CHAD: Compact Hand Assistive Device for Enhancement of Function in Hand Impairments

Hassan Umari, Fady Alnajjar*, Peer Mohamad, Adel Al-Jumaily, Munkhjargal Gochoo, and Shingo Shimoda

Abstract— **Hand assistive devices are used to help stroke patients with hand impairment during activities of daily living (ADL). Unlike robotic rehabilitation devices which operate in fixed medical settings and for defined periods of time, hand assistive devices are meant to be portable allowing them to be used for extended time periods during ADL. Several designs exist in literature for hand assistive devices. The designs usually focus on a certain aspect of the device, such as the size, the weight, the motion profile of hand fingers, or the generated grip force. However, it's desired to have a design that takes into account all of the device aspects together without trading off any. In this paper, we propose a compact design for a hand assistive device (CHAD). The device is formed as a single unit worn on the patient forearm and encapsulates all the components. Hence, the design focuses on making the device as compact as possible without compromising its functionality. The proposed design is based on a cable-driven mechanism where fingers are connected to linear actuators through tendon-like cables. The device is connected to the thumb, the index, and the middle fingers. Flexion of fingers is achieved by the pulling action of the tendon cables connected to the actuators. Whereas fingers extension is achieved passively using elastic rubber bands attached on the dorsal side of the glove. Experimental results have shown the device can generate an adequate force enough for ADL tasks. It's been also shown that during flexion, the device produces a grip motion similar to that of the free natural grip without causing any abnormal muscle activities.**

I. INTRODUCTION

Strokes and spinal cord injuries are common causes for upper limp paralysis and hand impairment [1]. Such disabilities have a severe effect on the quality of life of survivors and their family members. Among other types of disabilities, hand impairment plays a great role in limiting patient independence during the activities of daily living (ADL), such as eating, dressing, and maintaining personal hygiene.

Some robotic rehabilitation devices have been used for hand physical therapy to help patients regain motor functions in their hand. Such devices are intended to operate in a fixed medical setting and for defined time windows. The outcomes of rehabilitation can be improved if variable practice tasks are performed during a rehabilitation session [2] and by increasing the volume of practice [3].

On the other side, hand assistive devices are used to assist patients in their ADL. These devices are designed to be wearable and portable. Patients using hand assistive devices can try variable tasks in real environment and for extended periods of time during ADL. Additionally, they can also be designed to overcome the pathological patterns of movement and to align to physiological patterns. Consequently, hand assistive devices can be used for rehabilitation and can greatly improve patient recovery.

The hand is a complex organ with multi-axial and multi-planar components of movement. The permutation and combinations of joint movements that provide the base for the myriad grips, grasps and prehensions are numerous. In addition to the complexity of the hand, the size and weight limitations of hand assistive devices make their design more challenging. In terms of the mechanism used to actuate the fingers, hand assistive devices can be classified under four categories: I) rigid linkage-based mechanism, II) compliant-based mechanism, III) soft actuator-based mechanism, and IV) cable-driven mechanism.

Linkage-based mechanisms [4], [5], [6], [7] are rigid exoskeletons consisting of rigid links pinned together. The linkage converts actuator motion into rotational motion of finger joints. Normally, a linear actuator is used for each finger, hence the mechanism restricts finger's motion to a 1 DoF motion. The links are usually secured to finger's phalanges. Linkage-based mechanisms are efficient in transferring the power, an actuator can push or pull to cause the finger to flex or extend respectively. However, they have to be customized for each user in order to ensure that center of rotation (COR) of the hand joints coincide with the COR of the mechanism joints. They also tend to be bulky and heavy which makes them less portable. In terms of wearability, linkage-based mechanisms are usually harder to wear as the patient has to secure the links to finger's phalanges.

Compliant-based mechanisms utilize flexible elements for transferring the bi-directional force of linear actuators to hand fingers [8], [9]. In [8], the mechanism takes a single linear input motion and converts it into a 3 DoF finger joint motion applied equally to all fingers being actuated. The device controls all hand fingers except the thumb which was made fixed. Targeted motion is finger extension and

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flexion. The device itself consist of rigid bodies connected together through three layers of the compliant material which act as springs. The middle layer actively slides forward and backward as a result of input motor actuation. This causes the whole structure to flex or extend when motor pushes or pulls respectively. The device is portable weighing 320 g, and it's relatively easy to wear. Another example of a compliant-based mechanism is found in [9]. Flexible bowden tubes were used for transferring the bi-directional forces of the linear motors to the fingers. Although both devices offer compactness and wearability, the generated grasping force is low due to the flexible nature of the mechanism that is used for applying the force in two directions. In [8] and [9], the tested loads are 3 N and 5 N respectively, where higher loads caused distortions in the motion profile of the hand grip.

Examples on soft actuator-based mechanisms are found in [10], [11], [12], [13], [14]. Normally, these devices consist of a flexible structure that bends when pressure is applied. A pressure creating device is therefore needed (usually a pump). In [10], a design of an elastometric pneumatic actuator is proposed. The proposed design of the actuator allows it to have a bending profile that conforms with the hand grasping profile. The shape of the bending profile is controlled by varying the stiffness of the elastomer at certain regions. In [12], a silicon-based modular and customizable pneumatic glove is presented. it consists of pneumatic actuator modules connected together by rigid spacers. The actuator modules consist of a silicon tube covered with fabric. The structure of the actuator module allows it to bend when inflated. The presented assistive device actuates all fingers and targets the pinch and full fest grips. In general, soft actuator-based mechanisms are less portable compared to other types of mechanisms. Their portability is greatly affected by the size of the pump which is usually used for creating the required pressure. The size of such devices can get even larger if a liquid is used instead of air for actuation, as it requires a reservoir for the liquid [14].

Cable-driven mechanisms [15], [16], [17], [18], [19] are gloves made of silicon [15] or fabric [16]. The gloves are embedded with tendon-like cables attached to the fingers from one side, and to the actuators from the other side. Cable paths (e.g. bowden tubes) and mounts are embedded within the glove which makes them easier to don and doff. They also consist of less mechanical components as they rely on the hand structure to produce motion that conforms with finger joints COR. As a result, they have a reduced size and weight. Due to these reasons, hand assistive gloves overcome previously mentioned mechanisms in terms of wearability and portability. However, a cable-driven mechanism can produce force in one direction only (i.e. pull direction). Hence, these devices are more complex as it requires a special mechanism for providing a bi-directional force, otherwise additional actuators are needed. In [16], rotary motors are used as actuators for pulling the tendon cables by winding them around a spool. A common problem when using such configuration is cable derailment. When cables are not in tension, they tend to derail from the spool. A slack prevention mechanism is therefore needed [16].

The previously mentioned devices consist at least of two units. A common configuration is by having the mechanism itself (i.e. could be an exoskeleton, or a glove) as the first unit. While, the actuators, the controlling circuit, and the powering component all as a second separate unit. The first unit is directly connected to the patient's hand. Whereas the second unit is usually fixed on a different part of the patient's body such as the back [13], or the chest [9]; or either possibly fixed outside the body such as on a wheel chair [16] in the case of handicapped patients. This common configuration uses long cable paths (bowden tubes) to transfer the power from the actuation unit to the mechanism fixed on the hand. The separation between the first and the second units is required for patients suffering from weakness in arm and shoulder muscles. However, it opposes restrictions on hand movement.

In this paper, a cable-driven compact hand assistive device (CHAD) is proposed. The design we propose focuses on portability, by reducing the size of the device and making it more compact. The proposed device consists of a compact single unit that fits on the forearm of the patient. Weighing around 600 g, this unit contains a fabric glove, linear actuators, the controller, a rechargeable battery, elastic rubber bands, tendon cables and cable tubings. Having the device consisting of one unit minimizes restrictions on hand movement. The choice of the cable-driven mechanism reduces the size of the device and allows it to be more compact. Cable derailment problem is avoided by using linear actuators instead of rotary actuators. Additionally, the device uses a self-locking power screw mechanism as a linear actuator. This mechanism allows the device to hold the grip force without constantly powering the motors which extends battery's life. The device controls three fingers, the thumb, the index, and the middle fingers. Both fingers' extension and flexion are supported. The device actively flexes fingers using tendon cables connected to linear actuators. In order to reduce the number of motors used, extension of fingers is achieved passively using rubber bands attached on the dorsal side of the glove. Hence, the normal hand posture is with fingers being extended. Additionally, the presented device uses two tendon cables for each of the index and middle fingers (four tendon cables in total) which allows different sequences of actuation that can produce different motion profiles of hand fingers.

This paper is organized as follows. Section II describes in details the proposed design of the hand assistive device and its components. An evaluation of the proposed device is presented in section III. The paper is finally concluded in section IV.

II. Proposed Design

CHAD is shown in figure 1, it is compact consisting of a portable single unit weighing around 600 g (including the battery). The device height is around 4 cm measured from the forearm. The novelty of the design is the use of active and passive actuation for supporting fingers flexion

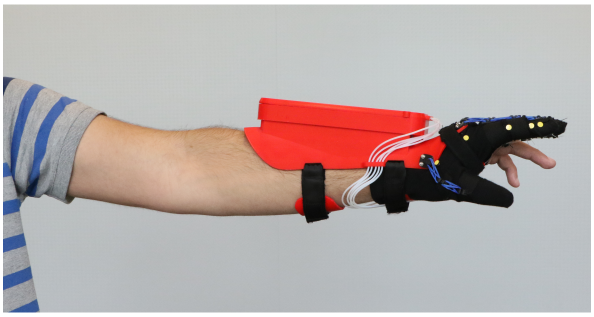


Fig. 1: The proposed compact hand assistive device (CHAD). It consists of a single compact unit which contains all device components (i.e. the actuators, the glove, the battery, and the circuit board).

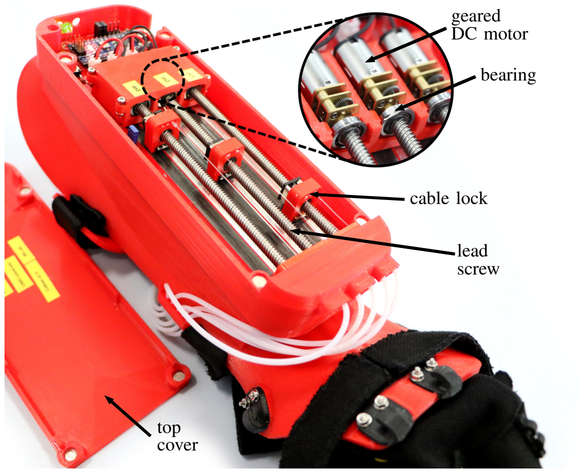


Fig. 2: A design overview of the proposed hand assistive device (CHAD).

and extension respectively. The use of passive actuation to support fingers extension reduces the number of actuators needed which decreases the size of the device. Furthermore, the device uses a cable-driven mechanism with cable routing that allows to control the motion profile of hand fingers. Moreover, the generated grip force can be held without continuously powering the motors due to the used power-screw mechanism.

Three design criteria have been set for the proposed device to satisfy:

1) Portability: in order for the device to be effectively used in ADL, it has to be lightweight and small in size. Additionally, the device should be compact consisting of one unit that includes all the components: the power source, the actuators, and the controller.
2) Wearability: for mechanical efficiency, the wearing action should take into account COR of finger joints, such that the motion axes of the joints are aligned with the axes of the actuated motion. Additionally, the device should be easy to don and doff by the patient.
3) Functionality: the device should support both fingers' extension and flexion. The targeted grip is the cylindrical grip. The device should also be compatible with natural hand motion profile when performing the targeted grip (cylindrical grip). Additionally, the generated grip force should be enough for ADL.

The proposed device actuates the thumb, index, and middle fingers. It consists of a fabric glove, three linear actuators, a controller, a rechargeable battery, elastic rubber bands, tendon cables, and cable tubings (bowden tubes). An overview of the design is depicted in figure 2. The use of cable-driven mechanism increases the portability of the device as it allows the device to be more compact and lightweight. Besides, the axes of the actuated motion in a cable-driven mechanism are inherently aligned with the COR of finger joints. The time needed to wear the device is less than 3 min (including the placement of the elastic rubber bands). Whereas doffing the device takes less than a minute. In section III, it is shown that the device can deliver a grip force of 28 N which is adequate for ADL. It is also shown the device can generate a motion profile that conforms with the natural hand motion. The following subsections describe in details each component of the device:

A. *Glove design*

A custom-made fabric glove is used to connect five tendon cables to the palmar side of hand fingers. The connected fingers are the thumb, the index, and the middle fingers. As shown in figure 3-a, cable 1 is connected to actuator 1 from one end, and to the center of the proximal phalanx (PP) of the thumb from the other end. Cable 2 and 3 are connected to actuator 2 from one end, and to the centers of the intermediate phalanges (IPs) of the index and middle fingers from the other end. Cable 4 and 5 are connected to actuator 3 from one end, and to the centers of the distal phalanges (DPs) of the index and middle fingers from the other end. To reduce glove deformation during the pulling action of the actuators, inextensible fabric is used at each finger-cable connection.

Other configurations of the glove were also tested, however, the current configuration has a better control over the motion profile of the index and middle fingers during flexion. The tested configurations where: a) cable 1 is connected to the PP of the thump (left unchanged), cable 2 connected to the PPs of the middle and index fingers, and cable 3 connected to the DPs of the middle and index fingers (left unchanged). The second tested configuration is b) cable 1 is connected to the PP of the thump (left unchanged), cable 2 is connected to the DP of the index finger, and cable 3 is connected to the DP of the middle finger. While the second tested configuration allows independent actuation for each of the index and middle fingers, it does not produce a motion profile that conforms with the natural hand grip motion.

Fingers extension is achieved passively using elastic rubber bands. The rubber bands are fixed on the dorsal side of the glove, as shown in figure 3b. Consequently, the patient's hand is normally extended, and the linear actuators cause hand fingers to flex. The use of rubber bands to support fingers extension is inspired by the SaeboGlove (SaeboGlove,

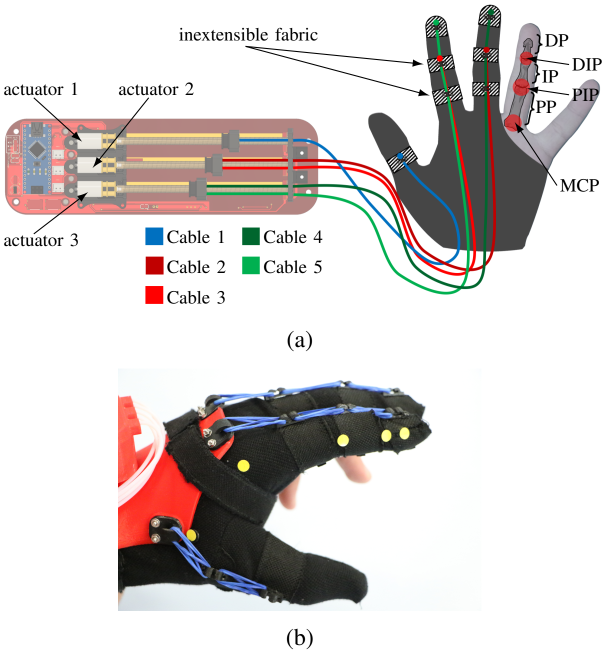


Fig. 3: Glove design. In (a), cable connections between the palmar side of the glove and the actuators are shown. The figure also shows the Metacarpophalangeal (MCP) joint, the Proximal Interphalangeal (PIP) joint, the Distal Interphalangeal (DIP) joint, the Distal Phalanx (DP), the Intermediate Phalanx (IP), and the Proximal Phalanx (PP). (b) shows the elastic rubber bands attached on the dorsal side of the glove which support fingers extension.

Saebo Inc, US).

As shown in figure 3-b, each of the index and the middle fingers use three rubber bands, the first is connected between the center of PP and the head of the Metacarpal Bone (MB), the second is connected between the center of the IP and the center of the PP, and the third is connected between the DP (near the tip) and the center of the IP. Whereas two rubber bands are used for the thumb; one is connected between the center of the PP and the head of the MB; and the second is connected to the head of the MB from one end, and near the wrist from the other end.

B. Actuators

A common actuation method in cable-driven hand assistive devices is by winding the cables around a spool. The spool is driven by a rotating actuator. However, this method requires a mechanism to prevent slacking of cables which causes them to derail from the spool [16]. To avoid using such a mechanism, and to reduce the size of the actuation unit, linear actuators are chosen over rotating actuators. Three linear actuators are used to pull the tendon cables connected to the fingers. The linear actuators consist of a 12V brushed DC motor with a gear reduction of 100:1. The DC motor is connected to a four-start lead screw of a 1.25 mm pitch or equivalently a lead of 5 mm. A cable lock is fixed on each lead screw nut and is used to connect the cables to the actuators, see figure 2. The cable lock slides back and forth in accordance with lead screw rotation. Table I lists the specifications for the overall mechanism (the motor, the gearbox, the lead screw, and the cable lock). The lead screw, the gearbox, and the lead screw nut, are obtained from the internal parts of an off-the-shelf linear motor (L12-100-100-12-S, Actuonix Motion Devices Inc., Canada). The power screw provides a self-locking mechanism which can hold the gripping force without continuously powering the motors. This can greatly extend the battery life of the device.

TABLE I: Actuator Specifications at a supplied voltage of 11 V

Max load	40 N
No load speed	20 mm/s
Stall current	800 mA
Stroke length	100 mm

C. Circuit board

A Printed Circuit Board (PCB) is designed to hold the mechanical components as well as the electronic components. The main electronic components are: a microcontroller board (Arduino Nano is used), motor drivers (L293D, Texas Instruments Inc., US), and a WiFi module (ESP-8266-12E module), see figure 4. The WiFi module is used as the only interface to control the device. The WiFi module creates a soft access point and act as a User Datagram Protocol (UDP) server. It handles received command data for controlling the device (extend/flex fingers). UDP protocol is chosen as it allows multiple devices to send command data simultaneously. Additionally, client devices wishing to control the hand assistive device are not required to be continuously connected to it. Hence, client devices can connect and reconnect freely (a client device is allowed to go idle for power saving when inactive). Possible patient interaction scenario with the hand assistive device is by using voice commands. A client device (can be a gadget or a mobile application) listens to voice commands from the patient. Accordingly, the client device sends UDP command messages to the hand assistive device for controlling it.

In order to obtain position feedback of each cable lock, the PCB board incorporates a resistive carbon layer printed on the top side of the board. The carbon layer consists of three resistive carbon stripes located directly under each lead screw, as shown in figure 4. Furthermore, a voltage is applied at the two ends of each carbon stripe. The position of the cable lock is obtained by measuring the voltage between cable lock contact and one end of the carbon stripe. The voltage is measured through a conductive pad located next to each carbon stripe and is connected to an analog channel of the micro-controller. The contacts of the cable lock create a connection between the conductive pad and the carbon stripe at the current location of the cable lock.

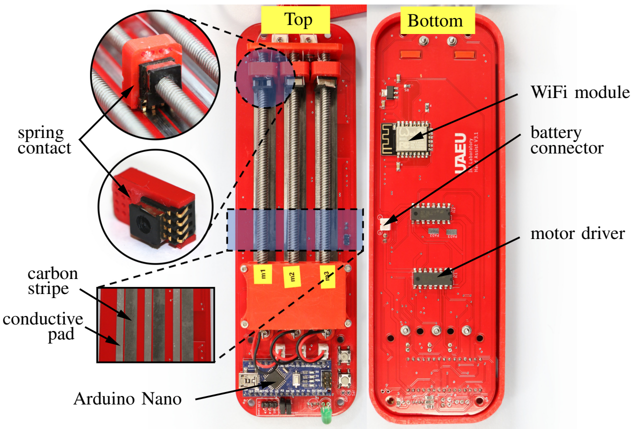


Fig. 4: PCB board used in the hand assistive device. The spring contacts shown in the figure are short circuited, hence they connect the carbon stripes to the conductive pads.

The voltage across the conductive pad is linearly proportional to the cable lock position. In order to ensure continuous connection between the cable locks and the carbon stripes, spring contacts are fixed on the bottom of the cable lock, as shown in figure 4.

D. The battery

Four 3.7V lithium polymer (LiPo) battery cells are connected together in series. Each cell has a capacity of 850 mAh. A DC buck converter is used to step the output voltage of the battery down to the required voltage of the actuators. The battery cells are arranged so they fit in the battery compartment under the PCB board.

E. The base

The base part supports the hand and fixes wrist motion. It is designed to match the arm shape by using a 3D scanner (Sense 3D Scanner, 3D Systems, US). The arm is scanned while the hand is in a functional grasping posture (i.e. wrist is slightly tilted).

III. Evaluation and Discussion

The proposed CHAD is evaluated in terms of the actuated motion profile of the grip, the generated grip strength, and the device compatibility with hand muscles during actuation. The following sections discuss each of these evaluation metrics and their experimental setups.

A. Motion profile of the grip

Finger's motion is captured using a 240 frames per second camera (Hero4, GoPro Inc., US). Finger's joints are marked using colored tags. The actuated motion profiles and the motion profile of the free grip are captured for comparison. After a video is captured for a grip, the video is processed offline. At each frame, the position of each colored tag is extracted and used to calculate joint angles and the motion profile. Five colored tags are fixed on the index finger: three of them are fixed on the Metacarpophalangeal (MCP) joint, the proximal Interphalangeal (PIP) joint, and the Distal Interphalangeal (DIP) joint; one on the DP; and the last colored tag is used as a reference point and is fixed near the wrist.

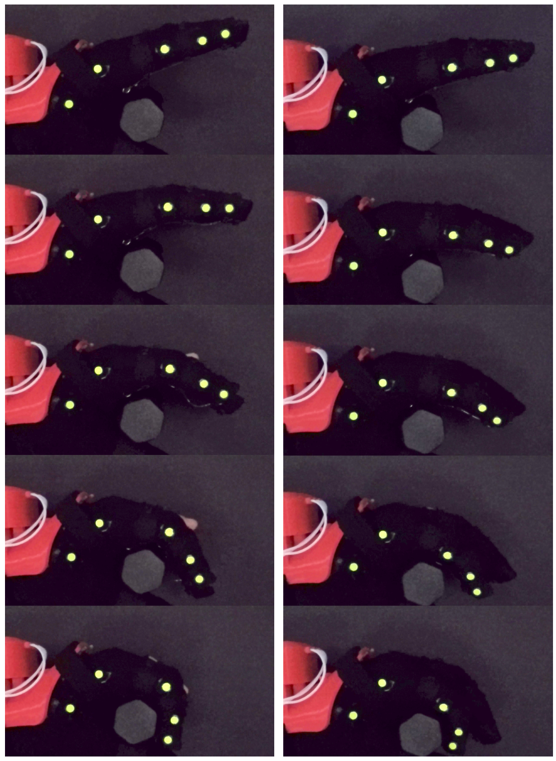
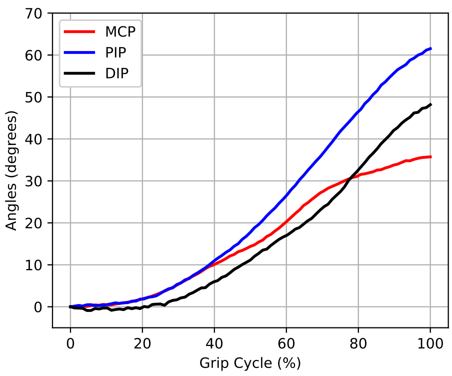


Fig. 5: Time series for the natural hand grip (left column), and for the actuated hand grip (right column).

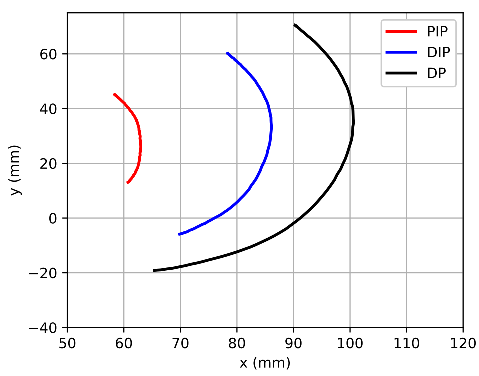
1) Fingers flexion: the left column of figure 5 shows a time series for the natural hand grip (free unactuated grip), the right column shows a time series for one of the actuated hand grips (PP-DP actuation sequence). Figure 6 shows the motion profiles and joint angles for the natural grip, and for three actuated grips of three different sequences of actuation. All the subsequent motion profiles are captured during fingers flexion.

The first sequence of actuation is generated by pulling the IP first, followed by pulling the DP with a delay of 0.3 seconds in between (around 6 mm difference in distance). Similarly, the second sequence of actuation is generated by pulling the DP first, followed by pulling the IP. The third sequence of actuation is generated by pulling the PP first, followed by pulling the DP (for this actuation sequence, tendon cable connections are changed).

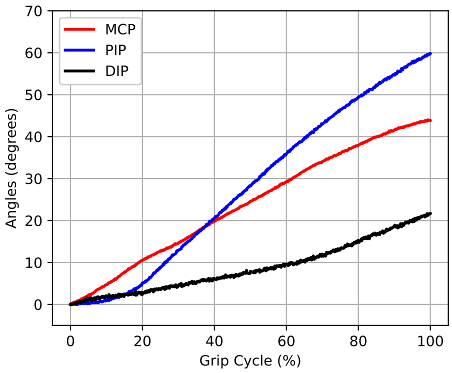
It is desired to have an actuated grip motion profile that is similar to that of the free grip. In order to measure the similarity between the different motion sequences with respect to the motion profile of the free hand, the Dynamic Time Wraping (DTW) algorithm is used. The DTW algorithm is chosen as it allows measuring similarity between joint angle profiles of different grasping speeds, which is required in our comparison (free grip is faster than the actuated grip).



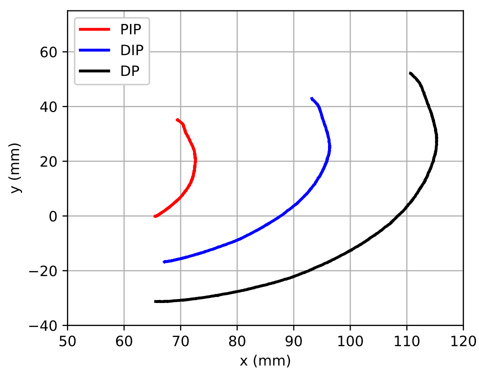
(a) Joint angles of the free grip



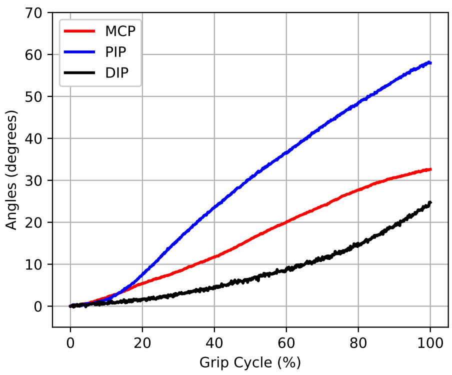
(b) Motion profile of the free grip



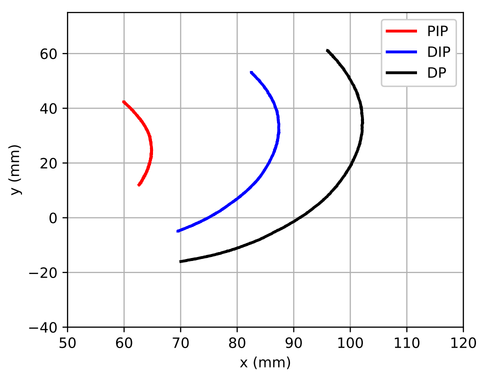
(c) Joint angles of the IP-DP actuation sequence



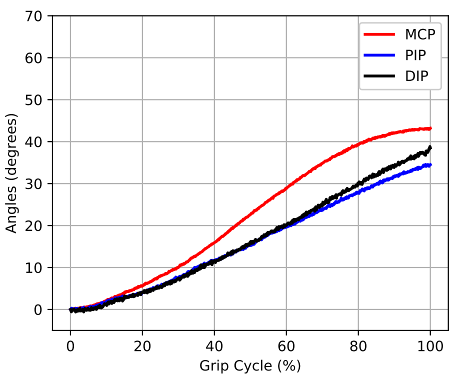
(d) Motion profile of the IP-DP actuation sequence



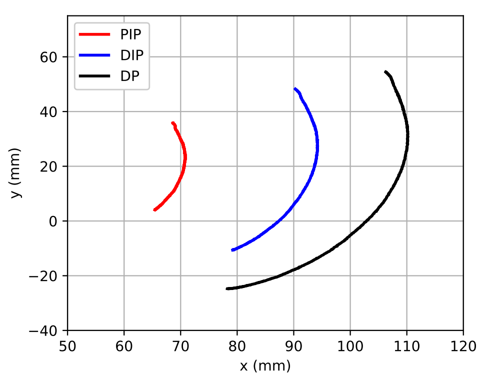
(e) Joint angles of the DP-IP actuation sequence



(f) Motion profile of the DP-IP actuation sequence



(g) Joint angles of the PP-DP actuation sequence

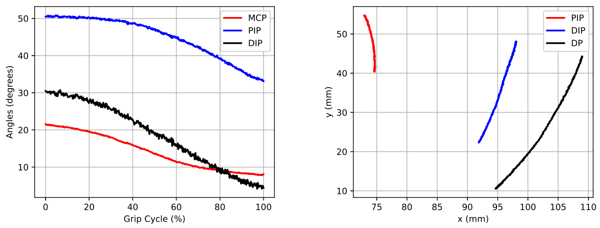


(h) Motion profile of the PP-DP actuation sequence

Fig. 6: Analysis of hand fingers motion during different actuated and free cylindrical grips.

TABLE II: Similarity percentages of the actuated joint angle profiles compared with the free joint angle profile

Actuation Sequence	MCP (%)	PIP (%)	DIP (%)	Average (%)
IP-DP	33.7	92.0	60.0	61.9
DP-IP	91.5	91.8	66.6	83.3
PP-DP	15.0	70.2	81.4	55.5



(a) (b)

Fig. 7: Fingers motion during extension. Joint angles are shown in (a), and the motion profile of the hand is shown in (b)

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A similarity percentage (P) is calculated for each joint angle profile as follows:

$$P = \frac{d_{fr,0} - d_{fr,act}}{d_{fr,0}} \times 100\%, \quad (1)$$

$$d_{fr,0} = DTW(F_{1\times n}, 0_{1\times n}), \quad (2)$$

$$d_{fr,act} = DTW(F_{1\times n}, W_{1\times m}) \quad (3)$$

where F is a 1-D array of joint angle values corresponding to the free unactuated grip, W is a 1-D array of joint angle values corresponding to the actuated grip, and DTW is a function that computes the DTW distance of a given pair of 1-D data sets. Table II lists the calculated percentages of similarity for each joint (i.e. MCP, PIP, and DIP) in all the different actuated motion sequences.

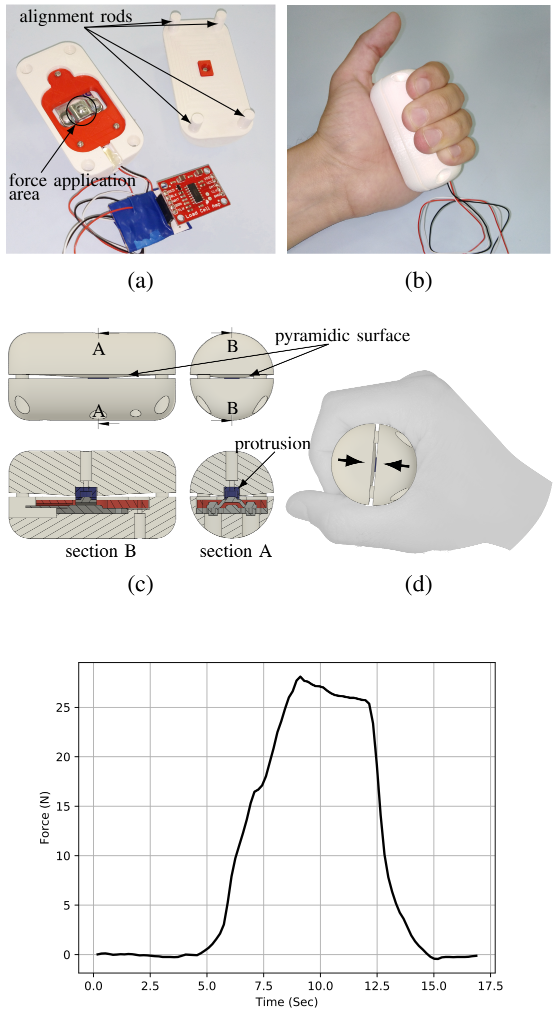
According to table II and figure 6, the DP-IP actuation sequence has the closest matching motion profile with the free grip. Additionally, it can be seen that different motion profiles can be generated by varying the sequence of actuation. This is possible due to having two tendon cables attached to two different phalanges on each finger (middle and index fingers).

2) Fingers extension: figure 7 shows the motion profile and the joint angles of the fingers during extension. No sequence is applied, and all actuators start (release action) simultaneously.

B. Grip Strength

The grip of interest is the cylindrical grip, where the strength of the grip is measured as the sum of all normal forces applied by the hand while grasping a cylindrical object. A half-bridge load sensor is used to measure the applied forces. The load sensor is placed between the halves of a split cylinder of 40 mm diameter, see figure 8. The cylinder is 3D printed and made of Polylactic Acid (PLA) plastic. The first half of the cylinder fixes the load sensor's base. The other half has a pyramidic surface with a protrusion in the center that matches the force application area of the load sensor. This ensures forces are correctly transmitted from the hand to the load cell only.

In order to validate grip force measurements obtained using this setup, the normal hand grip (unactuated grip) is measured and compared against previous existing data. The recorded maximum force of the normal hand grip is around 420 N. This grip force measurement agrees with reported human hand grip strength data [20]. The subject is a 27 years old male, with a hand breadth of 91 mm, a hand length of 205 mm, and a hand circumference of 229 mm.



(e)

Fig. 8: Measuring hand grip strength generated by CHAD. In (a-d), the measuring setup is shown. In (e), the grip strength measurement is plotted.

As shown in figure 8, CHAD generates a maximum grip force of 28 N which is adequate for ADL. Figure 9 shows the device being used to grasp different objects.

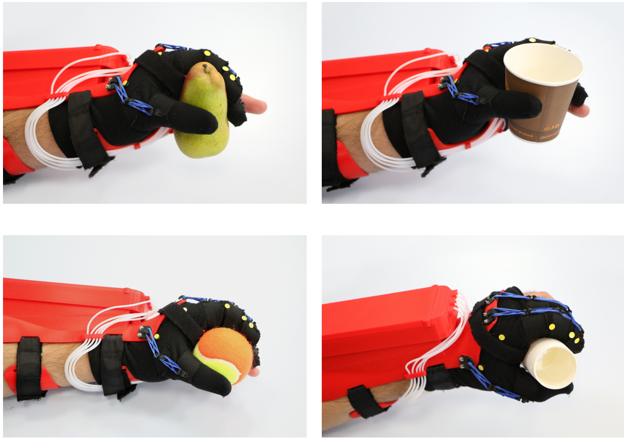
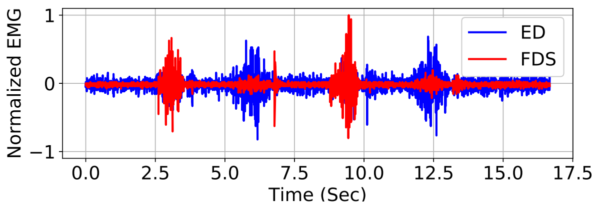


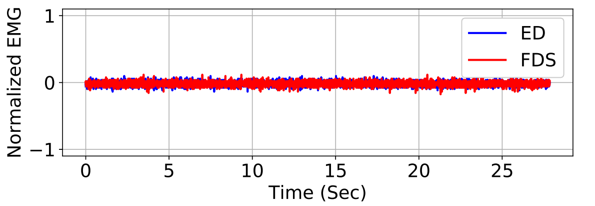
Fig. 9: Grasping of different objects.

C. Device Compatibility with Hand Muscles

In order to capture any incompatibility with hand muscles, Electromyography (EMG) data for muscles activity are recorded during device actuation. Figure 10 shows muscle activities without actuation (on top), and with actuation (on bottom). The two monitored muscles are the Flexor Digitorum Superficialis (FDS), and the Extensor Digitorum (ED). As compared with muscles activity of the free hand, it can be seen that the device does not cause any reflexes in muscles activity during actuation, hence the device does not cause any abnormal finger movements.



(a)



(b)

Fig. 10: Normalized EMG data for ED and FDS muscles activity. In (a), muscles activity during unactuated fingers flexion and extension. In (b), muscles activity during actuation.

The discussed evaluation metrics above show that the device can deliver enough gripping force for ADL with hand motion profile that is compatible with the natural hand grip. In addition, CHAD provides various features such as precise control over motor stroke, a self-locking mechanism for holding the grasping force without draining the battery, lightweight, easy to wear, and has a compact design. We believe that all these merits can encourage the patients to engage their stroke affected arm in ADL. Although the proposed device focuses, at this stage, on motion support only, we argue that a long-term and repetitive use of the device during ADL can have a beneficial effect on patient's motivations which may reflect on better chances of hand motor recovery.

IV. Conclusion

A design for a robotic hand assistive device (CHAD) is proposed in this paper. The proposed design is compact consisting of a single unit worn on the forearm. The device uses linear actuators attached to tendon-like cables for actuating three fingers. The actuated fingers are the thumb, index, and middle fingers. Flexion of fingers is achieved through the pulling action of the motors, while extension is achieved passively through rubber bands fixed on the dorsal side of the fabric glove. Different experimental evaluations are used to assess the device. In terms of the motion profile of hand fingers during an actuated grip, it is shown that the device generates a hand motion profile that is similar to the motion profile of the natural free hand. Additionally, it is also shown that the device generates a grip force of up to 28 N, which provides enough strength for the patients to handle ADL. By checking EMG signals of the FDS and ED muscles, the device is found to be safe not causing any abnormal muscle activities. In future work, we aim at actuating all hand fingers, and improve the wearability of the device.

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