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Development of Upper Limb Assistive Robotic Devices for Arm Functionality Rehabilitation- A Review

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ABSTRACT: *Use of assistive robotic devices and exoskeletons help to achieve the main purpose of rehabilitation and increased functionality in medical sector. In order to treat patients after stroke or with a condition of myasthenia, physiotherapy is needed for rehabilitating the weakened set of muscles. The exoskeleton devices not only treatthe patient well but also help them to relearn the basic movements of the affected limb. They help strengthenthe weak part/limb of a person withcondition of partial paralysis / myasthenia with the help of assistive exoskeleton rehabilitation device via training sessions to improve daily primary activities.*

KEYWORDS–*Assistive –robotics, Exoskeleton,Myasthenia,Physiotherapy,Rehabilitation.*

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I. Introduction

In our country, every year there are almost a million people affected with paralysis and myasthenia.According to social security disability (S.S.D.) myasthenia is a disability and there is no cure. But it can be treated with medication, physiotherapy and sometimes surgery. To avoid the surgery stage, in this condition the affected patient needs to take specific treatment to give considerable strength to the affected limb.

Myasthenia is the state in which abnormal weakening of muscles takes place. It is caused due to severe strokes & accidental nerve damage. In most of the cases severe strokes & nerve damage leads to weakening of arm muscles & it becomes necessary to get expensive physiotherapies in rehabilitation centers or hospitals.Here a particular device that is perfectly designed to impart confidence in the patient to exercise by themselves and work efficiently to strengthen the muscles of affected limb is beneficial,under the guidance of a physiotherapist. In this paper, we will discuss different devices/exo-skeleton which are used for rehabilitation of weak muscles to find the most effective device and ways by which they achieve their objective of strengthening the weakened part or a limb and regain its functionality.

II. Different Devices And Exoskeletons For Rehabilitation Of Upper-Limb

2.1 Robotic Exoskeletons: A Perspective for the Rehabilitation of Arm Coordination in Stroke Patient

[Nathanaël Jarrassé, Tommaso Proietti, Vincent Crocher,Johanna Robertson, Anis Sahbani,Guillaume Morel,and Agnès Roby Brami]

This study consists of the following topics that are of detailed study in order to achieve the desired results in the robotic exo skeleton devices-

2.1. A) Shoulder-Elbow coordination andSynergies in Stroke Patients

Nathanaël Jarrassé and Tommaso Proietti [1] investigated that even though stroke causes lesions of the motor areas of the brain, motor impairments commonly occur in the body on the side opposite to the lesion (hemiplegia). In the weeks following the lesion, symptoms generallyrecover spontaneously butpartially and inconstantly, and many patients are affected by a condition of impairment of upper-limb movement (hemiparesis).

Various practical and theoretical approaches are used to define the shoulder-elbow coordination. As Bernstein(1967) in one of the studies, described synergies to be the fundamental blocks of motor control which reduces the redundancy of the system. Infact, the motor system has more DOF(Degrees of freedom) than necessary to perform any task. For instance, the articulated upper-limb requires only 6 degrees of freedom for any grasping task but it actually has more than 7 degrees of freedom. As per this concept, synergies 1) combine several elements that share same spatio-temporal properties and work together and 2) might be combined in a task specific way by which a continuum of responses can arise with a limited number of synergies. But still we do not see an agreement on the space (muscles or joints) where in the synergies are organized.

The recovery mechanisms after stroke are multifactorial and the effect of rehabilitation programs is complex (Langhorne et al., 2011). Cortical map's activity-dependent neural plasticity adjacent to the lesion mostly occurs, particularly during the acute period after stroke (Nudo, 2013). In order to stimulate such plasticity, several new rehabilitation methods, which includes robotic assistance, have been developed according to the motor learning principles (Huang and Krakauer, 2009). In addition, measured improvementsby clinical scales can be due to the development of compensatory strategies. There's an immediate benefit on daily life activity due to compensatory strategies but, because of the learned disuse phenomenon, it mayhave a negative impact on the quality of movement performance and put a limit to the long-term prognosis.

2.1. B) Robotic and mechanical assistance for recovery

Vincent Crocher [1] studied that since the late 90s, many rehabilitation-robotic devices have been developed particularly for the neuro-rehabilitation of post-stroke patients (see review in Brewer et al.(2007)). Most of these devices have guided the movement of the hand in one plane. Some robots can mobilize the limb of patients passively with poor recovery or can provide precisely controlled active assistance as a function of patient's capacity. An advantage of robotic assistance is the possibility that patients can carry out a great number of movement repetitions, increasing the intensity of therapy. Recent extensive clinical testing of one of these devices, the InMotion© robot (that has been used in clinical practice for many years) has presented its effectiveness with significant improvements in arm motor capacity after a program of robot therapy. However, till now, there is no significant qualitative benefit of robotic devices over a therapist performing the same quantity of movements (Volpe et al., 2008, 2009; Lo et al., 2010).

Still the robot therapy remains particularly interesting, since it enables more movement opportunities than standard therapy. Most of the earlier clinical studies have been carried out with planar robotic manipulanda, which can only control the hand movements in space. In contrast, more conventional therapies (Brunnstrom, 1970; Bobath, 1990) particularly insist on the coordination quality based on the handling skills of the physical therapist. The physiotherapist supports the weight of the upper limb by simultaneously holding the upper and the lower arm in order to mobilize the upper arm or to assist voluntary reaching movements. In addition to this, the support provided by the therapist for the prevention of shoulder–hand syndrome due to shoulder subluxation is very important. A combination of these approaches would involve the insistence on the quality of coordination, under guidance of a therapist, while the patient practices a motor learning program (Levin and Panturin, 2011).

There needs to be a lot more research and prototype making if we are to make a considerable growth in robotic assistive technology for rehabilitation which should better manual treatment by therapists.

2.1. C) Design Challenges for Rehabilitation Exoskeletons

Even though the upper-limb manipulanda and lower limb exoskeletons have been used in the clinical practice for several years now (check the manipulandum by InMotion© and the Lokomat© by Hocoma), not long ago the upper-limb exoskeletons have only been developed (mid 2000s) and their effects have been studied on a lesser scale. Indeed, at the end of 2011, the first commercially available upper-limb exoskeleton for rehabilitation was released (Riener et al., 2011).

Johanna Robertson,Anis Sahbani [1] found out thatthe complexity of the interaction between mechatronic structures and the human body has been one major reason for its slow development, both at the physical and at the control level. While the hand motion is controlled in a single plane by thepioneer devices, exoskeletons do provide 3D interaction at the joint level through their kinematic redundancy and the presence of multiple attachment points between the device and patient's limb.New and interesting perspectives for rehabilitation are offered by these characteristics, but they also make the devices much more complex in terms of design and control.

Moreover,compared to other exoskeletonsone fundamental particularity of rehabilitation exoskeletons, which are designed to assist fully paralyzed patients, is that they should be able to respond to any movement carried out by the patient (even pathological). This must be based on a fine control of the mechanical interaction with the patient's limb (Maclean et al., 2000): the goal is to help the patient recover his/her sensorimotor capability, more than providing assistance to the movement. To be able to perform such a task, great amount of challenges relating to the global mechanical design of the given structures, their coupling with the human limb and, above all, their control, needs to be overcome.

2.1. D) Discussion and Perspectives

Guillaume Morel, and Agnès Roby Brami [1] discussed the outputs and stated thattherapy via exoskeletons can theoretically put together motor learning principles, which firmly insist on the importance of intensive therapy using active movements, and the more classical methods, which are based on upgrading the quality of coordination. Some simple technological rehabilitation devices have been developed recently for this purpose. Most focus on one joint or a local group of joints is observed in those Example: Wrist or hand rehabilitation.

Thus, the use of a multi-contact robotic device for the rehabilitation of coordination really seems promising. However, as stated in this paper[1]the development of exoskeletons for rehabilitation is only the start and numerous technological, physiological, and clinical challenges lie ahead. Taking into considerations, the results of clinical investigations, a few studies that have addressed the spatial and temporal relationships between joints directly have only been introductory, involving a limited number of patients. Consideration of joint coordination in the exoskeleton control needs to be taken care of too. It includes problem of the reference trajectory, joint torque coordination, joint kinematic coordination-One approach used with the ARMin III robot, is based on a time-independent functional training (TIFT) algorithm (Brokaw et al., 2013).This controller can generate virtual joint-space walls in order to keep the subject close to the ideal joint-space path, acting both on feedback position control and multiple joint motion. Though this strategy corrects the undesirable coordinate patterns between shoulder and the elbow joints, main issue remains still remains the position dependency which requires different reference paths for each joint and motion.

Progressive advances in these scientific fields need to have an important impact on clinical exo-skeletons, that leads to the design of innovative approaches to rehabilitation with the inter-joint coordination training. This improved upgrade at the impairment level must limit the development of compensatory strategies, helping patients to attain their full functional potential (Levin et al., 2009).

2.2 DEVELOPMENT OF LOW COST PORTABLE HAND EXOSKELETON FOR ASSISTIVE AND REHABILITATION PURPOSES

[STEFANO CAPITANI, ARIANNA CREMONI, LUKAS LINDENROTH, NICOLA SECCIANI, ALI SHAFTI, AGOSTINO STILLI, MATTEO VENTURI]

On the basis of strict requirements of user friendliness to wear, cheapness, portability and modularity, an assistive and rehabilitative device for disabilities of hand opening consisting of innovative kinematics, has been developed and tested by Stefano Capitani and his colleagues [2] in the project. This robotic orthosis which is designed to be a low cost and portable hand rehabilitator assists people with hand opening disabilities in their daily lives. It could even be used as a rehabilitative device in restoring the hand gestures post injury or condition of functional impairment. The testing phase of real prototype with patients has been going on. The main objectives of this device are

- good reliability of the device through a closed loop control which uses angular feedback, increasing the usability of the exo-skeleton, by developing an intention sensing method based on the electromyography(EMG).
- Implementing an automatic scaling algorithm to extend the mechanical solution of the device to many people with different sizes of hand.

The aspect of modularity is very critical due to variations in human hands and so modularity requires a device adaptable to multiple users who obviously have different hand characteristics and disabilities.

Today, the first cause of adult disability is the Cerebral Vascular Accident (CVA) in Europe. Patients suffering from hemiparesis of the upper limb post-stroke are at least 80% of the crowd. Post stroke survivors, patients with genetic disorders and elderly with hand disease need on one side whereas timely and persistent rehabilitative training for regaining previously dexterity and, on the other side an aid in the Activities of Daily Living (ADLs). They have also used the research papers to convey different types of recuperative devices and their objective of exo-skeleton's optimized usage for strengthening the hand muscles and regain the motor skills of fingers to considerable extent.

In order to obtain and use specific trajectories of some points of interest of the hand, a parametric hand model is produced artificially (in Matlab) through which implementation of an optimization algorithm to adjust the characteristics of the exo-skeleton will reproduce the desired trajectories.

This device aims at improving the reliability, adaptability and modularity in a cost effective way.

1.3 Human Assistive Rehabilitation Pneumatic Exoskelton (HARPE) for Stroke Patients

[Majid Jamialahmadi, Alawiyah Al Hashem, and Wesley Conn]

Majid Jamialahmadi, Alawiyah Al Hashem, and Wesley Conn [2], studied and came to the facts thatstroke is the third leading cause of death in the U.S.A., which led to the development of HARPE that focuses to restore the functional impairment occured in individuals post stroke.

HARPE device consists of three artificial muscles (air muscles)/pneumatic actuators to control the extension, intrinsic flexion and extrinsic flexion movements which the hand does. The solenoid valves programmed through an Arduino microcontroller controls the contraction and relaxation of air muscles by opening and closing. This device initiates either by patient's minor hand movements or by utilization of flex sensor controller glove on the unimpaired hand.

The conceptual design proposed for HARPE displays a glove device controlled by an Arduino microcontroller that can be programmed computerized. Seven air muscles are utilized to control different hand movements. Intrinsic and extrinsic flexion are controlled by three air muscles while extension, flexion, abduction and adduction movement of the thumb are controlled by four other air muscles respectively. Likewise the diameter of the air muscles and their length define the amount the amount of force required for targeted movements.

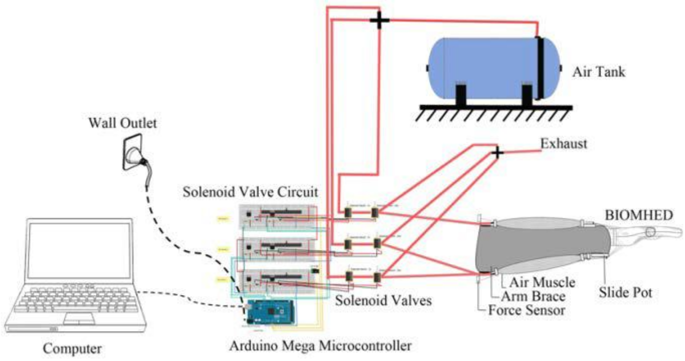

Figure 1: HARPE Complete System Schematic

In addition to the objective of restoring of functionality, HARPE device also consists of a force sensor and linear measurement sensor that enhances HARPE's safety and helps in the movement initiation. In the upcoming modifications, HARPE device would be integrated with additional air muscles to operate thumb movements along with an emergency kill switch to shut down the device in case the microcontroller causes issues as an additional safety.

2.4 A Pneumatic Robot for Re-Training Arm Movement after Stroke:
Rationale and Mechanical Design

[R. J. Sanchez, Jr., E. Wolbrecht, R. Smith, J. Liu, S. Rao, S. Cramer, T. Rahman, J. E. Bobrow, D. J. Reinkensmeyer]

In this paper, the authorstudies the development of a pneumatic robot for training of thefunctional movement of armand hand post stroke. Based on the Wilmington Robotic Exoskeleton (WREX), the device is a passive, mobile arm support developed considering children with weakened arm caused by a debilitative condition. Earlier, WREX for usage by adults, instrumented it with potentiometers, and consisted of a simple grip strength sensor. In order for theindividuals with severe motor impairment to practice functional movements (reaching, eating, and washing) in a casualenvironment; a passive device allows this (namely Training WREX or "T-WREX"). Virtual reality called Java Therapy 2.0. Since, it can only apply a fixed pattern of assistive forces to the arm, the device is limited. In addition to this, full range of motion is not restored by its gravity balance function "Therefore, the need for the development of 'Pneu-WREX', a robotic version of WREX, that focuses to apply a wide range of forces to the arm during naturalistic movements". In order to allow application of a wide range of forces during naturalistic upper extremity movementspneumatic actuators, non-linear force control, and passive counter-balancing are used.The authors have shown results from 29 therapist's tailor-made surveys on the use of such a robotic device, apart from the detailed description of the mechanical designing and kinematics of Pneu-WREX, an extensive research is in progress.

III. Conclusion

The Literature Review on the Development of Upper Limb Assistive Robotic Devices for Arm Functionality Rehabilitation concluded that,

- The are 2 main types of upper limb rehabilitation devices or exo-skeletons:

1) Motor driven
2) Pneumatic compressor driven which consists of air muscles.

- All the devices of rehabilitation had their own advantages and methods of treating the patients with certain limitations too.
- Amongst all the above discussed exo-skeletons and rehabilitation devices HARPE was the most user friendly device due to its application oriented design and placement of the device on human body .
- Placement of the device was good for hand-finger exo-skeleton too, simplifying the method in its treatment.
- Shoulder-elbow exo-skeleton(Robotic exo-skeleton for arm coordination) has a great theoretical background but hasn't been able to make it practically significant compared to the manual treatment offered by the physiotherapists. It needs more extensive research and betterment in user friendliness.

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