Global Journal of Enterprise Information System

DOI: 10.18311/gjeis/2017/15849

Implementing Exoskeleton to Re-Enable the Disabled: A Review

Divya Agarwal[1*], Ajay K. S. Singholi[2] and Pushpendra S. Bharti[1]

[1]*University School of Information and Communication Technology, Guru Gobind Singh Indraprastha University, Dwarka, Delhi, India; er.divya7@gmail.com, psbharti@ipu.ac.in*

[2]*Department of Mechanical Engineering, Delhi, India; ajay.igit@gmail.com*

Abstract

With the growing trend of robotics, curiosity in exoskeletons field has increased speedily. People with disabilities suffer from many social and mental pressures due to exclusion from society just for being different from normal human beings. Hence, the usage and purpose of robotic technology trims down this segregation and promote vocational incorporation. Having attempts made for the last five decades, researchers still face many challenges in the field of exoskeletons. Exoskeletons are used not only to provide movement to the user but to enhance the motion of disabled limb also. Therefore both humans and exoskeletons maintain a symbiotic relationship. Challenge for researchers is to offer precise and accurate performing exoskeleton with negligible chances of failure for human operator. In this review article, authors attempt to highlight significant advances in the field of upper-limb exoskeletons, challenges pertaining to them and aims at suggesting concrete solutions to the difficulties encountered so far.

Keywords: Anthropomorphic Teleoperation, Assistive Devices, Dexterous, Exoskeleton, Master Slave; Rehabilitation, Upper Limb

Paper Code: 15849; **Originality Test Ratio:** 11%; **Submission Online:** 09-March-2017; **Manuscript Accepted:** 15-March-2017; **Originality Check:** 19-Mar-2017; **Peer Reviewers Comment:** 04-April-2017; **Double Blind Reviewers Comment:** 11-May-2017; **Author Revert:** 27-May-2017; **Camera-Ready-Copy:** 01-June-2017

1. Introduction

The research in the field of robotics progresses ever since the word Robot was coined in the play Rossum's Universal Robot by Karel Capek meaning "forced labor". Accidents, health disorders such as diabetes, stroke, and brain hemorrhage are the frequent cause of death and leading cause of permanent disability worldwide. All above incidents lead to neurological impairment causing partial or permanent paralysis of the body, thereby affecting the person's ability to perform daily chores with ease[1]. The lost functions of a person can be regained after physical therapy i.e. rehabilitation so as to provoke patient's motor plasticity and improve recovery with minimal functional deficiency[2]. Rehabilitation through movement is dependent on limb thus exercise of affected limb becomes mandatory[3]. Rehabilitation is a three cycle process involving three phases such as Mobilization of bedridden patient into chair, Restoration of limb movement pattern, and Improvement in movement[4,5].

Conventional rehabilitation therapies were labor intensive for the patient, as the pain of the patient couldn't be felt and the degree of freedom was also less compared to the latest methodologies (assistive devices such as exoskeletons, orthotic devices etc.), involved in rehabilitation therapies[6]. Robotics is an emerging field in the field of assistive technology for rehabilitation treatment, and exoskeletons are one such class of robots which find their usage in rehabilitation therapies. Exoskeletons are used to augment or amplify the human limb capability and hence allowing the person with impaired or disabled limb to move hands, muscles or skeletal parts which got weak and non-functional due to a disease or a neurological condition[6,7].

The increasing trend in the field of robotics is due to the progressive switching towards human machine interaction from the industrial workplace by the manual labor[8]. This interaction between the human and the machine like exoskeleton is increasing because of the easy flow and exchange of information. The use of exoskeletons to assist the weak and disabled is becoming a rage among the researchers[8]. Therefore the developing and developed countries are funding a lot of money in this field[9]. The exoskeletons not only provide movement to the wearer but also enhance the motion of disabled limb thereby maintaining a symbiotic relationship between human and exoskeletons. The relationship between robotic systems and the humans points the boundaries and limitations in physical interaction. Exoskeleton robots are incorporated with many smart sensors, control algorithms, motors, actuators, encoding decoding strategies to capture human expressions and human psychology[6]. They use all such information to familiarize, learn skills and optimize their functions. This work presents a review of the research carried out in the field of the upper limb exoskeleton robots designed to assist impaired people in the execution of daily life activities.

There are few impressive and ground breaking opportunities to instill the movements in the limbs which stopped functioning

**Author for correspondence*

after getting affected with diseases like tetraplegia and injuries related to spinal cord, etc. due to the advancement and more inference of robotic technology in assistive devices[2,10-18]. People with disabilities suffer from many social and mental pressures due to exclusion from the society just for being different from the normal human beings. Hence, the usage and purpose of robotic technology trims down this segregation and promote vocational incorporation[12]. All the daily life activities are taken as granted by most of the human beings. We can easily accommodate and locate from one place to another without doing much effort. Thus, we are so dependent on these activities that we forget how complex and trivial these activities could be for the people suffering from problems of limb impairment[11-14,19]. So, the foremost basis for the advancement in the field of robot's hand is replication of the human hand's functionality and manifestation[6].

In biological terms, an exoskeleton can be termed as an outer covering of living creature to safeguard support, power augmentation or sensing and data fusion[20]. This basic idea is incorporated in exoskeleton robots applied in medical field for patients with impaired limbs or many such disabilities. An exoskeleton is a type of an electromechanical structure which is designed to match up with the figure and functionality of a human body as it is to be worn by the human operator[21]. It is designed to assist the weak, fragile or disorganized skeletal parts as it combines the intelligence of the human operator with the power of exoskeleton machine in order to improve the movement of the operator. It is believed that the exoskeleton performs parallel functions with the human body[16,19,22,23]. Robotic exoskeleton systems can be classified into three types as upper extremity (i.e., upper-limb)[67], lower extremity (i.e. lower-limb)[24], and full body[6]. A simple robotic exoskeleton is shown in figure 1.

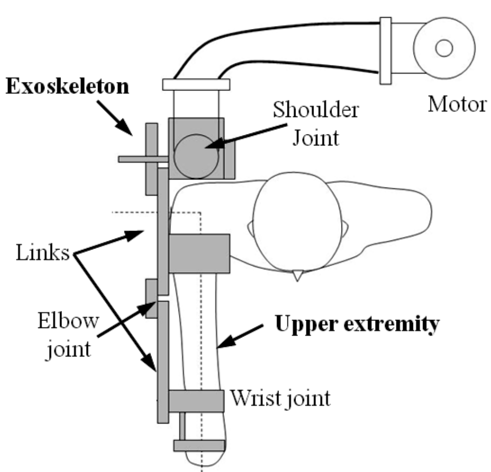

Figure 1. Simple Robotic Exoskeleton[1].

Although several effective exoskeleton robots have been developed for the upper-limb motion assist, more effective exoskeletons and their controllers are still desired in order to realize natural and effective power-assist. In some approaches preprogrammed exercises are used to control the robot[25]. Although this kind of exercise is sometimes important for rehabilitation, the user's motion intention is not adequately considered. An exoskeleton robot is able to assist the motion of the user effectively in accordance with the user's intention by applying the user's EMG signals as input signals to the robot controller[26].

Previously the robots which were designed were massive, colossal, unreliable, non-realistic and expensive to the operator, so the researchers are trying to make the robots system compact at the same time inexpensive keeping in mind safety parameters for operator. The objective of this review article is to draw attention towards the stimulating field of assistive devices such as exoskeletons, for handicapped or disabled people with introductions of latest developments in this field and conceptual issues. The focus area of this review article is upper limb exoskeletons. Initially concept of exoskeleton robotic devices is studied and acknowledged. Review is presented on the challenges faced by several researchers while designing exoskeletons and patients while using such systems. Within this short and brief review, we have covered the brief history related to exoskeletons, concept behind implementation of exoskeletons, challenges while designing and application, and the scope of improvement. Besides, all the important and key technologies or developments in upper limb exoskeletons are reviewed with state-of-the-art robot as examples.

2. Background

An electromechanical structure which is worn by the user to match the shape and functioning of human limbs is known as exoskeleton[27]. Exoskeletons are the devices that augment or enhance a person's physical capabilities by helping a person lift heavier loads, run faster, and jump higher etc. Exoskeletons find applications in several diverse fields such as in medical science, exoskeletons are used as an assistive technology for the impaired or disabled people, in military services, exoskeletons are used to augment soldier's capability to fight better and carry heavier arms or weapons with ease, etc[28]. An exoskeleton system makes full use of the human intelligence and the power of the machine to greatly enhance the performance of the man–machine system[3,8].

Exoskeletons are in application since 1960s. While studying exoskeletons and their emerging use in the field of medicine, researchers figured out a bilateral technique in which the master (human-operator) exploits the environmental forces acting on the arm and resultant force is applied naturally and smoothly on the patient's arm through exoskeleton arm structure[16]. A dexterous anthropomorphic mobile robotic arm with 9 DOF was designed and demonstrated with readily available low-cost components to perform different object picking tasks for immobile patients such as drinking water or tea, switching off lights, picking up of book etc., using a five-finger gripper[16]. Robot Suit Hybrid Assistive Limb (HAL) was designed by University of Tsukuba to provide a physical support for conducting daily chores and heavy work[17]. Exoskeletons were initially developed by US military to augment the capabilities of their soldiers during military purposes and sustain longer during wars[23]. First lower limb exoskeleton was designed by Berkeley University and was named BLEEX (Berkeley Lower Extremity Exoskeleton). It helped the operator for lifting significant load easily over varied topographies[24]. One another application of exoskeleton was for an industrial purpose by General Electric for handling radioactive equipment by using the concept of two-armed master–slave exoskeleton; this was the first haptic exoskeleton[29]. Since the inception of exoskeletons in assistive medical technology, they have been implemented and designed by many researchers or medical practitioner. The first application of exoskeletons as an assistive device was developed by John Hopkins University. They designed it for human upper-limb to help impaired or disabled person in elbow flexion[30].

On the basis of design complexity and the capabilities, researchers classified exoskeleton designs into three classes:

- *Human power augmentation*: The mechanism involved in the human power augmentation exoskeleton design was to augment the nurse's potential so as to provide better care, assistance and nurturing of the immobile patients by the use of the full body exoskeleton. This mechanism was proposed by the Kanazawa Institute of Technology[6,9,28,31]. Many such designs were Robot Suit HAL[17], BLEEX[24], etc.
- *Haptic Interactions*: Exostation was developed to direct the virtual slave robot remotel[6], 5-DOF haptic arm exoskeleton designed by Gupta et al.[1] for rehabilitation purpose in virtual environment[9] and one such exoskeleton design with the haptic interactions was developed by GE named as Hardiman robot with exoskeleton type master to be worn by the h6uman operator, and the slave was used to replicate or imitate the master's motion[29].
- *Rehabilitation:* Such exoskeletons have been designed for various rehabilitation purposes to help provide assistance to impaired people[32].

In recent years, a number of devices have been developed expressly for, or applied to, hand rehabilitation. Some of the assistive devices which were previously developed were low cost 5 finger anthropomorphic robotic arm[27], UB hand[33], UTAH/MIT dexterous hand[34], and Karlsruhe Humanoid Hand[35], etc. All these assistive devices were bulky and problematic for operator to wear. Some of the commercial assistive devices included, CyberGrasp (Immersion Corporation, San Jose, CA)[36], the Hand Mentor (Kinetic Muscles Inc., Tempe, AZ), and the Amadeo System (Tyromotion GmbH, Graz, Austria) and experimental devices, included the Rutgers Master II[37], HWARD[38], and HandCARE[39], among others[40-43]. Slings, support-bands have also been used as an assistive device to support and help an impaired or disabled person. An Intelligent Bed Robot System (IBRS) was designed to assist elderly and disabled to live an independent life in bed, which is equipped with two robot arms and an array of pressure sensors attached to the mattress. The pressure distribution on the mattress is used to estimate the pose of the patient, and an appropriate assistance is provided by the robot arms. This system was short of health monitoring feature and evaluation of rehabilitation progress[44].

Powered wheelchairs such as robot mounted on a wheelchair to assist patients in picking up items, drinking or generating emergency alarms etc., were one of the most important design considerations in the history of assistive devices[43,44]. Commercially available powered wheelchair is: Raptor (manufactured by Applied Resources)[18] and Manus (manufactured by Exact Dynamics)[45]. Powered wheelchairs were an alternative of patient's dependency but not a complete solution to the problem[46,47]. KAIST rehabilitation engineering system is a wheelchair mounted robotic arm to assist the disabled for independent livelihoo[48]. To perform autonomous tasks the robotic arm employs the sensor-based control using color vision and force information. It is revealed, however, that this prototype system shows a number of aspects yet to be improved. For example, the speed of the robotic arm should be enhanced while, for more, friendly looking and for weight and safety, a flexible arm is to be recommended, as the next version of design[48].

The application of service robots in Real Time Operating Situations (RTOS) deals with various challenges, technical tribulations because the foremost constraint comes when these devices have to interact and relate with humans. This paper is concerned with the review of designs of robotic arms in reference to people with difficulties. In the developing countries there are many people with disabilities due to which they can't move on their own and depend on others. For this purpose researchers are doing lots of work and innovations to provide some assistance in their mobility, few such researches are designing inexpensive and easily implementable anthropomorphic robotic arm[49]. Earlier it was believed that the higher the degree of freedom of a robot the greater is its flexibility,[50] because it allows the robot's end effector to perform analogous to that of human hand, to clutch and seize items at diverse positions in 3-Dimensional space at a variety of angles which is essential when managing delicate and fragile apparatus, [50] therefore arms with 7 Degree of Freedom (DoF) were desired because they could easily imitate the human arm with 3 DoF for wrist movement, 3 DoF for shoulder movement and 1DoF for Elbow movement[51]. The development of the first active anthropomorphic exoskeleton commonly known as Beograd was presented by Vukobratovic et.al, to help elbow flections for the paralyzed people[52].

3. Wearable Exoskeletons for Upper-Limbs

Wearable exoskeleton robots can be defined as the robots which are worn by human operators, either to complement the functionality of a limb or to replace the limb entirely. These types of exoskeleton robots act as the human power amplifier as they enhance, increase the power capabilities of the human operator[14]. Such robots might be operated along with the limbs, such as in exoskeletons, or they might replace the missing limbs, for example in case of an amputation. Wearability does not essentially mean that the robot is portable or autonomous yet the non-autonomous or non-ambulatory behavior of robots is due to the lack of enabling techniques, mainly actuators, smart sensors and energy sources[15,27]. A wearable robot can be thought of as a technique that broadens, complements or appreciates, replaces or augment human functionality and ability, or authorize or substitute (a part of or the whole structure of) the human limb where it is to be worn[22].

Exoskeletons are referred to as the species of the wearable robots and the wearable robots can be classified into 3 classes: [22]

- *Orthotic Robots:* In this type of wearable robots, a mechanical structure such as a robot or exoskeleton maps on the human limb's anatomy to reinstate weak functions of a limb due to the after effects of a severe disease or a neurological disorder. The purpose of the exoskeleton is to enhance the human limb's ability in terms of strength and reinstate the weak or handicapped functions[19,20].
- *Prosthetic Robots:* This type of wearable robots is used to substitute or replace the lost limbs after amputation. The robotic counterparts or prostheses acquire the shape as that of the wearable electro-mechanical limbs and imitate the natural human function. This is accomplished by the use of intelligent and efficient usage of robotics as in case of HMI[9,19].
- *Empowering robotics Exoskeleton:* This type of wearable robots is also referred to as extenders. The mapping of the exoskeleton structure over the human operator's anatomy is the fundamental characteristic of extender[40,53].

Few state of the art examples of the upper-limb exoskeletons are discussed in the below section. A comparative list of some ground-breaking and famous exoskeletons developed by various researchers and R&D organization can be seen from table 1.

Table 1. Review of Upper-Limb Exoskeletons

S. No	Name	DoF	Target Area	Methodology	Advantages	Gaps/Future Scope
1	NTUH-ARM[2]	7	Human arm	Assistive control system embedded with force and torque sensors.	Efficient implementation for rehabilitation of acute stroke patients	The approach is in testing stage for patients with less acute symptoms.
2	TTI-Exo Wearable exoskeleton[3]	2	Shoulder and Elbow joint	Model-based compensation control framework	light and wearable system with reduced complexity, and better safety	Same approach should be extended for whole-body motion control
3	minimal assist-as-needed (mAAN) [5]	5	Upper Limb Rice Wrist-S exoskeleton	mAAN controller with sensorless force estimation	Fast, stable, and accurate measurements regardless of subject interaction	In future, controller must be tested in clinical setting for neurological rehabilitation patients.
4	Wearable robotic arm [15]	7	Shoulder	Reduced computational load by using slip-ling mechanism.	Reduces operator's fatigue, pneumatic actuators are implemented to reduce weight of the robotic arm	In future, an enhanced control algorithm will be introduced to compensate time delay of pneumatic actuators and nonlinear effect of control valve.
5	Robotic Exoskeleton[21]	3	Upper-Limb	Adaptive fuzzy approximation control	Compensate disturbances, quick and first-rate path-following performance	Proposed model must be tested and validated in real-time situations.

6	sEMG-Driven musculo-skeletal model [26]	3	Upper Limb	Adaptive impedance neural network control using biological signals	Proposed model was able to match upto human forearm design and overcame deadzone effect	Joints were stiff and it should be incorporated into exoskeleton's control design.
7	ExoRob [56]	2	Elbow and Forearm	Nonlinear sliding mode control technique	Effective rehab therapy for disabled people in elbow and forearm motion deficiency	The methodology should be explored on 7DOF master exoskeleton arm (mExoArm)
8	Unpowered Upper Limb Exoskeleton[57]	4	Shoulder and Elbow Joint	Springs to equalize joint torques for the shoulder and elbow joints	Compact and Cost effective, easy limb movements in different planes, No risk of overextension injury	For consistency with the dumbbell curl motion, exoskeleton's shoulder joint must be held fixed for elbow flx-ext exercise with the upper limb exoskeleton.
9	Motion Assistance Equipment[64]	18	Index Finger, Thumb, Wrist	Self-motion control strategy through the use of a master-slave control	Designed to assist the motions, all of which the existing devices are not capable of:	Laterally symmetrical motions supported in training and effects have not been explored. An improved method for fixing the equipment to the hand is required.
10	W-EXOS[65]	3	Human forearm and wrist motion	Fuzzy-neuro control method,	Adapts itself to the condition of the user	Human Safety needs to be taken more care.
11	Upper-limb exoskeleton robot [66]	4	Shoulder	Intelligent system using image feedback and sonar sensor	Improved perception level, robot is intelligent in assisting user's motion when interacting with the environment	Vibration in the exoskeleton robot should be reduced
12	Actuated Finger exoskeleton (AFX) [67]	3	Index Finger	Separate actuators with closed-loop control	Able to assess strategies for optimizing rehabilitation of pinch and reach-to-pinch following stroke	A companion thumb exoskeleton needs to be developed to permit coordinated performance of pinch.
13	Exoskeleton Robot For Shoulder Joint Motion Assist [68]	3	Shoulder Joint	Fuzzy-neuro controller, a moving mechanism for center of rotation (CR) of shoulder joint, and intelligent interface	Effective control of exoskeleton robot for an intelligent interface.	Proposed method was verified experimentally on healthy human subjects, thus in future experiment should be done on elderly persons and handicapped persons.
14	Actuated Thumb Exoskeleton (ATX) [69]	5	Thumb	Independent actuation with considerable torque for each DOF of thumb	Reduced excessive captivation or stiffness in the affected thumb	In future position control for all 5 active joints of the ATX needs to be implemented and verified on different operation modes

15	Upper-Limb Power-Assist Exoskeleton Robot[70]	7	Shoulder Joint	Novel shoulder joint mechanism using only seven DC motors without the additional motors	Burden on motors has been reduced using springs; movement trajectory is wide compared to other exoskeletons	Not able to adapt to the changing environmental conditions; moreover effectiveness of the designed robot needs to checked experimentally
16	mExoArm [71]	7	Shoulder Joint	Nonlinear computed torque control technique	Passive mode of rehabilitation	Existing mExoArm lacks the real-time control capability
17	Actuated Finger Exoskeleton (AFX) [72]	3	Index finger	Independent actuation of each joint with real-time control	Versatile, capable of adjustment to accommodate finger segments of different lengths and thicknesses.	Force feedback and feed-forward kinematics needs to be explored as it mitigates shortfalls discovered during analysis and will include full bandwidth testing.
18	HX modular platform [75]	16	Index finger, thumb and hand dorsal modules	Hybridization self-alignment design	Compatible for Human-kinematics, easily wearable and portable	The experiments were conducted on healthy subjects and must be tested on unhealthy subjects.
19	Upper limb power assist exoskeleton [76]	3	Upper-limb	Intention guided control strategy with human robot interface	Effective and comfortable power assistance tool which is superior to conventional admittance control strategy	Proposed model holds the prospect to get more comfortable and human-centered
20	Upper Limb Exoskeleton [77]	5	Shoulder Joint	Shoulder Joint is titled to evade singularity issue	Capable of reaching all points in workspace	For future scope, model should be tested and implemented practically.
21	Upper-Limb exoskeleton arm [78]	3	Forearm movement assistance	Fuzzy approximation based adaptive backstepping control	Follows continuous preferred designed path in presence of uncertainties, instabilities from environments	Proposed control approach could be tested and simulated for real-time and dynamic trajectories.
22	Upper-Limb power assist exoskeleton robot [79]	3	Upper-Limb	sEMG based joint force control	Requires inexpensive and auxiliary sensors to get précised exoskeleton model	The proposed method is simulated in research lab and should be tested on practical subjects
23	Articulated Exoskeleton System [80]	3	Upper-Limb	Modular controller using a Lyapunov approach	Effective and robust controller, ensuring adequate performances in position and velocity trajectory tracking	Proposed controller must be practically implemented in collaboration with specialized hospitals.
24	LIMPACT [81]	2	Shoulder and Elbow joint	Supported by passive weight balancing mechanism	Safe, quick torque perturbations	Controller should be tested and implemented for zero impedance to enhance performance and reduce control effort.

In the earlier investigations[10,28] the human wearability was the main issue persistent upon the researchers. As the majority of the exoskeleton arms were quite a lot bulky and had heavy design and that's why had to be fixed at a particular solid structure like a wheelchair, table or a wall etc. In this field, as the researches progressed two high wearable robotic arms[11,12] were created; these exoskeleton arms were analogous to human muscles and the highlight was the motion tracking which provided controlled performance. But their limitation was weak force-reflection capability and complexity in computing kinematics[13]. A high wearability exoskeleton arm with better kinematics computations and high force- reflection capability[14] was designed using pneumatic actuators to provide smooth human motion and enhanced operator's workspace. A high joint torque wearable exoskeleton robotic arm[15], with 7 DOF was designed to help the operator to move around freely about its shoulder joint which is kept fixed with respect to the hand. Issues relating to the complexity of the load bearing and singularity problems were resolved efficiently due to the application of haptic technology i.e. parallel mechanism at the joints of shoulder and wrist of the operator's upper limb; and hence provided ease in solving the forward kinematics; moreover the slip-ling mechanism sidelined the yaw motion of the parallel mechanism[15]. The researchers emphasized on the use of pneumatic proportional small – size control valve, so as to obtain enhanced and improved pneumatic actuator's response characteristics and simultaneously trimming down the human exhaustion during procedure.

To assist the patients with impaired hands a 2 DOF wearable exoskeleton was designed by Kiguchi et.al.[25] for rehabilitation ; the exoskeleton they proposed was supposed to be attached to the patients upper limb so as to help in daily activities and provide assistance to the forearm motion (elbow flexion-extension; forearm supination- pronation) and was controlled by Electromyogram signals[27]. Electromyogram signals reflected the motion with same intensity for better understanding of natural motion assistance automatically. During such developments various other approaches were also implemented like the development of artificial muscles because without the metallic structure the exoskeletons will be light weighted and easy to carry and use for the user, as it also provided all the seven types of motion. Moreover this type of structure was able to provide more strength and a better posture to the human user. The uses of artificial suit along with the exoskeleton arms were beneficial and productive because of light weight and flexible, providing motion in all direction[54]. Its operating principle is depicted in figure 2.

Nakai implemented a human interface technique using force feedback mechanism attached to the operator's hand and named it sensor arm system[28]. The arm served the basis of the master-slave manipulator system in Teleoperation. The arm with which he experimented had 7-DOF same as that of human hand for better understanding and realization. The master and slave teleoperator with same compatibility and kinematics don't suffer with the problem of motion matching although the master-slave teleoperator which were kinematically distinct go through this model because, operating the manipulators within the workspace limit poses a constraint on the designer and ultimately on the user. Chin et al.[55] in their design solved this problem by adapting the workspace mapping technique to map the master teleoperator trajectory into reachable workspace of slave manipulator; though this method is complicated and costly yet the master being anthropomorphic could match human-hand's motion. They proposed that the key technique to satisfy the differently structured master slave teleoperator, movement capability is the workspace mapping technique with deficient-DOF.

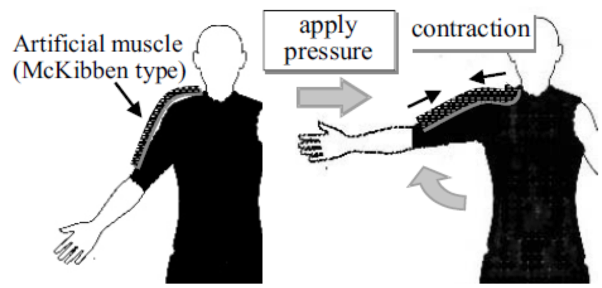

Figure 2. Operating Principle of an artificial muscle[56].

Wu et al.[57] presented an unpowered exoskeleton robotic arm for the upper limb disability. In their design approach they developed a shoulder joint with three degrees of freedom to provide roll- pitch-raw movements, and an elbow joint with one degree of freedom for strengthening the upper limb muscle of the patients with impaired hands. This design allowed the patients to complete their physiotherapy sessions. The exoskeleton arm prevented the patients from getting injured due to increased inertial forces fluctuations. This upper limb helped to recover the muscle strength because of its compactness and inexpensive design; moreover it was meeting the demands as per obligation. Kang et al.,[58] improvised the design by improving safety and with more DOF employing Adaptive control Technique.

The human arm movement is nonlinear in nature; so controlling the robotic arm linearly would have been very unrealistic in the real world situations so, their idea was to control the robotic arm nonlinearly by online updating the information provided by an adaptive viewer without any extra sensor. This design methodology was implemented in the RUPERT IV exoskeleton[59] to prevail over the non-linearity of the pneumatic muscle actuators and in the operator's limb. They opted for the passive therapy mode unlike the adaptive control algorithms implemented in

MIT-MANUS[59,60] and ARM Guide[61,62]. A comparison of End-effector robotic arm and Exoskeleton robotic arm is illustrated in figure 3. Yet another rehabilitation robot developed was KARES, (shown in figure 4) it was a 6 DOF robotic arm which was mounted on a wheelchair for the disabled persons. KARES had force sensors and vision sensors incorporated in the design structure for the robotic to operate intelligently on its own[48].

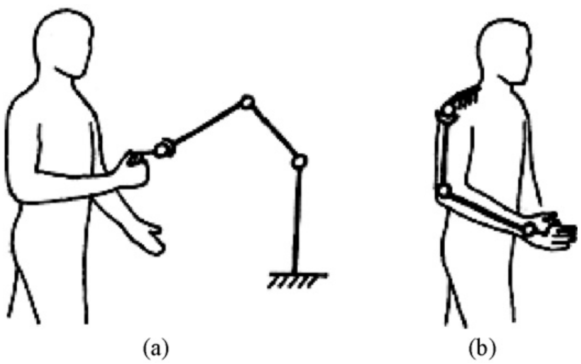

Figure 3. (a) End-effector robot. (b) Exoskeleton robot[62].

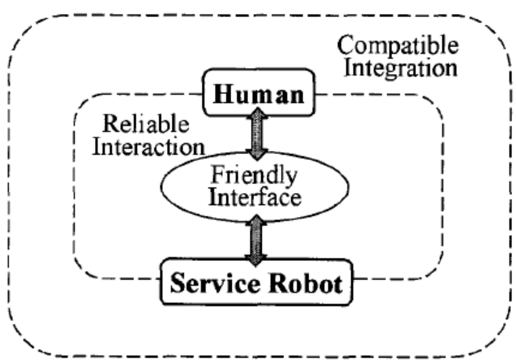

Figure 4. Triple I concept (Integration, Interaction and Interface) in Intelligent Service Robot[48].

4. Challenges for Exoskeletons

From the above literature review, following issues were persistent upon the researchers:

- Majority of the exoskeletons arms were quite bulky, thus there is a need of lightweight exoskeleton that is compatible with the operator's minimal metabolic requirements.
- Exoskeletons require high energy while having shorter battery lifetime, hence require maintenance.
- Some of the devices are often unnatural in shape, noisy and slow running, thus the design of their anthropomorphic mechanisms must be optimal and the control should be effective for the safety of operator.
- Unavailability of proper accessory devices.
- Some exoskeletons suffer from the problem of misalignment which can be solved by de-coupling of joint rotations and translations[63]
- Available actuation technology and power transmission technology are not in an appropriate state to develop a perfect robotic exoskeleton system.
- The exoskeleton robot should generate natural motions of upper-limb so that the wearer does not feel any vibration, jerk or sudden motion change.
- Back-drivability of the transmission is also essential for these systems to eliminate possible discomfort to the user.
- The materials of the exoskeleton structures used should be soft and convenient for operator as the exoskeleton acts as a second skin to the wearer.

5. Conclusion

The extent of human machine interface or the use of robotic technology depends on two primary factors firstly, the excellence of the integration of operator and the machine and secondly, performance and security of the overall machine (i.e. whether it is meeting the demands as per obligation). Any dissimilarity between the human limb and exoskeleton can create chaos and disturbance in the structure due to unwanted interaction forces and inaccuracy in the sensor measurements. Therefore, research in this field is going on to decrease the amount of misalignment by including the unnecessary DOF in the exoskeleton limb structure as these limbs serve to be passive and can translate or rotate freely i.e. provide flexibility to the robotic arm and to the dexterous hand manipulator.[51,53]

From the above review we can say that the exoskeletons is/are

- A substitute for the training effort of a therapist
- Serve as a reasonable therapy alternative, and
- A measure for force and movement pattern of user accurately.

Limiting factors for implementing exoskeletons as concluded from the above literature review are:

- *Information Exchange/ Communication:* Lack of accurate interface between human fingers at levels of velocity and torque comparable to everyday hand manipulation tasks.
- *Mechanical Interface:* Limitation of mechanical interface in design of exoskeleton devices.
- *Design Discomfort:* Discomfort in design often limit the time that a device can be worn.

Thus, it is certainly an achievable goal to provide comfortable and effective mechanical interfaces with the human body. The increasing development in the field of robotics will not only be enough for the betterment of the society or for the growth of the country but the major constraint is the acceptance by the end user. How much profitable is the device in use for the user? This parameter leads to the consideration of the factors like user preferences and acceptances to be given equal priority in future designs so as to resolve post production failure issues due to low market. In near future, more work could be done by synchronizing the exoskeleton applications and how the signals could be sent to the exoskeleton robot like in case of myosignal and Electromyogram (EMG) Techniques.

6. Scope of Improvement

Wearable systems should be improved to reduce discomfort. Improved models should deal not only with the performance of daily life activities, but also with fall prevention and stumble recovery as well. The designer should consider not only the outer anatomical features of human but also the physiological demand of the user. Exoskeletons should be more portable, fashionable, and svelte in the future. To develop such kind of system, the reliability, portability and inertia of robot, back-drivability of its actuators have to be improved. The actuation technology should be improved to develop small sized, more durable and higher performance actuators for these robots. Back drivability of the transmission is essential in robotic exoskeleton to eliminate possible uncomfortable to the user. More efficient back-drivable system should be required for the systems in the future. Since the brain-machine interface technology is developed in successful level, future robotic exoskeleton systems will be controlled based on the brain signals and/or combinations of EMG and brain signals so that user motion intention can be effectively reflected.

7. Acknowledgement

This research article is an extension of the research currently being done in the field of exoskeleton robots for the application in rehabilitation for the disabled and impaired people. Although several effective exoskeleton robots have been developed for the upper-limb motion assist, more effective exoskeletons and their controllers are still desired in order to realize natural and effective power-assist. Within this short and brief review, we have covered the brief history related to exoskeletons, concept behind implementation of exoskeletons, challenges while designing and application, and the scope of improvement.

8. References

1. Gopura RARC, Kiguchi K, Bandara DSV. A Brief Review on Upper Extremity Robotic Exoskeleton Systems. 6th International Conference on Industrial and Information Systems (ICIIS). 2011; 6. p. 346–51. https://doi.org/10.1109/iciinfs.2011.6038092
2. Chen SH et al. Assistive Control System for Upper Limb Rehabilitation Robot. In IEEE Transactions on Neural Systems and Rehabilitation Engineering. 2016; 24(11):1199–209. https://doi.org/10.1109/TNSRE.2016.2532478 PMid:26929055
3. Ugurlu B, Nishimura M, Hyodo K, Kawanishi M, Narikiyo T. Proof of Concept for Robot-Aided Upper Limb Rehabilitation Using Disturbance Observers. In IEEE Transactions on Human-Machine Systems. 2015; 45(1):110–8. https://doi.org/10.1109/THMS.2014.2362816
4. Yanco H. Integrating robotic research: a survey of robotic wheelchair development. AAAI Spring Symposium on Integrating Robotic Research, Stanford, California. 1998.
5. Pehlivan AU, Losey DP, O'Malley MK. Minimal Assist-as-Needed Controller for Upper Limb Robotic Rehabilitation. In IEEE Transactions on Robotics. 2016; 32(1):113–24. https://doi.org/10.1109/TRO.2015.2503726
6. Anama K, Al-Jumaily AA. Active Exoskeleton Control Systems: State of the Art. International Symposium on Robotics and Intelligent Sensors (IRIS), Procedia Engineering. 2012; 41:988–94. https://doi.org/10.1016/j.proeng.2012.07.273
7. Krebs HI, Palazzolo JJ, Dipietro L, Ferraro M, Krol J, Rannekleiv K, Volpe BT, Hogan N. Rehabilitation robotics: performance-based progressive robot-assisted therapy. Autonomous Robots. 2003; 15:7–20. https://doi.org/10.1023/A:1024494031121
8. Kumra S, Saxena R, Mehta S. Design and Development of 6-DOF Robotic Arm Controlled by Man Machine Interface. IEEE International Conference on Computational Intelligence and Computing Research. 2012. https://doi.org/10.1109/ICCIC.2012.6510243 PMCid:PMC3370928
9. Rosen J, Brand M, Fuchs MB, Arcan M. A Myosignal-Based Powered Exoskeleton System. IEEE Transaction On Systems, Man, And Cybernetics—Part A: Systems And Humans. 2001; 31(3):210–22. https://doi.org/10.1109/3468.925661
10. Tsagarakis N, Caldwell DG, Medrano-Cerna GA. A 7-DOF Pneumatic Muscle Actuator (pMA) Powered Exoskeleton. In Robot and Human Interaction. 1999; 327–33.
11. 11. Choi J, Kim J, Dongshin, Lee CW, Park JO, Park JH. Design and Characteristic Analysis of 7 DOF Hybrid Master Arm with Human Kinematics. Proceeding of the ASME Dynamic Systems and Control Division. 1998; 64:95–205. PMid:9735663 PMCid:PMC4531949
12. Choi JH, Song JH, Kim JT, Lee HW, Park JO, Park JH. Human Arm like Hybrid Master Arm for dexterous Teleoperation. Proceedings of the 13th Korean Automatic Control Conference, Korea. 1998; 10. p. 1807–10.
13. Kim J, Chang S, Kim I, Hwan Borm J, Lee JW, Park JO. Singularity Analysis and its Avoidance for KIST Hybrid Master Arm. Proceedings of 9th International Conference of Advanced Robotics, ASME. 67.
14. Jeong Y, Lee D, Kim K, Park JO. A Wearable Robotic Arm with High Force-Reflection Capability. Proceedings of the 9th IEEE International Workshop on Robot and Human Interactive Communication. 2000; 411–6.

15. Jeong Y, Lee Y, Kim K, Hong YS, Park JO. A 7-DOF Wearable Robotic Arm Using Pneumatic Actuators. Proceedings of the 32nd International Symposium on Robotics.
16. Gupta GS, Mukhopadhyay SC, Messom CH, Demidenko SN. Master–Slave Control of a Teleoperated Anthropomorphic Robotic Arm with Gripping Force Sensing. IEEE transactions on instrumentation and measurement. 2006; 55(6):2136–45. https://doi.org/10.1109/TIM.2006.884393
17. Sankai Y, Kaneko M, Nakamura Y. HAL: Hybrid Assistive Limb Based on Cybernics Robotics Research. Springer, Berlin / Heidelberg. 2011; 66:25–34.
18. Mahoney RM. The Raptor wheelchair robot system. Integration of Assistive Technology in the Information Age. 2001; 135–41.
19. Lo HS, Xie SQ. Exoskeleton robots for upper-limb rehabilitation: State of the art and future prospects. Medical Engineering and Physics. 34:261–8. https://doi.org/10.1016/j.medengphy.2011.10.004 PMid:22051085
20. Yang C-J, Zhang J-F, Chen Y, Dong Y-M, Zhang Y. A Review of exoskeleton-type systems and their key technologies. Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science. 2008; 222:1599–612. https://doi.org/10.1243/09544062JMES936
21. Li Z, Su CY, Wang L, Chen Z, Chai T. Nonlinear Disturbance Observer-Based Control Design for a Robotic Exoskeleton Incorporating Fuzzy Approximation. In IEEE Transactions on Industrial Electronics. 2015; 62(9):5763–75. https://doi.org/10.1109/TIE.2015.2447498
22. Pons JL. Wearable robots: bio Mechatronics exoskeletons. Wiley Online Library. 2008; 70. https://doi.org/10.1002/9780470987667
23. Cloud W. Man amplifiers: Machines that let you carry a ton. Popular Science. 1965; 187(5),187:70-73 & 204.
24. Zoss AB, Kazerooni H, Chu A. Biomechanical design of the Berkeley lower extremity exoskeleton (BLEEX). IEEE/ASME Transactions on Mechatronics. 2006; 11(2):128–38. https://doi.org/10.1109/TMECH.2006.871087
25. Kiguchi K, Esaki R, Fukuda T. Development of a wearable exoskeleton for daily forearm motion assist. Advanced Robotics. 2005; 19(7):751–71. https://doi.org/10.1163/1568553054455086
26. Li Z, Huang Z, He W, Su CY. Adaptive Impedance Control for an Upper Limb Robotic Exoskeleton Using Biological Signals. In IEEE Transactions on Industrial Electronics. 2017; 64(2):1664–74. https://doi.org/10.1109/TIE.2016.2538741
27. Sharma A, Noel MM. Design of a low-cost five-finger anthropomorphic robotic arm with nine degrees of freedom. Robotics and Computer-Integrated Manufacturing. 2012; 28:551–8. https://doi.org/10.1016/j.rcim.2012.01.001
28. Nakai A. Development of 7 DOF Exoskeleton Type Haptic Interface. Journal of Robotics Society of Japan. 1999; 17:1126–33. https://doi.org/10.7210/jrsj.17.1126
29. Mosher RS, S. O. A. Engineers. Handyman to Hardiman: Society of Automotive Engineers. 1967. https://doi.org/10.4271/670088
30. Schmeisser G, Seamone W. An upper limb prosthesis-orthosis power and control system with multi-level potential. The Journal of Bone and Joint Surgery (American). 1973; 55(7):1493–501. https://doi.org/10.2106/00004623-197355070-00017
31. Gopura RARC, Kiguchi K. Mechanical designs of active upper-limb exoskeleton robots: State-of-the-art and design difficulties. IEEE International Conference on Rehabilitation Robotics (ICORR). 2009. https://doi.org/10.1109/icorr.2009.5209630
32. Ren Y, Park HS, Zhang LQ. Developing a whole-arm exoskeleton robot with hand opening and closing mechanism for upper limb stroke rehabilitation. In: IEEE International Conference on Rehabilitation Robotics. 2009. p. 761–5. https://doi.org/10.1109/icorr.2009.5209482
33. Lotti F, Tiezzi P, Vassura G, Biagiotti L, Palli G, Mechiorri C. Development of UB hand 3: Early results. In: IEEE International Conference on Robotics and Automation, Spain. 2005. https://doi.org/10.1109/robot.2005.1570811
34. Jacobsen SC, Iversen EK, Knutti DF, Johnson RT, Biggers KB. Design of the Utah/MIT dexterous hand. In: Proceedings of the IEEE International Conference on Robotics and Automation, Spain. 2005.
35. Fukaya N, Toyama S, Asfour T, Dillmann R. Design of the TUAT/Karlsruhe humanoid hand. In: International Conference on Machine Automation. Japan. 2000. https://doi.org/10.1109/iros.2000.895225
36. Sergei GGF, Adamovich V, Mathai A, Qiu Q, Lewis J, Merians AS. Design of a complex virtual reality simulation to train finger motion for persons with hemiparesis: a proof of concept study. Journal of Neuro Engineering and Rehabilitation. 2009; 6–28.
37. Jack RBD, Merians AS, Tremaine M, Burdea GC, Adamovich SV, Recce M, Poizner H. Virtual reality enhanced stroke rehabilitation. IEEE Trans Neural System Rehabilitation Engineering. 2001; 9:308–31. https://doi.org/10.1109/7333.948460 PMid:11561668
38. Takahashi LDCD, Le V, Motiwala RR, Cramer SC. Robot-based hand motor therapy after stroke. Brain. 2008; 131:425–37. https://doi.org/10.1093/brain/awm311 PMid:18156154
39. Dovat OLL, Gassert R, Maeder T, Milner T, Leong TC, Burdet E. Hand CARE: a cable-actuated rehabilitation system to train hand function after stroke. IEEE Trans Neural System Rehabilitation Engineering. 2008; 16:582–91. https://doi.org/10.1109/TNSRE.2008.2010347 PMid:19144590
40. Hommel AW. Development and control of a hand exoskeleton for rehabilitation of hand injuries. IEEE/RSJ International Conference on Intelligent Robots and Systems. 2005.
41. Sarakoglou NGTI, Caldwell DG. Occupational and physical therapy using a hand exoskeleton based exerciser. IEEE/RSJ International Conference on Intelligent Robots and Systems. 2004.
42. DiCicco LLM, Matsuoka Y. Strategies for an EMG-controlled orthotic exoskeleton for the hand. IEEE International Conference on Robotics and Automation. 2004.
43. Kawasaki ISH, Ishigure Y, Nishimoto Y, Aoki T, Mouri H et al. Development of a hand motion assist robot for rehabilitation therapy by patient self-motion control. IEEE 10th Intl Conf Rehabilitation Robot. 2007; 10. p. 234–40. https://doi.org/10.1109/icorr.2007.4428432

44. Seo K-H, Choi T-Y, Oh C. Development of a robotic system for the bed-ridden. Mechatronics. 2011; 21:227–38. https://doi.org/10.1016/j.mechatronics.2010.10.011
45. Eftring H, Boschian K. Technical results from Manus user trials. Proceedings of the 1999 ICORR. 1999; 136–41.
46. Alqasemi R, Dubey R. A 9-DoF Wheelchair-Mounted Robotic Arm System: Design, Control, Brain-Computer Interfacing, and Testing. Advances in Robot Manipulators, Ernest Hall (Ed.) InTech. 2010.
47. Uehara H, Higa H, Soken T. A Mobile Robotic Arm for People with Severe Disabilities. Proceedings of the 2010 3rd IEEE International Conference on Biomedical Robotics and Biomechatronics. 2010; 3:126–9. https://doi.org/10.1109/BIOROB.2010.5626937
48. Song W-K, Lee H, Bien Z. KARES: Intelligent wheelchair-mounted robotic arm system using vision and force sensor. Robotics and Automation System. 1999; 28:83–94. https://doi.org/10.1016/S0921-8890(99)00031-7
49. Biihler C, Hoelper R, Hoyer H, Humann W. Autonomous robot technology for advanced wheelchair and robotic aids for people with disabilities. Robotics and Autonomous Systems. 1995; 14:213–22. https://doi.org/10.1016/0921-8890(95)00030-J
50. Torres-Jara E. Obrero: A platform for sensitive manipulation', IEEE-RAS International Conference on Humanoid Robots. 2005. p. 327–32. https://doi.org/10.1109/ichr.2005.1573588
51. Paik JK, Shin BH, Bang YB, Shim YB. Development of an Anthropomorphic Robotic Arm and Hand for Interactive Humanoids. Journal of Bionic Engineering. 2012; 9:133–42. https://doi.org/10.1016/S1672-6529(11)60107-8
52. Vukobratovic M, Hristic D, Stojiljkovic Z. Development of active anthropomorphic exoskeletons. Medical and Biological Engineering and Computing. 1974; 12(1):66–80. https://doi.org/10.1007/BF02629836
53. Gopura RARC, Kiguchi K. SUEFUL-7: A 7DOF upper-limb exoskeleton robot with muscle-model-oriented EMG-based control. In: IEEE/RSJ International Conference on Intelligent Robots and Systems. 2009. p. 1126–31. https://doi.org/10.1109/iros.2009.5353935
54. Kobayashi H, Shiiba T, Ishida Y. Realization of All 7 Motions for the Upper Limb by a Muscle Suit. Journal of Robotics and Mechatronics. 2004; 16(5):505–10. https://doi.org/10.1109/roman.2004.1374835
55. Chen Y, Zhang J, Yang C, Niu, B. The workspace mapping with deficient-DOF space for the PUMA 560 robot and its exoskeleton arm by using orthogonal experiment design method. Robotics and Computer-Integrated Manufacturing. 23:478–87. https://doi.org/10.1016/j.rcim.2006.05.007
56. Rahman MH, Saad M, Kenne JP, Archambault PS. Exoskeleton Robot for Rehabilitation of Elbow and Forearm Movements. 18th Mediterranean Conference on Control and Automation. 2010; 18:1567–72. https://doi.org/10.1109/MED.2010.5547826
57. Wu T-M, Wang S-Y, Chen D-Z. Design of an exoskeleton for strengthening the upper limb muscle for overextension injury prevention. Mechanism and Machine Theory. 2011; 46:1825–39. https://doi.org/10.1016/j.mechmachtheory.2011.08.003
58. Kang HB, Wang JH, Shenyang. Adaptive control of 5 DOF upper-limb exoskeleton robots with improved safety. ISA Transactions. 2013; 52:844–52. https://doi.org/10.1016/j.isatra.2013.05.003 PMid:23906739
59. Balasubramanian S, Wei HR, Perez M, Sheppard B, Koeneman E, Koeneman J. Rupert: an exoskeleton robot for assisting rehabilitation of arm functions. In International Conference of virtual rehabilitation. 2008. p. 163–7. https://doi.org/10.1109/icvr.2008.4625154
60. Dario P, Guglielmelli E, Genovese V, Toro M. Robot assistants: Applications and evolution. Robotics and Autonomous Systems. 1996; 18:225–34. https://doi.org/10.1016/0921-8890(96)00006-1
61. Kahn LE, Rymer WZ, Reinkensmeyer DJ. Adaptive assistance for guided force training in chronic stroke. In: Annual International Conference of the IEEE Engineering in Medicine and Biology Society. 2004. p. 2722–5. https://doi.org/10.1109/IEMBS.2004.1403780 PMid:17270839
62. Frisoli A, Borelli L, Montagner A, Marcheschi S, Procopio C, Salsedo F. Arm rehabilitation with a robotic exoskeleton in Virtual Reality. In 10th International Conference on Rehabilitation Robotics. 2007. p. 631–42.
63. Stienen AHA, Hekman EEG, Van Der Helm FCT, Van Der Kooij H. Self-aligning exoskeleton axes through decoupling of joint rotations and translations. IEEE Transactions on Robotics. 2009; 25:628–33. https://doi.org/10.1109/TRO.2009.2019147
64. Ito S, Kawasaki H, Ishigure Y, Natsume M, Mouri T, Nishimoto Y. A design of fine motion assist equipment for disabled hand in robotic rehabilitation system. Journal of the Franklin Institute. 2011; 348:79–89. https://doi.org/10.1016/j.jfranklin.2009.02.009
65. Gopura RARC, Kiguchi K. A Human Forearm and Wrist Motion Assist Exoskeleton Robot with EMG-Based Fuzzy-Neuro Control. Proceedings of the 2nd Biennial IEEE/RAS-EMBS International Conference on Biomedical Robotics and Biomechatronics. 2008; 2:550–5. https://doi.org/10.1109/biorob.2008.4762793
66. Kiguchi K, Liyanage M. A Study of a 4DOF Upper-Limb Power-Assist Intelligent Exoskeleton with Visual Information for Perception-Assist. IEEE International Conference on Robotics and Automation. 2008; 8:3666–71. https://doi.org/10.1109/robot.2008.4543773
67. Worsnopp TT, Peshkin MA, Colgate JE, Kamper DG. An Actuated Finger Exoskeleton for Hand Rehabilitation Following Stroke. Proceedings of the 2007 IEEE 10th International Conference on Rehabilitation Robotics. 2007; 10:896–901. https://doi.org/10.1109/ICORR.2007.4428530
68. Kiguchi K, Iwami K, Yasuda M, Watanabe K, Fukuda T. An Exoskeletal Robot for Human Shoulder Joint Motion Assist. IEEE/ASME Transactions On Mechatronics. 2003; 8(1):353–61. https://doi.org/10.1109/TMECH.2003.809168
69. Wang F, Shastri M, Jones CL, Gupta V, Osswald C, Kang X, Kamper DG, Sarkar N. Design and Control of an Actuated Thumb Exoskeleton for Hand Rehabilitation Following Stroke. IEEE International Conference on Robotics and Automation. 2011; 11:3688–93. https://doi.org/10.1109/icra.2011.5980099
70. Kiguchi K, Kado K, Hayashi Y. Design of a 7DOF Upper-Limb Power-Assist Exoskeleton Robot with Moving Shoulder Joint Mechanism. Proceedings of the 2011 IEEE International Conference on Robotics and Biomimetics. 2011; 11:2937–42. https://doi.org/10.1109/ROBIO.2011.6181752

71. Rahman MH, Saad M, Kenne JP, Archambault PS. Modeling and Control of a 7DOF Exoskeleton Robot for Arm Movements. Proceedings of the 2009 IEEE, International Conference on Robotics and Biomimetics. 2009; 9:245–50. https://doi.org/10.1109/ROBIO.2009.5420646
72. Jones CL, Wang F, Osswald C, Kang X, Sarkar N, Kamper DG. Control and Kinematic Performance Analysis of an Actuated Finger Exoskeleton for Hand Rehabilitation following Stroke. Proceedings of the 2010 3rd IEEE International Conference on Biomedical Robotics and Biomechatronics. 2010. p. 282–7. https://doi.org/10.1109/BIOROB.2010.5626057 PMCid:PMC2923230
73. Kiguchi K, Rahman MH, Sasaki M, Teramoto K. Development of a 3DOF mobile exoskeleton robot for human upper-limb motion assist. Robotics and Autonomous Systems. 2008; 56:678–91. https://doi.org/10.1016/j.robot.2007.11.007
74. Rahman T, Sample W, Jayakumar S, King MM, Wee JY, Seliktar R, Alexander M, Scavina M, Clark A. Passive exoskeletons for assisting limb movement. Journal of Rehabilitation Research and Development. 2006; 43(5):583–90. https://doi.org/10.1682/JRRD.2005.04.0070 PMid:17123200
75. Cempini M, Cortese M, Vitiello N. A Powered Finger-Thumb Wearable Hand Exoskeleton with Self-Aligning Joint Axes. In IEEE/ASME Transactions on Mechatronics. 2015; 20(2):705–16. https://doi.org/10.1109/TMECH.2014.2315528
76. Huang J, Huo W, Xu W, Mohammed S, Amirat Y. Control of Upper-Limb Power-Assist Exoskeleton Using a Human-Robot Interface Based on Motion Intention Recognition. In IEEE Transactions on Automation Science and Engineering. 2015; 12(4):1257–70. https://doi.org/10.1109/TASE.2015.2466634
77. Jung Y, Bae J. Kinematic Analysis of a 5-DOF Upper-Limb Exoskeleton With a Tilted and Vertically Translating Shoulder Joint. In IEEE/ASME Transactions on Mechatronics. 2015; 20(3):1428–39. https://doi.org/10.1109/TMECH.2014.2346767
78. Li Z, Su CY, Li G, Su H. Fuzzy Approximation-Based Adaptive Backstepping Control of an Exoskeleton for Human Upper Limbs. In IEEE Transactions on Fuzzy Systems. 2015; 23(3):555–66. https://doi.org/10.1109/TPWRS.2014.2331361 https://doi.org/10.1109/TFUZZ.2014.2317511
79. Li Z, Wang B, Sun F, Yang C, Xie Q, Zhang W. sEMG-Based Joint Force Control for an Upper-Limb Power-Assist Exoskeleton Robot. In IEEE Journal of Biomedical and Health Informatics. 2014; 18(3):1043–50. https://doi.org/10.1109/JBHI.2013.2286455 PMid:24235314
80. Madani T, Daachi B, Djouani K. Modular-Controller-Design-Based Fast Terminal Sliding Mode for Articulated Exoskeleton Systems. In IEEE Transactions on Control Systems Technology. 2017; 25(3):1133–40. https://doi.org/10.1109/TCST.2016.2579603
81. Otten A, Voort C, Stienen A, Aarts R, van Asseldonk E, van der Kooij Y. LIMPACT:A Hydraulically Powered Self-Aligning Upper Limb Exoskeleton. In IEEE/ASME Transactions on Mechatronics. 2015; 20(5):2285–98. https://doi.org/10.1109/TMECH.2014.2375272

Citation:

Divya Agarwal, Ajay K. S. Singholi and Pushpendra S. Bharti
"**Implementing Exoskeleton to Re-Enable the Disabled: A Review**",
Global Journal of Enterprise Information System. Volume-9, Issue-2, April-June, 2017. (http://informaticsjournals.com/index.php/gjeis)

Conflict of Interest:

Author of a Paper had no conflict neither financially nor academically.