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Recent Developments of Robotic Exoskeletons for Hand Rehabilitation

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Abstract: Over the years, exoskeleton devices for rehabilitation technology have advanced. But because of the complex structure and intricateness of the human hands, it imposes a great difficulty on the development of a hand exoskeleton system. Hands play one of the most significant roles in living an independent and healthy life. Its natural motor capability is crucial for Activities of Daily Living (ADL). However, stroke remains a leading cause of physical impairments and functional disability. Post-stroke hemiparesis frequently results in persistent hand dysfunction. Rehabilitation therapy during post stroke activities with highly repetitive exercises is an effective method to improve the recovery process to regain previous dexterity and to combat long - term effects. Conventionally, most physiotherapists perform these therapy exercises manually or use simple devices offering passive assistance. To overcome the inefficiency of traditional therapy, robotic exoskeletons, have been developed to help regain motor function by means of repetitive and task-oriented exercises. Though, this technology should not replace the therapists, but should come hand in hand and complement each other for increased efficiency. In this paper, the current developments of robotic exoskeletons for hand rehabilitation are showcased that includes a review of the progress, concepts, prototypes and commercially available devices for hand rehabilitation. It also discussed the future directions and challenges of hand exoskeletons.

Key Words: hand rehabilitation; robotic exoskeletons; stroke

1. INTRODUCTION

Hand is one of the most vital part of the human body. Its natural motor capability is crucial for Activities of Daily Living (ADL). The hands offer of a wide variety of functions, such as touching, feeling, holding, grasping, typing, writing, molding and the like. Although, there are neuromuscular disorder or aging may lead to losing or weakening hand functions. Worldwide, stroke remains a leading cause of physical impairments and functional disability (Mozaffarian, 2014). According to research, the most prevalently affected neurological domain of stroke is the motor system (Rathore et al., 2002). Most patients may regain the ability to walk, but they still suffer from mild to severe upper limb hemiparesis. Hemiparesis is the paralysis or loss of physical strength on one side of the body. Typically, the disabled motor deficit impairs the hand function (Duncan et al., 2003).

Musculoskeletal therapy assists in strengthening and restoring functionality in the muscle groups and the skeleton and in improving coordination. Rehabilitation therapy can significantly improve the recovery process during post stroke activities to regain previous dexterity. Currently, most physiotherapists perform these therapy exercises manually or occasionally use simple devices offering passive assistance. Also, the quantitative evaluation of the patient's performance and progress is difficult with the conventional therapy. Results of therapeutic treatment indicate that the chances of impaired hand recovery are low (Kwakkel et al., 2003). However, highly repetitive active training exercises requiring finger flexion and extension motion can aid the grasping and object manipulation capabilities of an impaired hand (Carey et al., 2007; Mark et al., 2004; Taub et al., 1993). One of the solutions to overcome the inefficiency of traditional therapy is through robotic rehabilitation.

The exoskeleton devices for rehabilitation technology in general have advanced over the years. But because of the complex structure and intricateness of human hands, it imposes a great difficulty on the development of a hand exoskeleton system. Compared to lower extremity exoskeleton systems and arm rehabilitation, the devices for hand or fingers are few, but are receiving growing attention. The devices for the robotic hand exoskeleton vary widely in terms of Range of Motion (ROM), number of actuated degrees of freedom (DOF), design strategy and nature of intended movements.

This paper reviews the recent progress, concepts, prototypes and commercially available devices for hand rehabilitation. Also, the future directions and challenges of hand exoskeletons are also discussed.

2. DESIGN CONSIDERATIONS OF ROBOT DEVICES FOR HAND REHABILITATION

Design considerations of a hand exoskeleton device incorporates the right number of DOF, length of links, type of actuators and sensors in order to provide the desirable functionality along with ergonomics. Based on several researches in hand exoskeleton systems, these requirements can be focused on: low mass and inertia, comfort of wearing, extensive range of motion, complexity (Iqbal et al., 2009).

3. ROBOTIC HAND EXOSKELETON TECHNOLOGIES

In the field of research, several groups have developed hand exoskeleton devices for rehabilitation, which can be potentially helpful in reducing the recovery time and the treatment cost. Recent researches showed that exoskeleton devices based on rehabilitation theory are feasible and effective. Robot-based rehabilitation extends precise execution of therapy procedures and heightens repeatability of exercises (Patton et al., 2004). Autonomous robots can share the workload of therapists conducting the rehabilitation paradigms.

3.1 EMG Controlled Soft Robotic Glove for Assistance during Activities of Daily Living (Polygerinos et al., 2015)

The EMG controlled soft robotic glove consists of soft actuators that conform to the user's hand with a combination of elastomeric and inextensible materials. Application of electromyography electrodes on the user's forearm is used to detect his/her intent, whether closing or opening of the palm, by monitoring gross muscle activation signals with surface. It offers an open-loop surface electromyography (sEMG) logic that distinguishes muscle contractions and feeds the information to a low-level fluidic pressure controller that regulates pressure in pre-selected groups of the glove's actuators.

With the soft wearable technology used in the device, it is simple, lightweight, easy to fabricate, customizable, and safe/comfortable to wear. The study was able to confirm that it is possible to use an open loop sEMG signals as a way to detect the objective of the wearer, whether to grasp, hold or release.

3.2 HandTutor™ glove (Carmeli et al., 2010)

HandTutor™ is a commercially available device manufactured by MediTouch Ltd. It is an ergonomically designed glove with sensitive electro optical position, speed wrist and finger movement sensors. Its dimension is 350[mm] x 120[mm] x 70[mm]. The device monitors and records patient's finger/s and wrist movements. The system provides repetitive and intensive active flexion and extension movements of the finger/s and the wrist.

Since this technology is commercially available, it has gained reviews from several clients. In the customer reviews they have been positive about the device, aiding them on their Activities of Daily Living, improving their motor skills.

3.3 Finger Individuating Grasp Exercise Robot "FINGER" (Taheri et al., 2014)

The FINGER is a robotic exoskeleton incorporating two identical planar eight bar mechanism. The mechanism, actuators, and adjustment assemblies are located behind the hand. The robot is capable of individually assisting both the index and middle fingers through a natural grasping motion. The actuator used is a low-friction linear electric actuator. Each 8-bar mechanism is independently actuated using two brushless linear motors ("Servo Tube" actuators, Dunkermotoren STA116-168-S-S03C).

3.4 ExoHand (Festo, 2012)

The ExoHand is manufactured by Festo. It is an exoskeleton designed like a glove. The exoskeleton is fabricated using polyamide in the selective laser sintering (SLS) process. Moreover, it is customized to fit the hand of the individual using the 3D scan of the user's hand. It consists of eight double-action pneumatic actuators, which acts like a "force amplification device". The sensors include 8 linear potentiometers per hand as displacement sensors, 16 pressure sensors per hand track the force and position of the fingers. The ExoHand integrates human intelligence with the robot capabilities. Real time transmission of movements to the robotic hand through visual and tactile perception and decision-making capacity of the user is utilized.

3.5 Hand of Hope (Hand of Hope - Rehab-Robotics (www.rehab-robotics.com) - stroke recovery therapy. (n.d.)

The Hand of Hope is a commercially available device for hand rehabilitation by Rehab-Robototics Inc. based in Hong Kong. The device incorporates 2 EMG sensors attached to the extensor and flexor muscle to detect the patient's objective for hand motion. It also utilizes real-time interactive games to enhance the training. Velcro straps were utilized for quick set up. The data from the training is also stored and graphical results are generated for evaluation. The material used is a lightweight metal frame. According to an article, it costs €20,000 [HK$200,500] for a left and right pair (Evans, 2014).

3.6 SCRIPT project (Supervised Care and Rehabilitation Involving Personal Tele-robotics) (Scriptproject.eu., n.d)

The SCRIPT project designed a system focused on robotic gloves to aid stroke victims and allow patients to receive advanced therapy at home after in-clinic rehab sessions. The mechanical components uses forearm shell, hand plate, and digit caps with Velcro straps. The sensor includes integrated measurements units (IMUs), for forearm posture. The interface of the SCRIPT system includes of two parts: a user interface (UI) for the patient (Patient UI) and a UI for the health care professionals (HCP UI) SCRIPT is a passive device, which gives passive assistance for fingers and wrist extension using leaf springs and elastic.

3.7 CyberGrasp™ (CyberGlove Systems, 2015)

The CyberGrasp is a haptic device incorporating a realistic feeling of grasping, applicable to all finger segments (phalanges) and palm, unlike other devices. The grasp forces are perpendicular to the fingertips throughout the range of motion and forces can be specified individually. The hand model allows a full range of motion, which has 20 degrees of freedom for fingers and 6 degrees of freedom for hand. The maximum force is 12 N per finger. The device weighs 16oz, without the system and delivers a real-time hand modelling based on the position and motion data.

4. FUTURE DIRECTIONS AND CHALLENGES

Future developments for patient treatment may include the portability in a rehabilitation device, which can broaden its potential applications. A portable device may be used for prosthetics as well as for assistance to perform ADL. However, most of the reported hand exoskeleton rehabilitation devices, with very few exceptions lack portability. Moreover, virtual reality (VR) may be incorporate to do more realistic task-based exercises. The idea of integrating virtual games to provide therapy trainings has already been utilized with a number of exoskeletons. (Carignan, 2009; Frisoli, 2007; Stienen, 2007). The following action to be taken is to develop games based on physiotherapy principles and allow them to be calibrated to enhance the patient's level of motor deficiency.

The field of robotic exoskeleton for hand rehabilitation is still far from being perfected but continues to grow. The role of robot-assisted therapy in stroke rehabilitation currently works hand-in-hand rather than a replacement of traditional rehabilitation therapy. In the application for post stroke patients, telemedicine is one promising technology to improve access and increase treatment availability for stroke patients who live in remote areas where rehabilitation centers may not be readily available. Therapies and rehabilitation strategies should not only more effective but are more cost effective and efficient. Right now, 3D systems are being incorporated to prototype and manufacture the hand exoskeleton to fit the individual. Overall, the field of hand rehabilitation has a bright future. Doctors, patients and researchers involved in hand rehabilitation will benefit and have further tools in the coming years.

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