Exoskeletons and Robotic Devices for Mobility Assistance and Therapy: A General Perspective

Abdullah Özer and Jungwon Yoon

Gyeongsang National University

School of Mechanical and Aerospace Engineering

Jinju, Gyeongnam 660-701, KOREA

Abstract

Over the past few decades, an enormous amount of research effort has been put into developing exoskeletons and robotic assistive devices. Primary aims generally being rehabilitation use, these devices have variety of other application areas including rescue, military and recreational activities. Although the supplementary technologies such as measurement and control have advanced vastly in recent times, there are still many challenges related to the exoskeleton and robotic assistive device development for the progress in their improved and widespread usage. The natural and versatile human body structure and its multifaceted movement convey a huge potential together with the challenges for the improvement of exoskeletons and robotic devices for mobility assistance and therapy and, demand for the usage of such devices progressively growing. The associated challenges and the solutions to the problems can be virtually inestimable considering also the variety of circumstances of patients in need. In this paper, we summarize and review a number of researches performed in the field to provide a broad perspective for the current and potential future work relevant to the area of robotic assistive devices for mobility and their therapeutic usage.

1. Introduction

Humans possess a complex physical structure and can perform difficult movement tasks. The structure of the human body consists of bones that are linked together by muscles in joints called articulations. There are two-hundred six bones in the human body and approximately seven hundred muscles that drive the various parts of the skeleton using the bones as levers to preserve a certain posture or to produce movement, [A. Tozeren 2000]. Bone is essentially the facilitator of movement and protector of the soft tissues of the body. The muscles are connected to the bones through cable-like structures called tendons. About 40% of the body weight is composed of muscles and often the various large muscles of the human body produce forces that are multiples of the total body weight. Many researchers around the world have focused on building robotic assistive devices for people with disabilities and to assist the elderly or for other purposes. The intrinsic mechanisms of the human body movement necessitate increasingly more attention from researchers in different fields and continuously require collaborative work between multidisciplinary areas.

The use of robotic assistive devices and exoskeletons to supply movement therapy for the rehabilitation of patients following variety of diseases and the usage in daily activities have grown significantly in recent decades. As a result of these assistive technologies, disabled people are more and more able to live an independent, quality life and play an enhanced productive role in the society. Yet, these assistive devices not only provide or assist for locomotive movement of the human body but also give improvement in physiological behaviors of patients during recovery and their regular usage. Butler in an earlier study [Butler, 1986], had reported that such assistive devices for the disabled children at their early childhood have shown a favorable improvement in their physiological behaviors, as well as locomotor behaviors. The use of such devices and the demand are progressively increasing these days. Nevertheless, there is much to do in the field to improve the functionalities and extensive usage of robotic and assistive devices.

At present, there are various types of assistive devices for people with manipulative and locomotive disabilities [Kumar et. al. 1997]. These devices generally built for walking, climbing stairs or carrying things around and currently there is a growing interest in using robotic assistive devices to help providing more comprehensive rehabilitation therapy following neurologic injuries or other effects. The robotics field together with the associated technologies, such as instrumentation, measurement and control, has considerably improved over the last few decades opening more ways for the improvement of such devices. As a result, the possibilities in implementation of assistive robots and devices are in fact various by considering the current potential technology and the inherent complexity of human body movement in addition to the diversity of the conditions of patients.

One very important area for the application of robotic and assistive devices is the gait rehabilitation. Gait disabilities or gait disorders are serious problems and affect millions of people around the world. The treatments can take long time and bear immense efforts along with very high treatment costs. A multitude of causes lead to gait disability including stroke, limb amputation, traumatic brain injury, spinal cord injury, cerebral palsy, and progressive neurological disorders, [Tierney et. al., 2007]. As a result of the variety of illnesses and causes, large numbers of gait disorder types exist and patient to patient treatments may differ considerably even within the same category of the disability. Gait rehabilitation phase of rehabilitation plays an important role particularly for people with Spinal Cord Injuries (SCI) or with neurological conditions (such as Parkinson disease, Huntington disease and stroke patients) throughout the complete recovery process. In order to help the patients to regain the quality of their life and perform daily tasks in their homes or communities, therapists make an immense effort to teach walking again for these type of patients. As a result, the robotic and assistive devices play a very crucial role yet again in gait rehabilitation process to ease the therapists' work and achieve more pleasing outcomes in the recovery practice. Many types of assistive and robotics devices are developed by researchers such as exoskeletons, treadmill devices and gait rehabilitation robots.

Assistive robotic devices can be classified into two main categories for the two main parts of the human body as upper extremities robotic devices (for arm and finger therapy or as an assistive device) and lower extremities robotic devices (for gait rehabilitation or as an assistive device). In both categories the primary aims of these devices are to either provide therapy or to provide assistance during daily activities. As a general rule, the functioning of these assistive robotic devices can be based on end effector control or posture control. The end effector based robotic assistive devices are usually easier to adjust to the patient and more comfortable as the patient does not feel the strain wearing a bulky piece of equipment. However, since the posture of the upper or lower extremity is not fully determined during the use of such devices, a risk of joint injury can be an important issue in an operation and safety measures must be fully ensured. In the case of posture control based assistive devices, for instance in the case of exoskeleton type robotic devices, joint axes are determined in advance or during the maneuver depending on the control strategy and the desired motion of the joints can be altogether achieved parallel to the natural human body movement. On the other hand, since the robot axis have to align with anatomical axes this time, the posture control task can be challenging at some joints (for instance at the shoulder). The lower extremity robotic assistive devices, in particular the therapeutic use devices, are generally bulkier and therefore may not be easily transportable. Hence, this class of devices on the whole can also be classified as indoor and outdoor activity assistive devices to provide walking assistance or therapy respectively, Fig. 1. In following sections, we will review some of the proposed models of such devices with a focus on gait rehabilitation and mobility assistance.

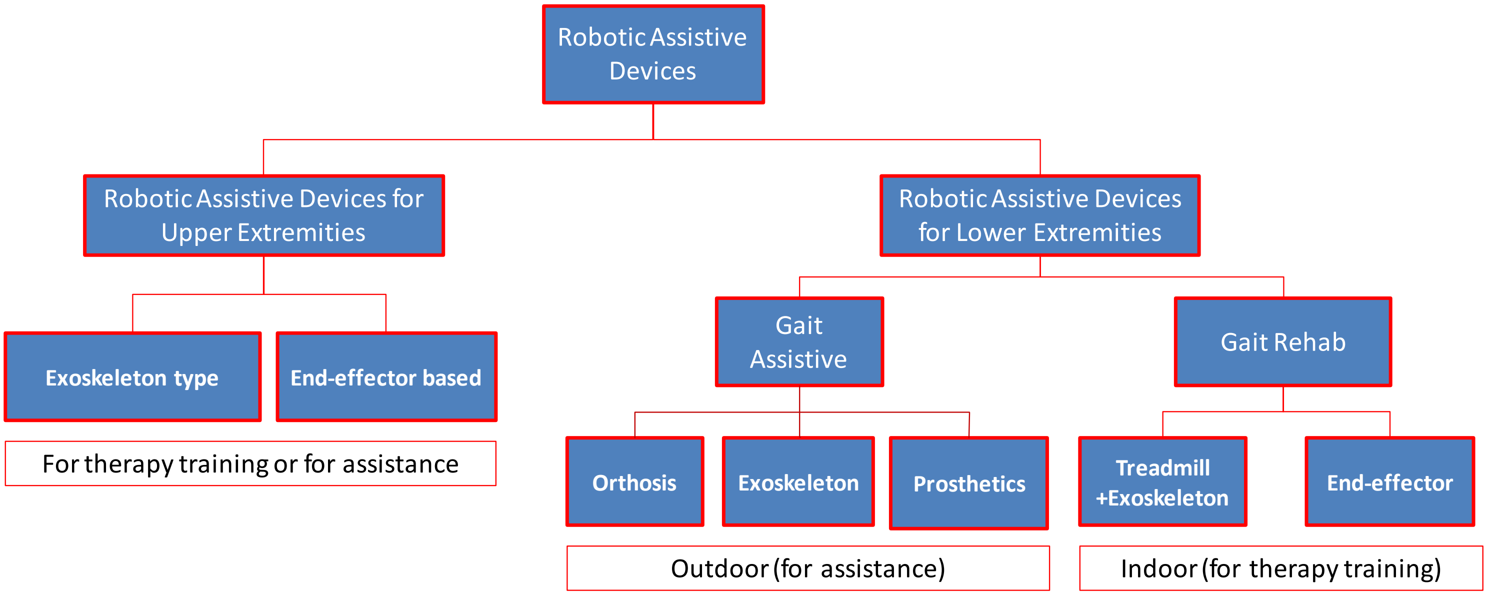

Fig. 1. Rehabilitation and mobility assistance robot classification

2. Exoskeleton type assistive/augmentation devices

Robotic therapy is a way of giving intensive, repetitive training of paretic limbs and exoskeleton type robotic devices increasingly being used in recent times in rehabilitation or as an assistive device. In this section we will summarize some of the exoskeleton devices developed or under development by a number of researchers. The researches centered on exoskeletons have either aimed to produce assistive devices for rehabilitation or to empower and aid the human limbs for other purposes, such as load-carrying augmentation.

Exoskeleton type assistive devices play an important role in gait rehabilitation as they can also be used in combination with treadmill devices or gait rehabilitation robots. The primary use of an exoskeleton is to enhance the physical abilities of the user. An exoskeleton can be defined as the hard outer structure of an insect or crustacean that provides support or protection in biological terms. Nowadays, the term can also correspond to a super suit, a system that can significantly augment a person's physical abilities as recognized in military research laboratories, popular fiction, and movies [E. Guizzo, 2005]. Exoskeleton-based assistive devices have several potential advantages as compared to wheeled vehicles, such as allowing the user to go over irregular terrain surfaces. Furthermore, particular occupational and military activities often require carrying heavy loads using a variety of backpack systems. When used for military purposes for example, the soldiers can carry heavier objects in their course of actions and wear heavier protective clothes without feeling the strain of extra weight and the walking speed can be increased as a result of these advantages. In addition, other physical capacity like jumping could be improved, all these benefits to help soldiers maneuver around their environment more quickly and easily. Exoskeletons can also be useful for rescue work by clearing heavier debris with no difficulty. Certainly, these technological suits would have more functions than just military or rescue purposes such as for improved movement for the elderly and rehabilitation purposes.

As mentioned earlier, fundamentally exoskeleton provides the foundation mechanisms to humans which make the complex movements possible. The beginning of the development of humanoid robotics also coincides with the beginning of the development of active exoskeletons

[M. Vukobratovic, 2008]. First active exoskeleton was developed in 1969 at Mihajlo Pupin Institute. Today, active exoskeletons are vigorously investigated and developed for enhancing human natural skeletal system (either for military purposes or rehabilitation & assistive reasons for the patients and elderly). Boosted by rapidly growing robotics technologies, the field is quickly emerging. It appears that there is still much more to realize in the field waiting for the prospective research efforts for the vast number of implementation possibilities of the extremely versatile human movement.

Many exoskeleton type assistive devices have been developed so far, we review only some of them here. One of the very earliest conceptual designs for augmenting exoskeletons goes back to XIX century, [Yagn,1890 Patent No: 420,178]. The idea of Yagn's apparatus design was related to facilitating walking, running, and jumping more effectively. He proposed, as the main idea of his design, to use bow leaf springs to utilize elastic energy storage capabilities of the springs during walking, running or jumping to lift or to assist in lifting the body into its normal position, Fig. 2 (a). The idea of energy storing and using the energy when it is needed is still popular in today's research applications. He possessed several other patents [Yagn, 1890; Patent No: 440,684; 438,839 and Patent No: 438,839] as well from the U.S. Patent office based on similar to the idea of this proposal, however, no implementation has been reported in the literature possibly due to practicality issues. Hardiman was one of the early attempts to build a practical powered exoskeleton worn by a human operator, by General Electric in 1965 with the funding from the US Department of Defense, Fig. 2 (b). The machine was intended to allow the wearer to lift loads of 1500 pounds (680kg) with ease in an approach similar to a master–slave system. The outer exoskeleton (the slave) followed the motions of the inner exoskeleton (the master), which followed the motions of the human operator. The practical uses were limited with its excessive weight of 341 kg and further researches concentrated on one arm only. The program outcome revealed that duplicating all human motions and using master–slave systems were not practical at that time. Difficulties in sensing and system complexity kept it from walking and no further work related to this Hardiman project was reported after early seventies [Final report on hardiman 1971, H. Kazerooni 2008, R. Bogue 2009].

A powered exoskeleton can also be defined as a portable device worn by a person for power augmentation or as an assistive piece of equipment. It principally consists of an exoskeleton-like structure and a controller with the power supply to provide or assist for the desired limb movement. Today, extensive application areas do exist for powered exoskeletons, prominently for medical applications or military and rescue type operations. As a matter of fact, the powered lower extremity devices or robots are very important as this part of body needs greater power to move and carry the whole body. Several research laboratories around the world have studied or currently investigating in powered exoskeletons research field concentrating particularly for the lower extremities.

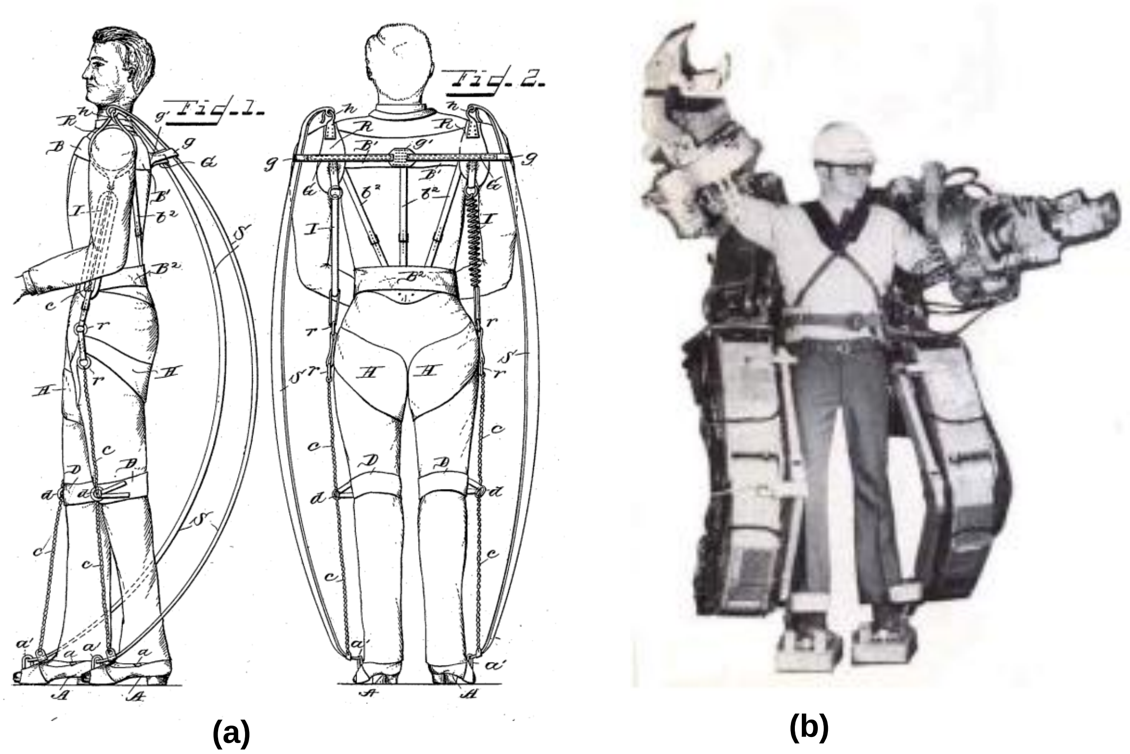

Figure 2. Earlier design and implementation examples assistive robotic devices and augmenting exoskeletons; (a): [Yagn,1890 Patent No: 420,178], (b): [Final report on hardiman 1971, H. Kazerooni 2008, R. Bogue 2009].

In a recent study, Yobotics, Inc. have developed a one degree of freedom exoskeleton device (called the RoboKnee and aimed for commercial production) to enhance the knee joint for the purpose of effortless stair climbing or squatting while carrying heavy loads [J. E. Pratt, 2004], Fig. 3 (a). It simply determines the desired knee torque based on the measured ground reaction forces. Low impedance was achieved through the use of series elastic actuators to avoid the impediment with the user's natural motion. A spring was intentionally placed between the motor and the load. A linear potentiometer used to measure the spring deflection which is proportional to the force on the load. This force is compared to the desired force and the error sent to a control system for positive-feedback force amplification. Due to several inevitable simplifying assumptions in calculating the required actuator force, the device reportedly has been used about 20% off its capacity. RoboWalker is aimed to be a commercially available product.

An assistive device predominantly aims to empower the human movement as an additional and wearable element of the body. As an another example for this aim, MIT's leg exoskeleton [Walsh et. al., 2007] as shown in Fig. 3 (b) has been designed to enhance the strength of healthy individuals and help people with disabilities in their walking. MIT's leg exoskeleton design comprised of passive and quasi-passive mechanisms to enhance mechanical energy storage and exchange so as to minimize the work required by the wearer to drive the exoskeleton. The exoskeleton did not have any actuators, instead an ankle and a hip springs along with a knee variable-damper therefore simpler to operate with less noise. The objective of the design of mechanical structures was to transfer much of the load directly to the ground rather than the wearer's legs. It used very limited power which is used to drive the variable damping mechanism, with a power consumption of about 2 W during walking. One drawback reported with this exoskeleton was the interference with the wearer's natural way of walking which in fact can be the reality for the other exoskeleton types to some extent.

Another exoskeleton system as a power assistive suit has been developed by the team at the University of Tsukuba, called HAL (Hybrid Assistive Leg) [Kawamoto et. al., 2002], Fig. 3 (c). The project aimed also the commercialization of the product for the wide spread usage. This exoskeleton suit provides the self-walking aid for gait disorder persons or aged persons and can be used both performance augmenting and rehabilitative purposes. DC motors with harmonic drive at the joints used to supplement joint torques necessary for flexion and extension at the hip, knee and ankle. The HAL system uses skin-surface electromyographic (EMG) electrodes attached under the hip and over the knee on both the front and the back sides of the wearer's body. Electromyographic (EMG) signals are used in the control system as input and produced the appropriate torques to perform the desired task. Potentiometers have been used for joint angle measurement. A gyroscope and accelerometer mounted on the backpack are used for torso posture estimation. The two control systems jointly decide user intent and operate the suit as desired. It is reported that an EMG-based system and a walking-pattern-based system takes two months to optimally calibrate the exoskeleton for a specific user.

In an another study, an active lower extremity exoskeleton which is capable of carrying a payload and being energetically autonomous has been developed at the University of California, Berkeley, (Berkeley Lower Extremity Exoskeleton: BLEEX), [H. Kazerooni, 2006], Fig. 3 (d). This model is reportedly the first exoskeleton which can carry its load and is actively autonomous. The exoskeleton consisted of seven degrees of freedom per leg; three degrees of freedom at the hip, one degree of freedom at the knee (pure rotation in the sagittal plane) and three degrees of freedom at the ankle. The basic principle for the control of BLEEX was based on a scheme such that the exoskeleton will shadow the wearer's voluntary and involuntary movements quickly and efficiently. In other words, the control algorithm performs its task with the aim that the exoskeleton moves in synchronized manner smoothly with the wearer with minimal interaction force between the two. High level of sensitivity was desired for the control system in response to all forces and torques on the exoskeleton, particularly, the forces imposed by the pilot to achieve the desired effectiveness. However, higher sensitivity reportedly made the exoskeleton prone to the effects of the disturbances and the pilot's ability to move quickly was crucial for the desired movement. BLEEX has established speeds up to 1.3 m/s and weight support up to 70 kg (exoskeleton weight plus payload), and successfully shadowed the operator through most maneuvers without any human sensing or preprogrammed motions.

Figure 3. An overview of example assistive robotic devices and exoskeletons, (a) : RoboKnee developed by Yobotics, Inc, (b) : MIT's leg exoskeleton, (c) : HAL-(Hybrid Assistive Leg) , (d) : BLEEX prototype.

A number of other exoskeletons have been also proposed and investigated by several research groups. In a recent article, Gordona et. al. [K.E Gordona et al., 2007] used a robotic exoskeleton to investigate human locomotor adaptation. A lower limb robotic exoskeleton was proportionally activated by the user's electromyography (EMG) thus enabling control by the wearer's muscle activity. They demonstrated that the exoskeleton effectively increased ankle torque produced by muscle activation. Subjects demonstrated a longer adaptation period in response to the imposed neuromuscular discoordination than has been demonstrated for environmental perturbations. However, their studies showed that subjects were able to learn to use the additional exoskeleton power effectively with practice during walking. In an another recent research, Durfee et. al. have aimed to deal with loss of mobility as a result of limb paralysis. Loss of mobility due to lower limb paralysis is a common result of thoracic level spinal cord injury, [W. K. Durfee et al., 2005]. With this research they have proposed a concept that utilizes a fluid power system to capture excess energy during the gait cycle by means of gas springs. Pneumatic cylinders at the hip and knee have been used to convert mechanical power to fluid power. The stored energy was subsequently transferred using pneumatic fluid power system between hip and knee pneumatic cylinders during the gait cycle. Storing energy with gas springs and, storing and transferring energy with a pneumatic fluid power system was shown to work in the dynamic system model and the physical prototype. The energy storage orthosis (ESO) was driven through a complete gait cycle using only stimulation of the quadriceps muscles. No studies were conducted with human subjects at this research. Also recently, Iida et al. [Iida et al, 2009] have proposed compliant leg human-like biped robot which include mechanical springs. The idea of the proposed model was to obtain a dynamic behavior which can be significantly comparable to that of a human. This research showed that the biarticular spring arrangement in the leg structure generates specific force patterns similar to the human-like joint kinematics of periodic gait with a minimalistic motor control.

Although the inherent difficulties of the complex human body movement and ascociated challenges of exoskeleton construction, today the accumulated knowledge and the experiences can be considered to come a good level in the field. As a matter of fact, many of the presently developed exoskeletons and assistive type robotic devices in general experience a number of technical and functionality difficulties such as necessitating bulky power supplies, higher sensitivities in their control procedures, heaviness of the main structure, the interference with the wearer's natural way of walking plus the sensing difficulties as in the case of skin-surface electromyographic (EMG) electrodes. It is likely that the research directions in the future will focus more on the development of light - weight exoskeletons and active orthotic devices, [Dollar et. al., 2008]. As a result, the supporting technologies such as motor technology, control, power supplies, transmissions, sensors and so forth will have crucial role in the development of more functional exoskeletons and active robotic assistive devices. In addition, better understanding of the complex human movement and its associated activities in muscles and interconnected body structures will also play an important role in the development of better mechanically designed and controlled light weight exoskeletons and robotic assistive devices which operates in synchronization with the natural human body movement. Certainly, the safety of the wearer must be assured and it will also be necessary to perform additional research alongside the core research for the design of the exoskeletons and assistive devices.

There are several more completed or at feasibility stage researches focused on exoskeleton systems in the literature, however, we only reviewed several of them here to provide general point of view. We anticipate that the prospective new ideas and implementation methods will help facilitating the exoskeleton systems increasingly in therapeutic or other applications in the near future. In the following section, another common device, treadmill and gait rehabilitation robots, will be briefly presented.

3. Treadmill and Gait rehabilitation Robots

Treadmill is a device consisting of a continuous moving belt on which a person can walk while remaining in one place. This device is also commonly used in rehabilitation purposes during gait training for the rehabilitation and improvement of patients’ mobility. The main motivation of gait training is to help a patient recovering from injury, illness or disease, to make progress some locomotor abilities in order to promote as much independence as possible in activities of daily living (ADL) tasks, and to assist the patient in compensating for deficits that cannot be treated medically [Yoon et. al., 2010]. In treadmill training method, the patient walks on a treadmill while wearing the robotic device or getting physiotherapist help depending on the condition and type of the gait disorder, Fig. 4. The major limitation of a manual therapy treadmill as a daily routine is the required involvement of one or in some cases two or three therapists in assisting the gait of severely affected subjects by setting the paretic limb and controlling trunk movements [Werner et al, 2002]. This difficulty has held back the widespread use of treadmill training in the past. A number of groups have already developed gait rehabilitation robots to overcome this drawback. These robots are capable of helping the therapists by assuming the task of ensuring repetitive motion while simultaneously helping the patient attain a more precise natural gait.

In conjunction with body weight support (BWS) and wearable robot devices, the technique can greatly contribute to the patients' progress and help the therapist to spend more time with less effort as a result of working more resourcefully. Treadmill training with partial body weight support (BWS) enables wheelchair-bound subjects to repetitively practice complete their gait cycles. The robotic devices such as wearable exoskeletons can again be helpful during the rehabilitation process as they may provide and assist the patient in generating the appropriate walking gait trajectories. It has been reported that treadmill training with partial body weight support can restore the gait ability of patients such as chronic non-ambulatory hemiparetic subjects. A combination of physiotherapy and treadmill training can further speed up the rate of recovery [C. Wernera,2002, Hesse et al., 1994; Visintin et al., 1998].

Figure 4. During treadmill training, if a patient needed assistance, a therapist stood behind the patient, straddling the treadmill belt (*http://www.rehabpub.com/features/42005/2.asp*).

There are two main approaches to gait rehabilitation in which the body weight is reduced and assistive devices used: treadmill training, Fig. 4 and 6 and, training with a programmable end-effector (gait rehabilitation robot), [Yoon et. al., 2010], Fig. 5. In treadmill training, the patient walks on a treadmill while wearing the robotic device or getting the therapist help. The robot helps the patient generate the appropriate walking gait trajectory. This technique was used by the Driven Gait Orthosis (DGO) group [Colombo et al, 2001]. The technique as an automated locomotor training holds also several advantages. Improvements noted in this study in regard to

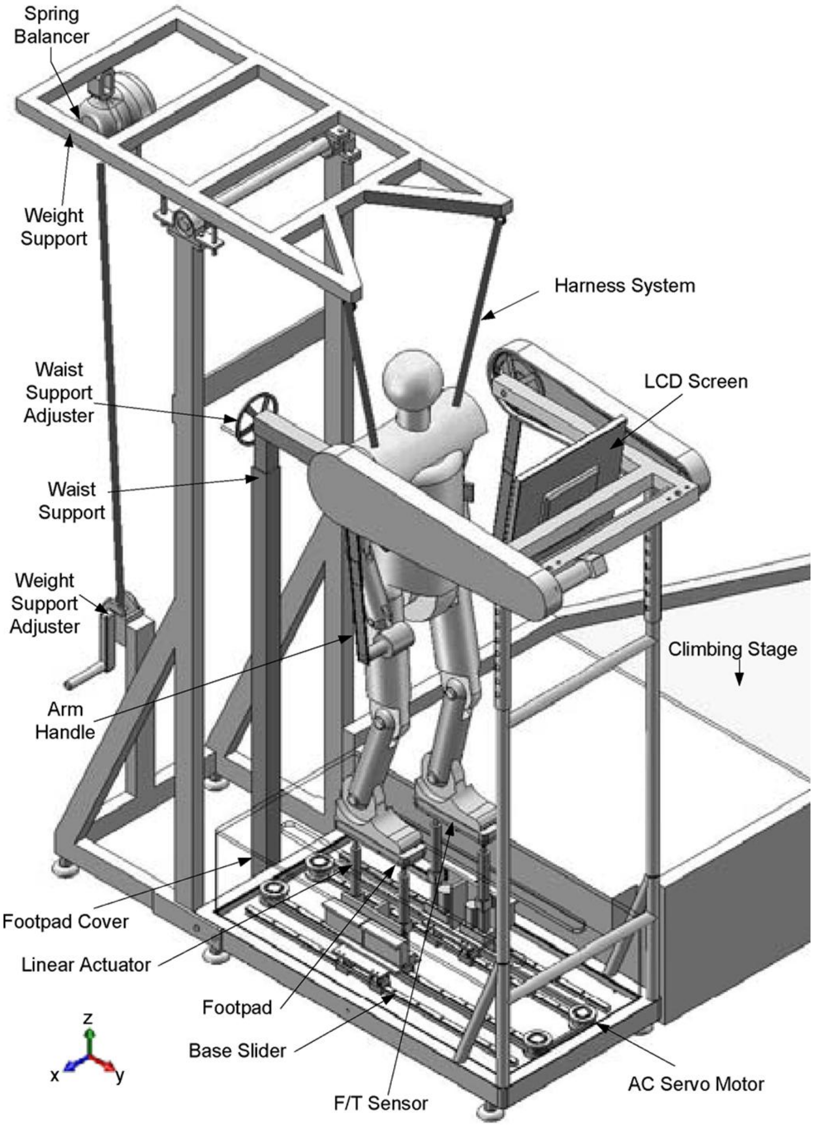

Figure 5. Overview of the gait rehabilitation robot, [Yoon et al, 2010].

gait quality and gait velocity. With this method it is possible to test and optimize the biomechanical gait pattern (speed, step length, amplitude) in order to get an optimal effect and, walking speed can be increased. This optimized gait pattern can easily be reproduced by the DGO, whereas therapists usually have to practice for longer time to become expert in performing an optimal training. An additional benefit is that the training sessions can be extended with the use of proposed method.

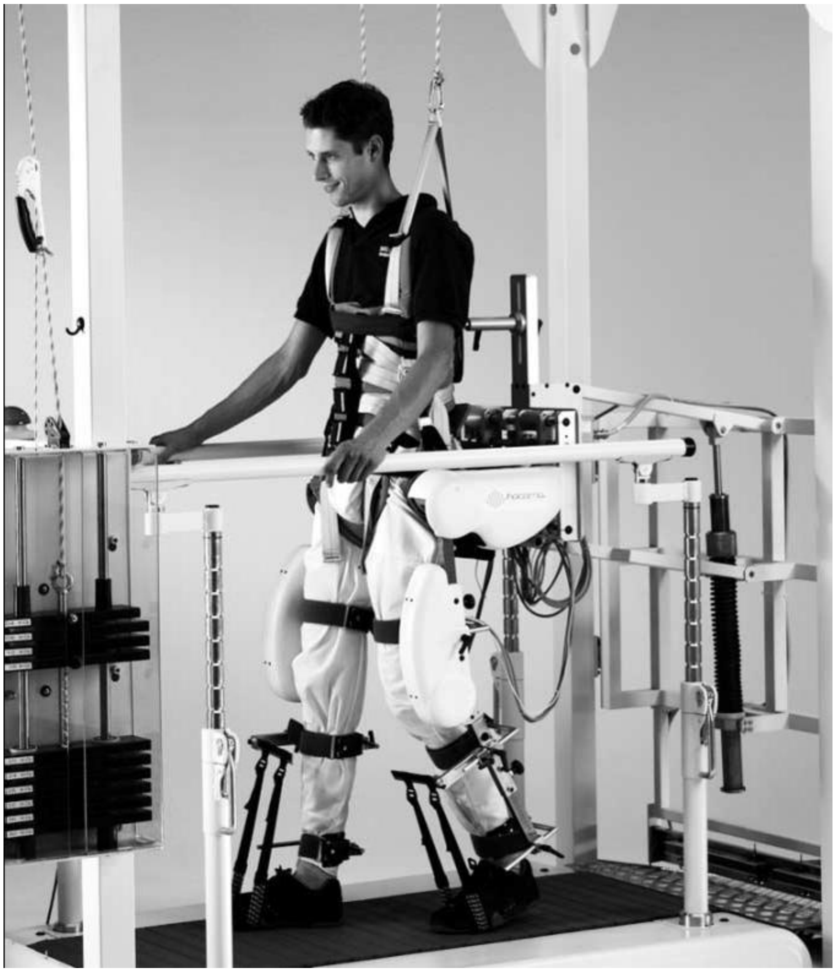

Figure 6. Illustration of a healthy subject suspended over the treadmill and walking with the use of the robotic orthosis Lokomat, [Jezernik et al, 2004].

An alternative training technique is used by the Mechanized Gait Trainer (MGT) group [Hesse et. al., 2000]. The intention of this research was again to build an advanced automated gait trainer which would enable severely affected wheelchair-bound patients to practice gait-like movements repetitively with no difficulty and without overstressing the therapists. In this technique, the foot is permanently attached to an end- effector that generates a human-like walking pattern. The main design objective were the partial

Figure 7. Robotic walking simulator: HapticWalker, [Schmidt et. al., 2005].

or complete support of gait movements by the machine, according to patients' abilities and control of the center of mass (CoM-control) in vertical and horizontal directions. During this training technique, the body weight is also partially reduced again through body weight support system. Clinical results had shown that the walking and standing ability of patients have improved significantly and the patients reported their added enjoyment during the use of assistive gait trainer as compared to treadmill training with several therapists. Driven Gait Orthosis (DGO) group from the DGO group in a recent article have developed the Lokomat [Jezernik et al, 2004], and performed newly developed algorithms for automatic adaptation of motion for a robotic rehabilitation device, Fig. 6. The algorithms aimed to adapt the gait pattern of patients with the gait trajectory during walk on a treadmill in real-time. The adaptation scheme was based on the interaction between the human leg and the orthosis. In this study, they tested several adaptation algorithms such as inverse dynamics and online minimization of the human–machine interaction torque, direct dynamics and estimation of the desired variation in the gait-pattern acceleration and impedance control with direct adaptation of the gait pattern angular trajectories. The proposed algorithms led to more than 40% reduction of interaction torques, the impedance-control-based algorithm being the best in the experiments. In an another study, Schmidt et. al. have presented a novel generic haptic walking interface which is based on the principle of programmable footplates with permanent foot machine contact, [Schmidt et. al., 2005], Fig. 7. The programmable foot device was capable of simulating level walking, stairs and stumbling. It comprised a specially developed robot kinematics, and is equipped with highly dynamic drives in order to be able to perform natural walking movements.

It is recognized that arm swing during human locomotion also helps stabilizing body motion thus will have an important affect for better results in the gait training, [Behrman et. al., 2000]. Recently Yoon et. al. have developed a six degree of freedom gait rehabilitation robot with upper and lower limb connections that allows patients to update their walking velocity on various terrain types and to navigate in virtual environments. The robot was composed of an upper-limb device, a sliding device, two footpad devices, and a body support system. The footpad device on the sliding device provided the three degree of freedom spatial motions for each foot on the sagittal plane to facilitate various terrain types. An upper-limb device has been also used to assist swinging the arms naturally with the help of a simple pendulum link. Harmonious and intentional gait patterns for a variety of choices were possible by a patient through the use of this robot as a result of estimating the interaction torques between the human and the upper-limb device, and synchronizing the lower-limb device with the upper-limb device. In addition, the patient was able to navigate in virtual environments by generating velocity update and turning commands using the control buttons located in the handles of the upper-limb device. A pilot clinical test with a hemiplegic patient has shown that a stable and safe therapy was possible with the proposed rehabilitation robot, Figs. 5 and 8.

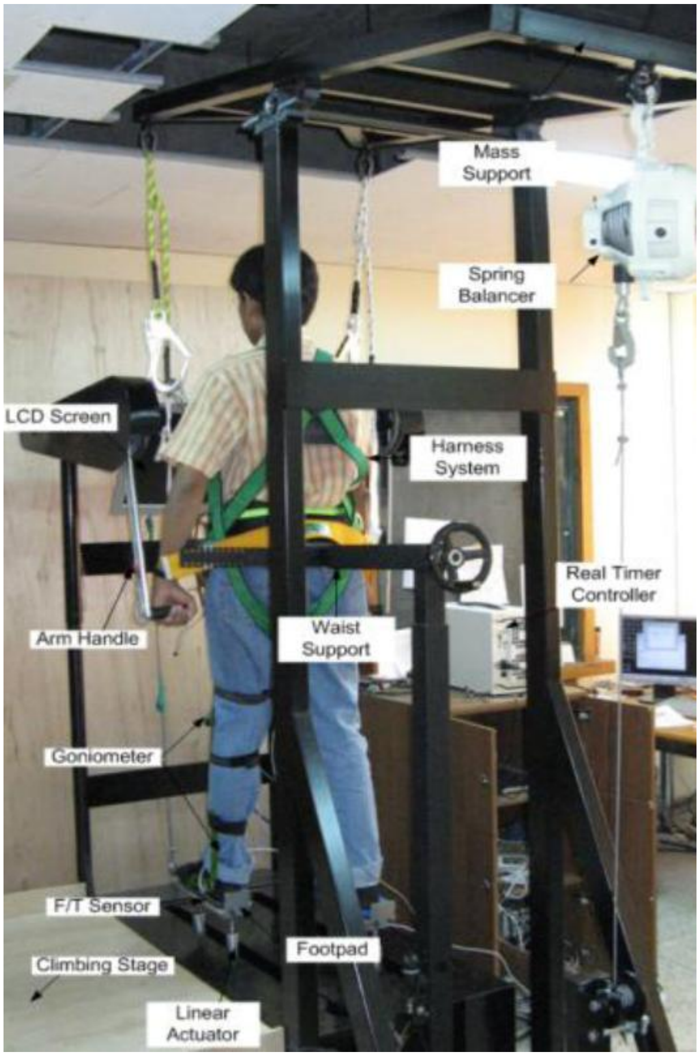

Figure 8. Photograph of the gait rehabilitation robot during an experiment with a healthy subject, [Yoon et al, 2010].

Several robotics devices are now also commercially available. These include the AutoAmbulator (HealthSouth Cooperation) and LokoHelp [Freivogel et. al., 2008] that are sufficiently compact to allow gait training at home. Another robotics orthosis [Veneman et. al., 2007] based on treadmill training has also been developed. Unlike Lokomat, this orthosis allows the sideways and forward/backward motion.

4. Virtual reality use in gait rehabilitation

In general, it is acknowledged that the regaining of locomotor skills is correlated with the intensity, the variety of goal-directed tasks and the environmentally appropriate practice provided. Patient empowerment and motivational, goal-directed practice are also important factors, [Fung et. al., 2006]. The gait rehabilitation with the traditional approach is generally labor intensive and may require long intervals for the rehabilitation sessions. In addition, the traditional approach may not correspond absolutely to the actual and uncertain environments outside the training platform. Therefore, virtual reality (VR) technology can be a valuable addition to the gait rehabilitation sessions to provide more effective and affordable practices in patients' home environments enabling them to experiment in a wide range of simulated circumstances.

VR-Gait system is created by a multidisciplinary team in a wide range of expertise fields such as computer science, engineering, modeling & simulation and physical therapy, [Tierney et. al., 2007]. With a VR-Gait system, VR software generates and displays a dynamic urban environment on a large high definition monitor mounted in front of a treadmill. The VR program includes an interactive graphical user interface (GUI) that allows the physical therapist to configure the virtual environment and record information about each training session. The combination of virtual reality (VR) and rehabilitation has several advantages, [Yoon et. al., 2010]. One important advantage is that VR can be used to simulate a variety of circumstances that are similar to the real environment, including slope, stairs and obstacles. Another advantage is that the virtual environment (VE) will motivate the patient to train and not feel confined in the physical environment as in traditional gait training, which is usually tiring and tedious. Therefore, if a gait rehabilitation robot can generate various terrain types to realize real walking environments and allow walking navigation in VEs through real walking, the rehabilitation performances can be enhanced. Successful implementation of rehabilitation with VR has been reported for stroke patients [Holden et. al., 1999], in gait rehabilitation [Tierney et. al., 2007]-[Jaffe et. al., 2004], and recently Lokomat with healthy subjects [Wellner et. al., 2007]. To the best of our knowledge, however, no one has ever implemented walking navigation according to user’s intention in VE for gait rehabilitation, an aspect that requires a walking user to execute a walking velocity change and a turn. Even though in locomotion interface applications, several devices have been suggested for straight walking and turning capability for realistic planar walking navigation, these machines will make the mechanical system complex and not easy to guarantee the safety of patients for gait rehabilitation, [Boian, 2005], [Yoon et. al., 2006],[Yoon et. al., 2003], [Iwata, 1999]. Thus, it is necessary to allow a patient to navigate on various terrain types through real walking and to generate a turning command without complex mechanical systems for rehabilitation purposes. VR technology appears to offer a means of practice that is motivational and empowering to the subject and not limited only to the robotic rehabilitation applications and can be used with the other rehabilitation applications. It optimizes goal oriented practice to promote improved learning skills, [Fung et. al., 2006].

5. Conclusion

In this review paper, we have summarized some of the existing robotic assistive devices and exoskeleton technologies for people with manipulative and locomotive disabilities and also for human body movement augmentation. The robotic assistive devices in recent decades have developed vastly parallel with the highly developing relevant technologies and the demand for the usage is progressively growing by the medical people at clinics and by the users in their home environments. However, there is still much to develop in the area and the challenging research outlook invites the potential researchers into this field. The positive outcome of the incoming research studies will certainly be crucial to help disabled people in order them to perform their regular daily activities at their home and in our societies. With this work, the challenges, technical problems and potential future expectations and directions have been highlighted through recent and past research project examples in the literature.

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