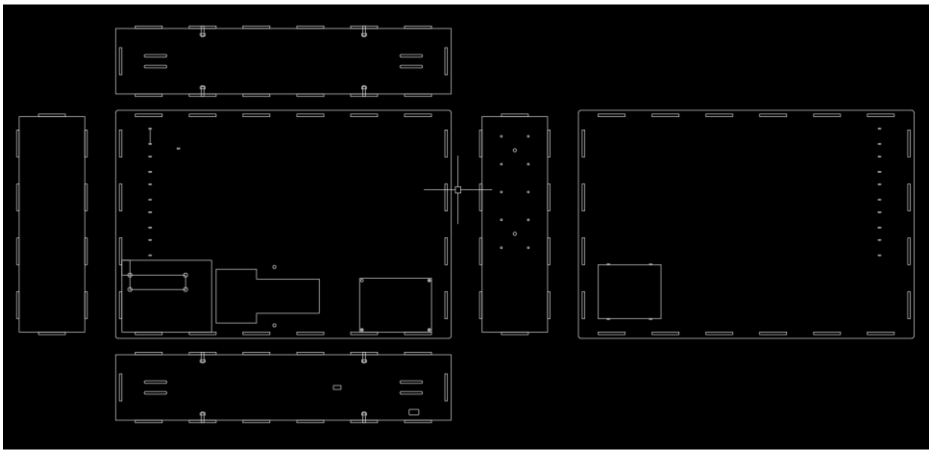

Figure 5: AutoCAD drawing.

2.4. Fishing Wire

This is also a foundation of the device. This acts as the tendons of the glove that goes through the rings on each joint of the glove. When pulled, the fishing wires pulls the fingers in the direction pulled and the finger contracts, as shown in Figure 6.

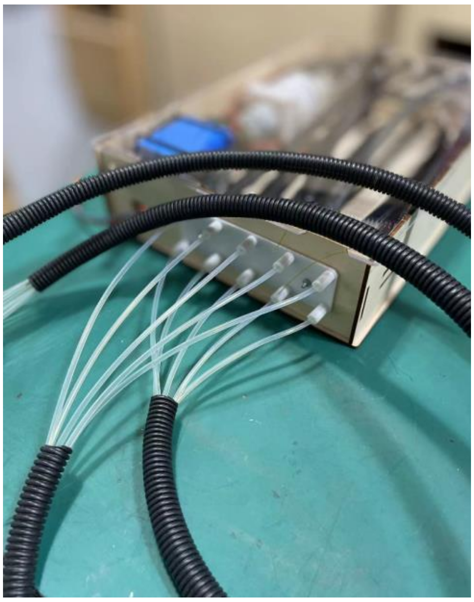

Figure 6: Fishing line structure 7.

2.5. Overall structure

The overall structure consists of three parts, the first part is the wire control glove, the second part is the pneumatic muscle drive system, and the third part is the plantar operation sensor, as shown in Figure 7.

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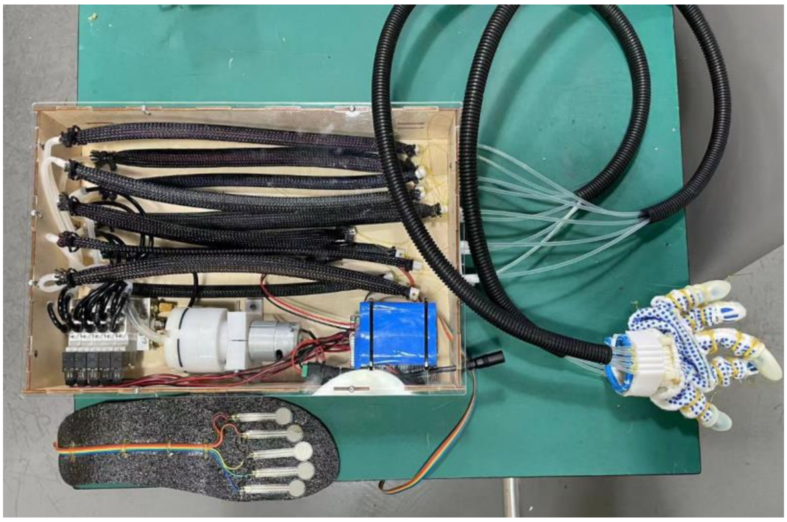

Figure 7: Overall structure.

3. Program

This is a control panel for the device, which runs on C++ code. It is connected to five pressure sensors that sense the pressure of the feet when controlling the device[3-6]. It then controls the air pump corresponding to each finger to either inflate or deflate the pneumatic muscles, as shown in Figure 8.

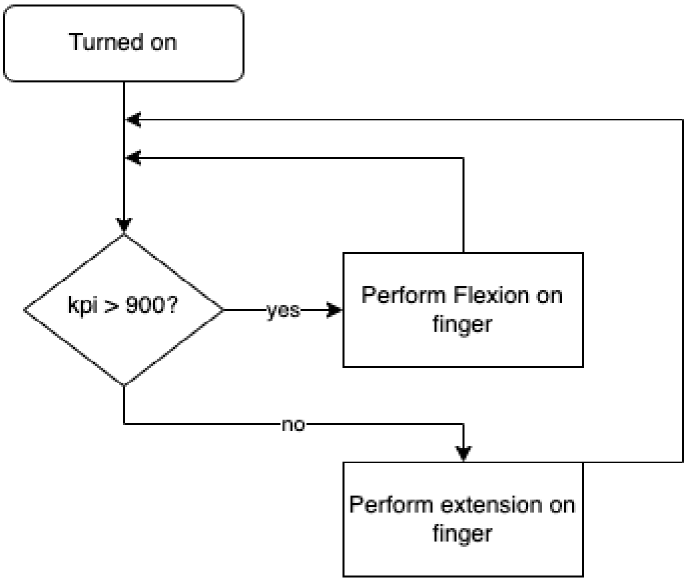

Figure 8: Program flow chart.

4. Experiment

4.1. Experiment 1

This is an experimentation on the independent grip strength of the device. The purpose of this experiment is to figure out the minimum and maximum parameters of the grip strength without the external force applied by the patient. The data gained from this experiment will help the patient estimate the limits of the device to prevent accidents. A cylinder with a radius of 30mm that has a certain weight will be placed in front of the device, and it will attempt to pick it up[7-9]. The object with that specific radius was chosen because it closely resembles the size of everyday objects such as water bottles, smartphones, and the straps of bags. If the object has been lifted for more than 10 seconds, “Yes” would be the answer for that weight. If not, it would be “No”. For each weight class, the test will be conducted five times, as shown in Figure 9.

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Figure 9: The glove grips onto a cylinder with certain weight.

Table 1: Grab Weight Test Form.

	150g	200g	250g	300g	350g	400g
1	Yes	Yes	Yes	Yes	Yes	No
2	Yes	Yes	Yes	Yes	No	No
3	Yes	Yes	Yes	Yes	Yes	No
4	Yes	Yes	Yes	Yes	No	No
5	Yes	Yes	Yes	Yes	Yes	No

The data of this experiment points to the fact that the independent strength of the device is around 350g, meaning the patient should not attempt to pick up objects with a greater weight that the maximum strength of the device can hold, as shown in Table 1.

4.2. Experiment 2

Then, rubber grip was added to add friction to the tip of the fingers, which increases the weight that the device can grip, as shown in Table 2.

Table 2: Grasping experiment after adding rubber finger cots.

	400g	450g	500g
1	Yes	Yes	No
2	Yes	Yes	No
3	Yes	Yes	No
4	Yes	Yes	No
5	Yes	Yes	No

After the grippers were added, the weight lifted increased 100g. With this in mind, better grippers will allow the device to pick up heavier objects, which would further aid the patient[10-11].

5. Conclusions

Though the use of pneumatic muscles to control the fingers of patients with hand dis-orders, the patients can have the functions of a healthy person while still being able to recover from their disorder. This device can increase the weight the patient can grip up to 450 grams. However, there are still many areas for improvement in this device. First of all, with better grippers, the weight assisted can improve even more. This can allow the device to support patients who would like to lift heavier objects and improve their lives drastically. Moreover, the pneumatic pump currently in the device could be re-placed with a stronger pump to increase the grip strength. With the points to improve discussed considered, this device has the potential to serve millions of people with hand disorders.

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