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Developments in Lower Limb Exoskeletons For Rehabilitation Application

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Abstract: As per the Census 2011, In India, 2.68 Crore people are disabled out of 121 crore population. Of these, 20 % of the people are suffering with disability in movement. Exoskeletons are for Augmenting, Assisting and Rehabilitating the needy people. Exoskeletons are mainly classified into Human augmentation, Assistive and Rehabilitation. Rehabilitation exoskeletons are used in Therapeutic training to bring the affected people into their normal life. In stroke patients and SCI affected people, normal walking becomes difficult. For these people, Gait training is given to restore. This could be with either fixed Setup on a Treadmill, preferably in Hospitals and Therapy centers or Mobile devices for personal use. Many devices are developed around the Globe for walking practice. Also, for Hip-knee-ankle- foot movement. Modular designs with Assist-when-needed technology make these models effective. Recently developed models are taken for review. Commercial models available in the market are also presented with their features.

Index Terms: Exoskeleton, Lower Limb, Rehabilitation, Electromyogram.

I. INTRODUCTION

As per the Census 2011**,** in India, 2.68 crore people are disabled out of 121 crore population. Of these, 20 % of the people are suffering with disability in movement. Most of the people are in the age group of 20-39, 40-59 and >60. In these groups, near to 25 % are with movement difficulty[1]. These people are to be brought into normal life with Rehabilitation and Assistive Technologies. With Exoskeletons, this dream comes to reality by reducing dependence and making them to live independently without further health disorders. If Lower limb movement is affected, then movement disorders result. Thus lower Limb Exoskeletons give the solution for different disabilities.

In this review, the features of Exoskeletons developed for Rehabilitation are discussed. New devices appear from different parts of the globe. This review could give us an overview of these developments in a brief way.The robotic exoskeletons could be divided into three broad categories based on their application. First one is "human performance augmentation exoskeletons" for expanding physical abilities of Healthy people. These could be utilized for lifting substantial articles, conveying overwhelming burdens over long separations, or working with Tools like Heavy drilling Machine at a height. These are utilized in stockrooms, building destinations, crisis alleviation tasks, or army installations

The second one is "Assistive devices for individuals with disabilities". Disorders like Neural Stroke, spinal cord injury, muscle weakness, and Post operative Patients would face difficulty in walking or moving the arm. As per the Survey in 2011, India has a population of with difficulty in movement. These devices could bring people into normal life. A person affected with lower limb paralysis could walk on his own by wearing this device.

The third one is "Rehabilitation exoskeletons for restoration". These gadgets can help, oppose, or irritate the client's movements to accomplish remedial exercise. They can prepare a person's muscles as well as sensory system to enable them to beat the limitations of an inability, when they are not utilizing the exo skeleton. ease of use[2].

Assessing the progress becomes very difficult due to the fast developments in technology and the availability of scientific publications in the field. For devices that are focused on solely assisting able bodied individuals with locomotion, metabolic cost is clearly the most accepted standard. As designs, hardware, and control systems improve, the hope is that more robotic exoskeletons will actually provide an energetic benefit to the userfor walking and running. Fatigue, productivity, and safety are the parameters to evaluate Assistive exoskeletons. Also, EMG analysis is used to monitor the variations and estimate the progress in the patient. Wheelchair bound patients face other complications due to movement less position. Exoskeletons for rehabilitation are aimed to be used in clinical environments.

II. EXOSKELETON MODELS - WORKING

In post stroke condition, normal gait deficits observed in lower-limb-affected people include a combination of weakened muscle strength, coordination and excessive muscle tone in the paretic limb. Due to these, knee function is instable in flexion or hyperextension, and foot clearance would be less on the paretic side during the swing phase of gait[3].

Post-stroke gait training primarily focuses on improving load acceptance on the paretic leg during stance. This results in larger stride length. During swing, Foot clearance would be increased due to increase in hip and knee flexion of the affected leg.Training for stroke patients corresponds to only one leg. Thus, the healthy leg motion is monitored, and path is analyzed. The same is applied in the process of training the effected leg. But, for SCI patients, both sides would be paralyzed. Thus the training involves both the legs [4].

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The Devices developed for GAIT training could be classified in two ways. In case of acute disorders, the first phase of training is given by fixed Lower Limb models. These include a Treadmill or a similar structure. Assisted treadmill training is available either manually or robotically. In this therapy, a portion of the patient's body weight is suspended above a treadmill through an overhead suspension point. In manual mode, one or more therapists change the patient's pelvis and limbs as needed. In Robotic version, manipulation of the legs is by robotic control. Thus having consistent interaction with the patient.

LOKOMATFig. 1(a) from HOCOMA is the first generation Device designed for Rehabilitation, based on treadmill.It consists of a support system for the body and lower limb attachments. Hip and knee joints are actuated by motor drives. Force sensors are placed to measure the torques at joints. Measured signals are used for monitoring the effect of training. It was added with an adaptive controller to provide the required torque based on the user initiative. Further models include Graphical user interface for the use of physiotherapist during training. This device was proved as an Automatic gait trainer [4].

While the Treadmill is used to train post stroke patients with walking at higher speeds, a Balance training system, Kine - AssistFig. 1(b). was designed [5]. The patient is pushed to walk at further speed. When the person tends to fall due to slip, tumble, the pelvis height is monitored. When it crosses a threshold, a harness system will catch hold of the person and forward movement will be stopped by halting the belt mechanism. Thus the patient is stopped from fall and even from its feel. They could feel safe. This gives the confidence of walking at higher speeds and to check the maximum limit.

Another treadmill based RheoAmbulatorFig.2(a). was developed by Motorika, USA. It works with Virtual Reality and closed loop feedback. As per the needs of the patient, a Specific program could be applied by a selected or modified version. During the Training, various parameters are monitored and given as feedback. Base on these the real time audio will be presented. The Visuals reflect the changes observed. With this continuous monitoring and feedback, the person would understand the effects and the Training is more effective. Thus the training cycles are reduced[6].

Fig.2(a).RHEO AMBULATOR Fig.2(b). LOW COST

A lowcost Rehabilitation exoskeleton at an estimated price of 25,000 EUROsFig.2(b) was developed in Federal University of Minas Gerais, Brazil and ETH Zurich, Switzerland [7]. In Children with Neurological disorders, the walking ability could be restored with this model. The developed model is intended for Robotic assisted gait training for CP patients as well in Clinical practice.This model could be attached to a Tread-mill and be synchronized with its operation. The hip–knee–ankle–foot attachment is connected to the patient. The ankle driving system is driven by 0.33kw motors, PLCs and PID control. To cater for range of people, Body weight support system is included.To control the ankle’s movement, the guidance unitconsists of a cam system, a chain to pull, a motor, a sprocket for chain movement, and sensors to indicate the start and stop points in the gait phases.

HOISTFig.3(a)exoskeleton was developed for the use in rehabilitation of walking after injuries or neural disorders. A multi-step process is needed to restore the walking. The device is built on a stable chassis with four free wheels and another two motor driven wheels. Abattery, Control circuits and two 100 W geared motors are on the unit. A support rods are interfaced with a ball joint and adjustable coaxial springs. This balancing mechanism would limit the user movement due to the limited degree of freedom, they have. The user would be prevented from a fall. HOIST is to observe the patient and adapt the control to maintain the neutral position. For this purpose, user position is determined with tilt sensors and pelvis rotation is taken as intention to take a turn. This becomes the fail safe approach as the user is stopped from falling[8].

Fig.3(a). HOIST

Fig.3(b).SAU - DER

A lower limb exo-skeleton, SAU-DER Fig.3(b). was developed to assist the paralysed individuals in regaining the ability of walking with an independent, functional and reciprocating gait [9]. Also the standing up function could be performed, all with the help of two crutches. The device is designed with special materials to reduce weight and improve comfort. It has total 10 DOF for two legs, of which the hip and knee joints with one DOF each as active and ankle joint with 3 DOF as passive. The total weight is optimised to 21 kgs including Batteries. It is attached to the user with 14 belts including two waist, four thigh, four calf and four feet belts. For the recovery of walking in the persons affected with lower extremity hemi paresis after stroke, an exoskeletonFig4(a) was developed at Vanderbuilt University[10]. This employs an assistive controller that works with active and passive controls. It fully depends on the user initiation and further to assist when required in a step.


Fig4(a).Vanderbuilt Fig.4(b). ALTER G

This assistive control resulted in fast recovery as the patient is involved in movement co-ordination. Thus, the patient is involved in every step. At Vanderbuilt University, these developments continue to produce models for multiple applications

Alter G Bionic legFig.4(b) was a proven Lower Limb Exoskeleton. It is of a single joint control and an unilateral device. As a self contained device, it could be directly mounted on the effected knee with both the parts on either side. This is mainly intended for stroke patients with single leg affected. With its powered joint, it strengthens the knee. But, its large size and weight are termed as limitations [11].

For augmentation of human performance as well as for rehabilitation of musculoskeletal system, a lower limb exo-skeleton KIT-EXO-1was developed [12]. Series elastic actuators are used as driving devices instead of motors. It is a 3 DOF design. Interaction forcebetween the exoskeleton and the human body itself is usedfor controlling the actuators. Based on this force and spring deflection, progressive helical springs change the stiffness and work along with Series Actuators.

IndegoFig.5(a). is a modular exoskeleton with five modules. a hip segment, an upperand lower leg segments for both right and left legs. These could be easily assembled and removed, also could be stored. The Battery pack is placed in the hip attachment. Hip and knee joints are driven by brush less DC motors placed in the thigh attachment. Knee joints are fitted with locked brakes. In case of power failure, this locking would save from the instability of the knee. This exoskeleton weighs around 12 Kg, including battery. It could be seen as self contained as no back pack is required[13].

A prototype of simple, light weight and low cost lower limb exoskeleton NODP – HMI Fig.5(b).for children is developed at Ibn To-fail University, Morocco[14]. This is intended for paraplegic children in poor countries. With an Atmega based design, it consists of Brushless motors and Gear boxes with bewel gears. Potentiometers are used for angle measurement, Ultrasonic sensors are used to measure user intention and Force sensors are used to find the foot movement. It was developed in 100 $ range.

Exoskeletons available in the market for rehabilitation are summarized in the following Tables 1 and 2 [15].

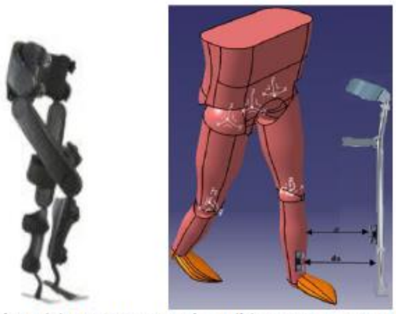
Fig.5(a). INDEGOFig.5(b).NODP-HMI

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Table I. FIXED REHABILITATION LLEs

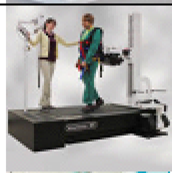
NAME	MAKE	ORIGIN	FEATURES	
Balance Tutor	MEDITOUCH	Israel	To train people in recovering their balance.	
G – EO System	REHA	Swiss	retraining correct walking along with stair climbing	
neAssistMX	HDT GLOBAL	USA	the robotic arm of the KineAssist MX is used "to catch them only after they have failed to stop their fall. Its working includes allowing the user to make mistakes, try to correct them and be allowed to fail and fall a short distance."	
Lokomat	HOCOMA			
NX – A3	GUANGZHOU	CHAINA	Works with a powered hip-knee exoskeleton on a treadmill	
ReoAmbulator	MOTORIKA	USA	"used as a test station to numerically assess the mobility capabilities of the user before and after training begins"	
RoboGait	BAMA	Turkey	"provides a safe, controlled environment for gait rehabilitation over a treadmill. The speed of the treadmill is synchronized with the exoskeleton and the rehabilitation program"	
Walkbot	P & S MECHANICS	South Korea	"This features powered hip-knee-ankle design. The Walkbot can be used as an evaluation device and the Walkbot_G has an integrated pressure plate to monitor each step in real time. The device is fully integrated with virtual reality for interactive training."	

Table. II Mobile Exoskeletons

ARKE	BIONIC LABS	USA	"empower paraplegics and other wheelchair-bound individuals to walk and rehabilitate. designed to utilize machine learning and analytics to improve neurological rehabilitation"	
ATALANTE	WANDERCRAFT	FRANCE	"envisioned to be a completely autonomous lower body exoskeleton that simulates natural movement and requires no additional balancing aids"	

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ATLAS 2030	MARIS-BIONICS	Spain	"a powered hip-knee-ankle orthotic device with the additional capability to self-balance. For 3-14 years pediatric clinical trials"	
Axosuit	AXOSUITS	Romania	"Startup in development designed for gait rehabilitation and walking assist"	
Bionic Leg	ALTERG	USA	"is a knee only powered exoskeleton with a thin foot plate that detects the load distribution on the sole of the leg"	
Ekso GT	EKSO BIONICS	USA	"a powered hip-knee medical rehabilitation exoskeleton developed"	
ExoAtlet	EXOATLET	Russia	"is a hip-knee powered medical rehabilitation and personal use exoskeleton. It is designed for individuals with spinal cord injury and similar conditions that result in mobility impairment. It has also been tested as a military augmentation suit in the past"	
H-MEX	HUNDAI	South Korea	"This lower body powered exoskeleton comes in two variations, H-MEX for users with lower spinal cord injury and HUMA (Hyundai Universal Medical Assist) for walking assistance for those with limited muscular power"	
HAL Lower Limb	CYBERDYNE	JAPAN	"It is a powered hip-knee wearable robot with a bio-electrical signal control scheme. The HAL® exoskeleton comes in two versions: HAL Medical and HAL Living Support. $96,000"	
HANK	GOGOA	Spain	"features a hip-knee-ankle actuation scheme. It is designed primarily for gait rehabilitation but there is also a version for personal use called Robotic Neuro-Rehabilitation and Robotic Neuro-Mobility respectively"	

Indego	INDEGO	USA	"The Indego® can be used for therapy as a gait training tool. The Indego Personal can also be employed as a supplementary mobility aid to a wheelchair. In addition to being able to see people eye-to-eye, research using this and other assistive medical exoskeletons has shown a strong correlation between standing up and a multitude of secondary benefits. These positive effects include but are not limited to improved bowel control, increased bone density and reduction in pressure sores"	
Phoeni x	SUITX	USA	"powered hip exoskeleton designed to assist people with mobility impairments. The PhoeniX sports a lightweight design, further simplified by having actuation only at the hips. This brings the cost and weight down. The exoskeleton knee component locks in place while standing or bearing weight and unlocks during the leg swing phase.The exoskeleton is also compatible with traditional orthotic devices. You can use your own orthotic and just add actuation at the hips. As a tradeoff, the PhoeniX is not capable of providing full assistance while climbing stairs."	
ReWal k	REWAL K	ISRAEL	"Approved by the FDA for clinical and home use for individuals with spinal cord injury"	
REX	REX BIONIC S	NEWZE ALAND	"There are two types of the REX exoskeleton: REX for Clinical Use and REX P for Personal Use"	
ROKI	ROKI ROBOTI CS	MEXIC O	"This is a modular, powered lower body rehabilitation hip-knee exoskeleton. It is designed by a start-up company in Mexico in association with a multitude of local academic and business groups. In 2016, the Roki exoskeleton could only be rented within Mexico."	

III. CONCLUSION

This review gives the brief details of Rehabilitation exoskeletons developed around the globe. Cost of the Exoskeleton is the limitation for the people in many countries. Custom built devices for a specific application and range would always cost less in comparison to the ones with multiple applications and wide range. Configuring the device becomes simple and it could be optimised in every aspect. As these exoskeletons bring the people back into their normal life at a faster pace at a minimum cost and effort, these should be considered as essential rather than additional by Government Agencies. Utilisation should increase with increase in commercial models and vice-versa. As many exoskeletons are developed in Universities with Industrial participation, Governments should take initiative to encourage and see that the exoskeletons should be made available for the local needy people.

In terms of Technology, fixed and mobile exoskeletons differ. Mobile devices should be compact, modular, Weightless and user friendly. Also, Assist – when – needed technology is found to be beneficial. With composite materials, Strength could be retained at lesser weight and price. APP based usage adds more benefits, such as remote monitoring and control. Fixed devices are for Hospital / Therapy centres, where as the mobile devices could be for personal use. The development of these exoskeletons require Mechanical frames, Electrical/ Mechanical actuators, Electronic sensors with controlling hardware and controlling Software even to monitor. More funds are to be pumped into this field to see that needy people use exoskeletons for Rehabilitation in the near future. Along with Developed countries, this should come to reality, even in developing countries.

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