

Robotic Glove for Rehabilitation Purpose: Review

Yahya Salim Ahmed^{*1}, Auns Q. Al-Neami², Saleem Lateef³

¹Medicine College, Mosul University, Mosul, Iraq
alhaleemay@gmail.com

² Department of Biomedical Engineering, College of Engineering, Al-Nahrain University, Baghdad, Iraq
uns_alneami@yahoo.com

³ Department of Medical Instrumentation Techniques Engineering, Electrical Engineering, Technical College,
Middle Technical University, Baghdad, Iraq
Saleem_lateef_mohammed@mtu.edu.iq

Correspondence

* Yahya salim ahmed

Medicine College, Mosul University, Mosul, Iraq

Email: alhaleemay@gmail.com

Abstract

Rehabilitation robots have become one of the main technical instruments that Treat disorder patients in the biomedical engineering field. The robotic glove for the rehabilitation is basically made of specialized materials which can be designed to help the post-stroke patients. In this paper, a review of the different types of robotic glove for Rehabilitation have been discussed and summarized. This study reviews a different mechanical system of robotic gloves in previous years. The selected studies have been classified into four types according to the Mechanical Design: The first type is a tendon-driven robotic glove. The second type of robotic glove works with a soft actuator as a pneumatic which is operated by air pressure that passes through a plastic pipe, pressure valves, and air compressor. The third type is the exoskeleton robotic gloves this type consists of a wearable mechanical design that can used a finger-based sensor to measure grip strength or is used in interactive video applications. And the fourth type is the robotic glove with a liner actuator this type consists of a tape placed on the fingers and connected to linear actuators to open and close the fingers during the rehabilitation process.

KEYWORDS: Robots, Actuator, Glove, Rehabilitation.

I. INTRODUCTION

Several types of rehabilitation robots have been developed for different purposes. These robots can provide additional or superior tasks to patients which can be used to help patients to do various tasks [1-2]. The patient with stroke is suffer from a constriction or discontinue of the blood flow in the brain which make a damage in the nervous system so to communicate with the remnant parts of the body will be reduce. Which causes damage on one side of the body by damaging the upper and lower limbs of this side and also weaken a human functional process as thinking and speech. Rehabilitation robots is use to help in rehabilitate this damage in acting as physical therapy [3]. The construction of the hand robotic glove is individual finger can be moved by servo motors which controlled by Arduino microcontroller and multi sensors to determine the hand clipper [4]. Another mechanical design for a rehabilitation robotic is the tendon actuator robotic exoskeleton for hand rehabilitation, can be classify as two types of design for the upper limb researched in the field of robotic gloves. The first one is a external robot which is inserts on the patient hand and robotically assisted him or a pre-determined tasks model and the second is a portable rigid to rehabilitate with another structure [5]. The

soft actuators are based on use elastomeric materials because for its flexible use when wearing as gloves. The pressure amount of hydraulic for the soft actuators are used to control the finger flexion/extension [6,8]. The soft actuator can be also used with motion capture system to be used as task specific training (TST) for a post stroke rehabilitation [7]. Another soft robotic glove as hand rehabilitation device designed to assist for hand opening during the rehabilitation by inflatable plastic actuators [8,9]. There are some steps to develop a rehabilitation system to increase patient assistance for acquiring, one of these developments has been used to control the system through the EMG signal generated from the muscles [10]. Another development of the systems by connecting a smart phone device to control the system through it by five servo motors connected to the fingers [11,20]. It is also possible to control the smart robotic glove by analyzing the movement of the hand through image processing or a tele-operation and it is considered one of the methods used with certain cases of stroke patients [12]. Although there are several types of raw materials for glove production, as Fabric, rubber and plastic, there is a glove made by silicon for easy sterilization and use in hospitals for more than one patient [13]. It is possible to add an electrical stimulus to the glove when manufacturing to develop it to



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reveal the intention of the patient to move his affected hand. This stimulation is through electrical currents to activate the affected nerves [14,15]. Other type of robotic glove control in addition to controlling by means of the EMG signal can also be controlled by sound instructions to control the process of opening and closing the glove during rehabilitation [16]. In some type of gloves, Bowden cables can be used during design as a means of transmitting movement from the glove to the motor. To reduce the additional weight carried by the patient's arm, which causes an obstacle to the design and an additional weight carried by the patient [17]. One of the modern developments of the robotic glove is the integration of a virtual – reality with the main design of the glove to stimulate the damaged brain area and enhance the relationship between the brain and the affected hand [18]. Another development could be added to the design, which is the possibility to monitor the patient remotely through the Internet during operations of rehabilitation [19]. One of the robotic glove designs is the X-Glove which is used for operations of rehabilitation [21]. The addition of virtual reality (VR) development to the pneumatic glove, to make the rehabilitation process of stroke patients more active [22]. Finally, most of the robotic gloves used for rehabilitation are designed to be suitable for the patient in terms of light weight, cheap and mobile so that the patient can use them easily without the need for a physical therapist and the possibility of combining easy methods of control.

II. MECHANICAL DESIGN ACCORDING ACTUATOR

It is important to show the principle of mechanical design of a robotic glove and select the commensurate with the actual need of the patient. There are several types of design depending on the type of Actuator used in the design and can be divided as shown in the (Fig. 1). Then the review will be present these designs with mentioning specifications.

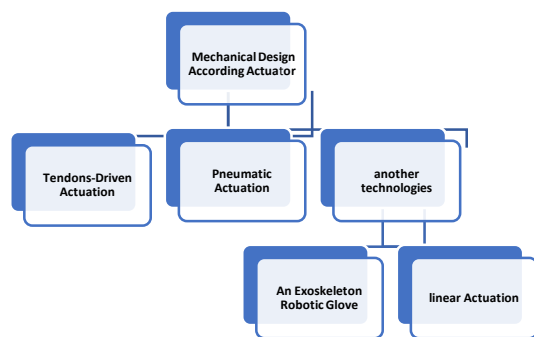


Fig. 1: Block diagram for several type of mechanical designs

A. ROBOTIC GLOVE BASED ON TENDONS-DRIVEN ACTUATION

These robotic gloves are work on the principle of tendons. This design is simulating the installation of the tendons of the human hand by transient the movement of muscles to the upper and lower limbs of the human body. The rehabilitation process mainly depends on the repetition the exercises and the results of this process are clearly shown by comparing

these results with the effectiveness of the hand before the exercises [37]. One of the most important characteristics of robotic glove when manufacturing is that it is low cost and light in weight [38]. Some robotic gloves Comprehension virtual reality technology to help stroke patients increase focus with the rehabilitation process [39]. The robotic glove should be arm fit so that it does not affect the patient's daily stroke activities [40]. After developing this glove, it is possible to send hand movement information to a(VR) program to determine if the rehabilitation movements are correct [41]. Tendons are rigidly attached to the glove to ensure safe opening and closing of the patient's hands during rehabilitation [42]. The parts needed to secure the tendons to the glove are designed by 3D printers [43]. The glove is controlled by attaching the Arduino processor to the actuators that perform the hand movement [44].

In 2013 Hyunki In et al. [23] Analyzed and discussed the force applied at the finger joints that produced by the force obtained from by the SNU Exo-Glove. By use a joint-less wearable robotic hand with fingers were driven by the tendons attached directly on the glove. The glove was operated by three motors the first to move the thumb, the second to move the index finger, and the third to move the middle finger, the movement is transfer from the actuators to the fingers by the tendons that similar to the action of the tendons in the human hand. The force generated at the human hand is analyzed before using the glove because the force applied to the joints of the fingers of the hand must be determined for the disable because it is weaker than the joints of the healthy fingers. The glove is shown in (Fig. 2a).

In 2015 Nycz et al. [5] proposed a technology has been rehabilitative and assist individuals has a hemi paresis in their upper limbs by a therapy outside of the clinic. The robotic glove has (6 DC actuators), five actuators attributed to five finger and the sixth for elbow. The actuators were located on the wrist to avoid burdened affected limb with heavy weights. Motors were located remotely in an external block, the glove's weight (2.75 kg) and size (260X200X85mm) dimension. Therefore, this robotic glove is light weight for the patient and is available with low cost and can be used outside the clinic for patients who need the rehabilitation and elbow rehabilitation has also been added in this system to become more useful it can be seen in (Fig. 2b).

In 2016 Kang et al. [13] presented a robotic glove based on tendon driven and used the silicone as a raw material in manufacturing so that more than one person can use it because it is sterile. The glove is driven by two actuators, one for thumb and the other for the index and middle fingers, in addition to pressure sensors for control the limit of the fling's movement. This is a new Exo-glove system that uses silicone instead of fabric in the glove design. The glove manufactured by a molding process using a silicone (KE-1300or KE-1300T, Shinetsu). In order to reduce the friction of wires in the glove a tube of Teflon was placed on the silicone glove to pass the tendons throw it. The glove actuators unit consists of two actuators (DCX22, 24V,20W, Maxon). The results show that the glove is capable of holding weight between (1 to 1.5 kg). The glove shown in (Fig. 2c).

In 2016, Bigger et al. [3] presented a novel design for a rehabilitative wearable glove depending on the principle of tendons to move three fingers through a system consisting of pieces like cups and tendons with the following specifications. The motors of the glove have the following parameter as rated torque (60mNm), speed (51rpm) and power (588mW). The extension process of the finger has been done by a elastic band which is implied on the glove. Various objects have been handled to calculate the angles of the finger's joints. The glove was developing an increase contribution to the metacarpophalangeal joint (MCP) (from 11.21 to 42.09%) and decrease contribution to distal inter phalangeal joint (DIP) (from 49.28 to 19.64%) increase motion has been increase the benefit of rehabilitation, the final structure of glove as shown in (Fig. 2d).

In 2017 Biggar et al. [10] proposed a systems development a glove will be treated with the physiotherapist during the rehabilitation process to be the recovery faster. The systems had been development was (J-Glove) and (X-Glove), this system works on principle of a cable-driven actuator that make it portable and wear by the patient. One of the most important specifications that must be considered when designing is the ease of movement of the finger joints, easy to wear, controllable and aesthetic properties. The glove is made by two layers of rubber material which the wires pass through a plastic piece that attached to the glove and the wires are connect to the actuators that move the fingers. The response rate of 35.14% for this glove. The protecting of patient in therapy was a factor should remain necessary consideration. Reductions in the weight of glove make it more comfortable to wear. The glove shown in (Fig. 2e). This type of robotic glove is used for post-stroke patients in the first weeks of injury to help them recover faster. One of the advantages of these gloves is the ability to open and close the patient's hand with a suitable force controlled by the actuators.

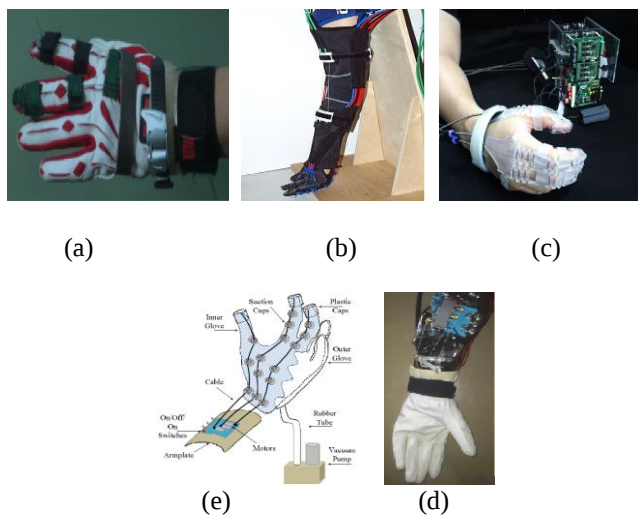


Fig. 2: Robotic Glove Based on Tendon Driven Actuation (a): SNU Exo-Glove [23], (b): Tendon Driven Glove [5], (c) Silicone Glove [13], (d): Tendon Driven Glove [3] and (e) (J-Glove) and (X-Glove) [10]

B. ROBOTIC GLOVE BASED ON PNEUMATIC ACTUATION

These types of robotic gloves are operated by the air pressure that passes through the air tubes and control by specific pressure valves and the source of this pressure is the air compressor. These pneumatic actuators are attached to the gloves to open and close the fingers. Glove can be designed to fit the size of the patient's fingers [23]. Pressure sensors are used with the glove to measure the grip strength of the glove used as a style of control [24]. From the design it is possible to control the glove via an interactive screen to specify the finger movements necessary for the rehabilitation process [25]. Most of these robotic gloves are operated by actuator that are controlled by the EMG signal after sensing it [26]. In this type of glove, the closing of the fingers is achieved by increasing the pressure inside the actuator and the opening is by reducing the pressure [27]. The bending value can be known by measuring the bending angles of the affected fingers to know the patient's recovery level [28]

In 2010 Connelly et al. [22] suggested a novel pneumatic glove (PneuGlove) which can provide independent extension assistance. It can be used for rehabilitation with real or virtual items because the most common motor deficit was the fingers extension. The rehabilitation of hand gesture practices has been enhanced by incorporating virtual reality (VR) with robotic glove action and the glove can also be used with a wireless system that can measure joint movements using bending sensors. Some pressure parts used in the design as the servo valve that provides air pressure between (0–10 psi). The virtual reality (VR) application used the Head Mounted Display (HMD) as display device. The glove is permanently controlled by the VR program, which receives movement values via the shadow screen. As shown in (Fig. 3a).

In 2014 Polygerinos et al. [6] suggested a soft robotic glove consist of elastomeric chambers with fiber reinforcement under fluid pressure. The control system is designed with pressure sensors to control the outlet pressure of the pneumatic actuators and then regulated by a closed-loop controller. The robotic glove produces a great Features like: more freedom, safety, low cost, portability and be customizable depending on the hand anatomy. The Weight of glove must be less than (0.5 kg). And the other controlling part less than (3 kg). A healthy person can generate a grip strength proximately (450 N) for a male and (300N) for a female. The components of the system are installed inside a bag and consist of (I) lithium polymer battery (5 Ah 14.8 V) with power regulator. (II) microcontroller (Arduino mega 2560R3), pressure sensors, and control boards managing. (III) Hydraulic pump with (9.6 W), volume of (250 ml), and (IV) other parts like: solenoid valves, mechanical switches, volt meter to show battery level. The sensors were used to monitor the pressure of actuator with a local feedback control loop is (150PGAA5, Honeywell, Morristown, NJ). That shown in (Fig. 3b).

In 2015 Polygerinos et al. [7] presented a robotic glove made by soft material to be safely on the length of the finger when it uses. The flexion of the glove is active and the extension of it is passive. The glove actuators are consisting of elastomeric bladders with a fiber reinforcement to give a

specific Features. Bending and extending depends upon the fluid pressure. A comparison was made between a patient with weak hand strength without using a glove and using a robotic glove. The rehabilitation process is applied to improve the hand function by repeating the exercise of rehabilitation tasks. Through the control box can move the fingers separately or implement a variety of preset finger movements. The cross section of the glove is (20 mm) wide and (7 mm) high to match the finger dimensions. The electrical and mechanical parts are placed inside the box (the electrical parts, pump and battery) necessary to operate the glove and are far from the glove. The actuation frequency must be 30flexing/extending hand cycles/minute. The glove shown in (Fig. 3c).

In 2015 Yap et al [1]. presented a soft pneumatic actuator and calculate its parameters as the radius of curvature and the output force produced by actuation to be suitable for hand rehabilitation use. It was finding by using two type of actuators (Eco flex 00-30) can be reach to (12.06 mm) of radius at (26 pa) and (Dragon skin 20) reach to (29.55mm) at (210 pa) .The relationships between the input pressure and the radius curvature was not linear but the relationship between input pressure and the linear displacement was linear .And the relationship between the output force and pressure similar to linear .Different type of silicone rubber give us different output characteristics. The requirement design was the bending actuator must can give suitable force to bend the finger joint. The actuator design was different from patient to another due to the complications of them diseases. The glove is shown in (Fig. 3d).

In 2016 Yap et al. [8] presented a robotic glove powered by inflatable actuators That is manufactured by the thermal bonding of flexible plastic sheets to be able to help patients open their fingers by generating a suitable force. The process of rehabilitating is done by repeating the exercise of tasks. The device can be designed to do opening the fingers by assist of the glove and the process of closing the fingers is voluntary by the patient. The air supply from the air compressor source to the actuator through a plastic tube. The total weight of this device was approximately (150 g) this type is lighter than other types. The control box can be carried away from the hand in order to minimize a weight on the hand and arm. The glove pneumatic system It consists of air compressor sensor, solenoid valves, small air compressor. A glove is shown in (Fig. 3e).

In 2018 Stilli et al. [17] presented an AirExGlove it was a light weight inflatable soft device combining the benefits of both pneumatic and tendon-driven. The glove consists of an external structure with pneumatic actuators that are placed on the back of the glove and tendons are installed along the glove from the inside to determine the amount of opening for the glove and the amount of closing force is by increasing the pressure applied by the actuators. The motors are placed inside a box away from the glove it may be fixed on the back or on belt. The tendons are connected to the motors through the Bowden cables and the air tubes transfer pressure from the air compressor to the motors installed inside the box. The weight of the envisioned actuation system is estimated to be less than (3 kg) as shown in (Fig. 3f). Patients are provided with this type of robotic glove for

the purpose of soft rehabilitation in a manner that is intended for patients to open and close their hands in a soft manner, such as older patients, they are used for patients who need relatively little force to open and close compared to the Tendons-Driven Actuation type.



Fig. 3: Robotic Glove Based on Pneumatic Actuation (a): Penu Glove [1], (b): soft robotic glove [6], (c): Penu robotic glove [7], (d): soft pneumatic actuator [1], (e) inflatable actuators [8], (f): AirExGlove [17].

C. ROBOTIC GLOVE BASED ON ANOTHER TECHNOLOGIES

There are other hybrids that are not included in the previous classifications. The use of myo arm band is one of the modern methods of glove controlling by sensing the EMG signal [29]. This type of glove is important because it provides the required amount of finger movements [30]. The glove can perform specific movement with animation and measure these movements to see the effectiveness of the hand [31]. It is possible to know the effectiveness of the hand by analyzing its movement through image processing [32]. One of the robotic glove Applications is the grab in addition to the rehabilitation process [33]. It is important in design to control holding objects to prevent slipping or falling from the glove [34]. Several experiments are performed to open and close the glove before starting to be used by the patient to ensure that the patient's hand is not harmed [35]. These gloves are designed for home use so they are uncomplicated, cheap and lightweight [36]

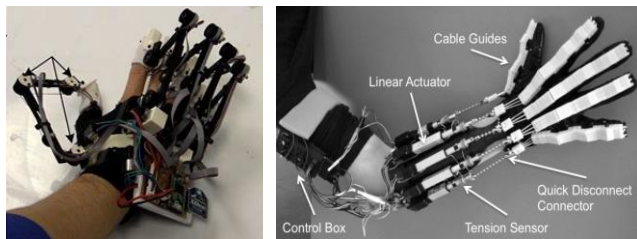
1. An Exoskeleton Robotic Glove

In 2015 Zhou Ma et al. [9] suggested a system was able to learn finger motion and force for move different objects to record and analyze the movements of hand function with grip and release patterns. Primary data have been collected from healthy hands and analyze to determine the glove's ability to effect on the hand. The actuator was a pneumatic piston located inside the glove; it can generate a force up to 16 N for each finger. The air compressor and the supporting devices were required to power and control the glove. The robotic glove was consisted of two main part: the forearm module and the glove module, control electronics, three

actuators, and a fabric cover were contained within the forearm module. The glove modules were including a glove, a conduit anchor and five FSR sensors Placed at the finger tips. The weights of the device were about 770 grams. The system components were: the demonstration procedure, the machine learning algorithm, the safe glove system, and a 3D GUI program, and the rehabilitation-assistive engineering procedure. The normal force had been controlled by the limitation of the force sensing resistors (FSR) sensor, the force measurement by Piezoresistive sensors. The surface electromyography (sEMG) can be used to determine the level of muscle activation (Fig.4a). This type of robotic glove is similar to the type of Tendon Drive but it is more complicated in terms of structure. It is usually used with interactive video systems that are used to enhance the mental ability of post- stroke patients in the rehabilitation process.

2. Robotic Glove Based on linear Actuation.

In 2015 Fischer et al. [21] presented a portable glove with linear actuator. the X-Glove was one of independently actuate each digit while also allowing free movement of each joint and cables serving as external extensor tendons run through cable guides attached to dorsal side of a modified batting acted with linear servo actuators (L12, Firgelli Technologies, Inc.) and Rabbit Core microcontroller (RCM 3410; Digi International, Inc.). After the used of the X-Glove there were an increase in grip and pinch strength. The initiation of treatment rather than over a longer period as the patient wished to start training as early as possible to maximize benefits (Fig. 3b). This type of robotic glove is suitable for treating patients who need rehabilitate the hand with characterized by accuracy in controlling the angles of opening and closing the fingers, but it is relatively heavy on the patient hand and is one of the undesirable features of the design.



(a) (b)

Fig. 4: Exoskeleton Robotic Glove

(a): Exoskeleton Robotic Glove [9]. (b): linear Actuation Robotic Glove [21]

III. DISCUSSION

Rehabilitation robots are usually used to help patients gain healing, such as stroke patients or spinal cord injuries, so these robots must have features that are appropriate for patients, and one of the most important is their effectiveness in the purpose of rehabilitation for the patient to benefit from them. In addition to being light weight so as not to be heavy on the affected limbs when used by the patient, by using

materials with a low density in manufacturing and avoid using heavy materials as much as possible. And the cost of manufacturing it is not high, so that the patient can use it or acquire it, meaning that it is cheap.

It has also been shown that there are multiple models for designing this robotic glove to be appropriate for use by patients. Therefore, these smart gloves can be combined with certain systems such as virtual reality systems or certain video games that will help the patient to enhance communication between the brain and the affected limb and train the brain to restore the ability to control the affected limb. As for the patient's need for the stages of the rehabilitation process, this will be decided by the specialist doctor, according to the patient's age group and the level of injury. During the operation of the robotic glove for several hours during the rehabilitation process, it needs a suitable mobile power source to work for long periods and at the same time it is appropriate for the design for the system, like a rechargeable battery, it must be lightweight or it can be placed in a box away from the robotic glove and connected via wires to the glove.

IV. CONCLUSIONS

In this paper, various design models for the robotic gloves are presented for the purpose of rehabilitation. There are many types that have been reviewed, including those that are driven by tendons and actuators such as servo motors or with soft materials with pneumatic actuator or other types of actuator. Then explain the properties of parts and the work of these robotic gloves. Discussing future developments of these systems based on the patient's need for these developments. Each type of glove has certain operating properties, but all types must be uncomplicated to install and inexpensive and can be used at home by the patient himself without the need for anyone's help and at any convenient time.

Several systems can be combined after completing the robotic glove design in order to increase the patient's recovery speed and increase the patient's reaction interaction during the rehabilitation process. One of these systems is the Interactive Screen System (VR) which is used extensively in patients' rehabilitation operations to enhancing the robotic glove with patient. This technology makes it more interactive system.

The process of controlling the robotic glove is one of the important things during design it most of the control operations are through programmable microprocessors to control actuator that move the fingers. The EMG signal produce by the muscles is relied on to control the actuator and this signal is obtained by Mayowear sensors and it presented a muscle activity. It is considered one of the most common methods of control. It is also possible to control the grip strength of the robotic glove to make it able to carry and hold things without destroying or sliding them to be suitable for use by the patient.

This review may provide useful information for researchers within this specialty or for developing these systems in the future.

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