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Review Article

Lower Limb Rehabilitation Exoskeleton Robots, A review

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Abstract
Using a lower limb exoskeleton for rehabilitation (LLE) Lower limb exoskeleton rehabilitation robots (LER) are designed to assist patients with daily duties and help them regain their ability to walk. Even though a substantial portion of them is capable of doing both, they have not yet succeeded in conducting agile and intelligent joint movement between humans and machines, which is their ultimate goal. The typical LLE products, rapid prototyping, and cutting-edge techniques are covered in this review. Restoring a patient's athletic prowess to its pr-accident level is the aim of rehabilitation treatment. The core of research on lower limb exoskeleton rehabilitation robots is the understanding of human gait. The performance of common prototypes might be used to match wearable robot shapes to human limbs. To imitate a normal stride, robot-assisted treatment needs to be able to control the movement of the robot at each joint and move the patient's limb.

Keywords
Gait Training Device, Rehabilitation Robot, Mechanical Design, Lower Limb Exoskeleton.

I. Introduction

There are approximately 40 million elderly people who have walking difficulties as a result of ageing, as well as approximately 15 million handicapped people who have lower limb motor dysfunctions such as cerebral palsy, hemiplegia, and paraplegia. 350,000 individuals urgently need specialized assistance for rehabilitation, but there are now only 20,000 workers available. By using rehabilitation robots, therapists can have some of their work taken care of for them, and quantitative recovery evaluation can be made easier and more consistent [1]. The development of exoskeletons with sufficient mechanical and control flexibility to perform a range of ADL (Activities of Daily Living) tasks, such as walking, climbing stairs, sitting, and standing up, is the aim of assistive robotics. In addition to physically supporting ADLs, these goals also include helping patients with motion direction or repetitive training, as well as facilitating labour-intensiveness by lightening the operator's load. Robotic therapy has the potential to significantly enhance patient outcomes while lowering therapy costs for the healthcare system [2]. Robot-assisted rehabilitation can significantly change the game for people with physical and cognitive disabilities thanks to developments in robot actuation and exoskeleton design. Less than half of stroke victims regain their independence after six months. Physical therapy, which also includes rehabilitation, aids in regaining lost abilities. Hemiparesis, or partial paralysis of one side of the body, is one of the most frequent complications of neurological impairment after a stroke [3]. Both in the US and in Europe, this is the main factor causing long-term impairment [4].

Robotic exoskeletons can be employed to move bulky items, transport loads over long distances and operate powerful machinery. Those in good physical condition can improve their physical strength, endurance, and other qualities with the aid of a human performance exoskeleton. You can find these devices most frequently in warehouses, hospitals, military bases, and outposts. It may be challenging for some people to walk and move their arms if they have neurological or musculoskeletal disorders like a stroke, spinal cord damage,

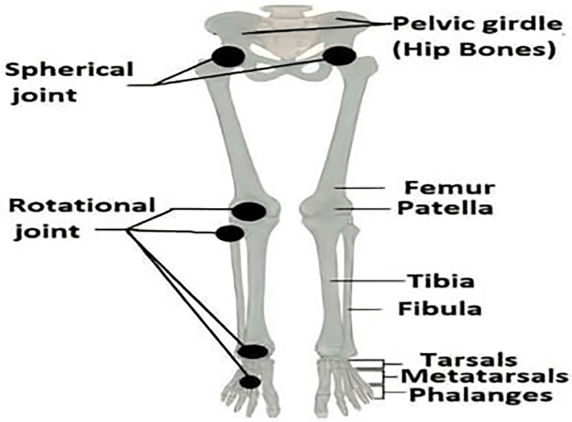

Fig. 1. Bones in the lower limbs with kinematic chains [2].

muscle weakness, or other conditions. Exoskeletons that are used for recovery and therapy make up the third major category. Exoskeletons with several uses can help, hinder, or restrict the user's movements. In the future, in addition to refining physical skills while worn, they might be helpful for rehabilitation. When not utilizing the exoskeleton, a person can develop their muscles and nervous system to help them overcome their impairment [5].

II. Lower Limb Anatomy

Because the lower limbs generate the majority of the power when walking, it is imperative to take their structure and movement patterns into account. The coordination of the pelvis, hip, knee, and ankle allows for walking [1]. To develop and construct a robot-based gait exoskeleton, it is imperative to investigate and comprehend the biomechanics of the lower limb. Lower limb biomechanics has received adequate research and writing in the literature. The hip, knee, and ankle are the three primary parts of the lower limb in general. Flexion, extension, abduction, adduction, and both internal and exterior rotation are the five possible hip movements. The joint has three degrees of freedom and is spherical (DoFs). The ankle joint has three degrees of freedom (DoF), compared to the knee joint's single DoF. The lower limb is made up of about 30 bones. The three primary ones are a person's femur, patella, and tibia [5], (shown in Fig. 1).
The knee movement is characterized by a rotational joint with 1 DOF that allows for flexion and extension, while the hip movement is described by a spherical joint with 3 DOF. Adapted in 2013 from OpenStax. phalanges, tarsal bones, metatarsal bones, and tibia as shown in Fig. 1 [2].

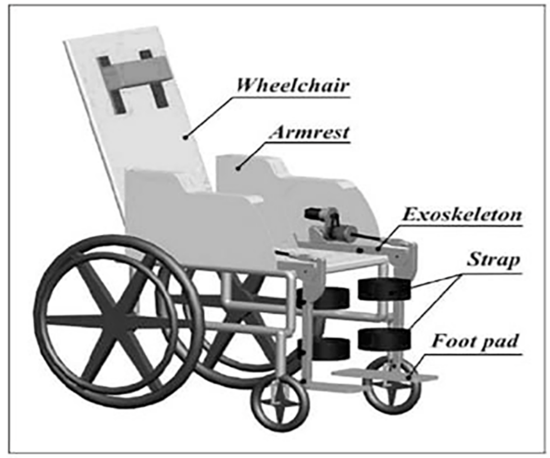

Fig. 2. Basic components of the exoskeleton robot [3].

III. Supporting Lower Limb Exoskeletons

This taxonomy considers the fact that robotic assistance is frequently beneficial to the rehabilitation process and that therapeutic and assistive exoskeletons have a great deal in common in terms of mechanics, actuation, and control [6]. Therapeutic rehabilitation exoskeletons are used at rehabilitation therapy facilities, and assistive exoskeletons are used to help with daily activities (ADL). In 1969, Mihajlo Pupin Institute scientists created the first assistive LLE when they created a pneumatically powered exoskeleton for people who had trouble walking. A therapeutic LLE was created in 1976 to enable physical therapists to teledirect patients using a master exoskeleton [6]. Recently, the general public might receive robotic therapy thanks to readily available commercial technology.
For instance, Corresponding Author Yang, State Key Laboratory of Fluid Power Transmission and Control, presents the design and validation of a lower limb exoskeleton robot for post-stroke patients in the early stages of neurorehabilitation. Instead of walking as you normally would, recumbent cycling is a popular type of exercise.
The hip, knee, and ankle are the three anatomical joints that control mobility in the lower limbs. During recumbent cycling, the ankle joint's range of motion (ROM) is constrained, and the hip and knee joints are principally in charge of the circular motion of the limb end. The lower limb exoskeleton robot depicted in Fig. 2 has four active DOFs in the sagittal plane of two legs that, respectively, represent mechanical hip flexion and extension and knee flexion and extension [7].
In order to reduce foot drop and give the ankle joints in post-stroke patients a small but acceptable range of motion (ROM), a pair of foot pads are passively fastened to the ends

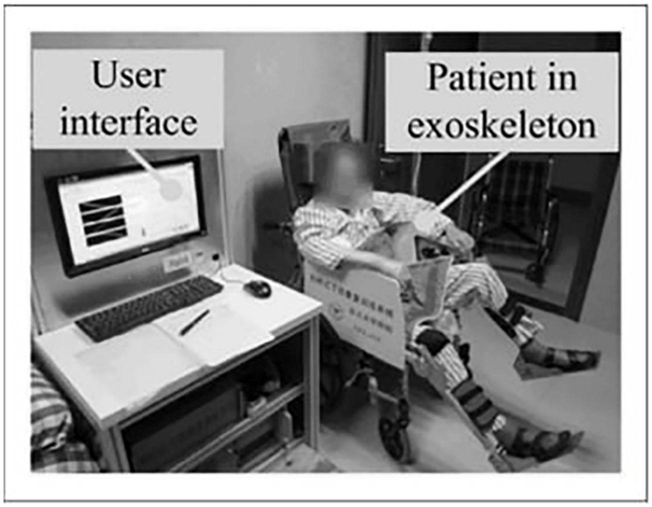

Fig. 3. The Exoskeleton for the lower limbs is worn by the patient throughout training [3].

of shank links (shown in Fig. 3). During mobility therapy, the wheelchair's backrest is adjusted to the patient's preferred position to support the patient's upper body weight. For the comfort and stabilization of the human body, armrests are put over the right and left thigh links, respectively [7].
Execution Not all subjects participate in online trials because of convenience and security concerns. To operate the robot for lower extremity exoskeleton rehabilitation, they are both participating in an online session. As shown in Fig. 4. The individual stood on a treadmill while wearing a lower limb exoskeleton robot and in front of a screen that displayed the prompt screen. As soon as the start cue showed on the screen, the subjects began employing motor imagery, and once the robot's purpose was found online, it moved as intended [8].
Di et al. [9] proposed a novel design for a lower limb rehabilitation robot. This model can spin in vertical planes since it has four degrees of freedom. It is interesting and the perfect size and weight for people to utilize outside. Lower limb rehabilitation robots can simulate typical human leg motions and instruct patients in treatment to hasten their recovery from sickness. By simulating the motion of a typical human walking stance, the lower limb rehabilitation robot can give patients essential rehabilitation training to speed up their recovery from disease. Its foundation is a dynamic model of a biped robot, and its goal is to examine the impact of an aid intended to lessen the burdens. This is shown in Fig. 5, The wearable gadget equally decreased compression in the thigh and leg. 4. A servo motor is attached to the left hip, left knee, right hip, and right knee. The hypothesis that a wearable device might be used to provide physical aid while lowering the risk of spinal damage is supported by this large decrease. The device was modelled in this first two-dimensional study utilizing just a weight and pressure. The following part goes a step further by examining potential design principles that could influence the creation of a hardware prototype [9].
Veneman et al. [10] exhibited an exoskeleton robot with impedance control that follows a specified joint trajectory for gait therapy. The lower-limb robot proposed by Dogan et al. [11] would move similarly to a physiotherapist by employing a human-robot interface. Wu et al. [12] created a powered exoskeleton to aid participants in doing practical tasks like walking with a certain gait. In order to determine the combined trajectory of the MINDWALKER, Wang et al. [13] observed a healthy individual moving in zero-torque mode during the swing phase. However, in these publications with predetermined paths, the patient's goal isn't considered, and the path can't be changed based on what the patient wants.
Fig. 6 shows the lower limb exoskeleton system with two levels of sagittal plane flexibility (DoF). The hip joint (joint 1) is controlled by one DoF, whereas the knee joint is controlled

Fig. 4. The subject was carrying out online experiments. The screen is directly ahead of him [4].

Fig. 5. System kinematics are represented schematically [5].

by another DoF. (Joint 2). It can be reduced to a two-link robot model for easier kinematics investigation. It was done using the modified Denavit-Hartenberg (MDH) approach [14].

The observer outputs the estimated external torque¿ 0 when the force is parallel to the human-robot system's motion direction, as illustrated in Fig. 7, indicating that the patient wants to go on a greater amplitude rehabilitation trajectory (a). The patient signals their wish to switch to a lower-amplitude rehabilitation pathway when they provide an opposite-direction contact force to a human-robot system other than the arm, as illustrated in Fig. 7(b), and the observer outputs the estimated external torque at that moment.

To automate, enhance, and reduce the effort needed by the therapist throughout this training process, many robotic devices have been developed [9]. These systems frequently feature a treadmill and robots that resemble exoskeletons [15]. The Lok Mat (Hocoma AG) is constructed from a treadmill, an advanced body weight support system, and a robotic gait

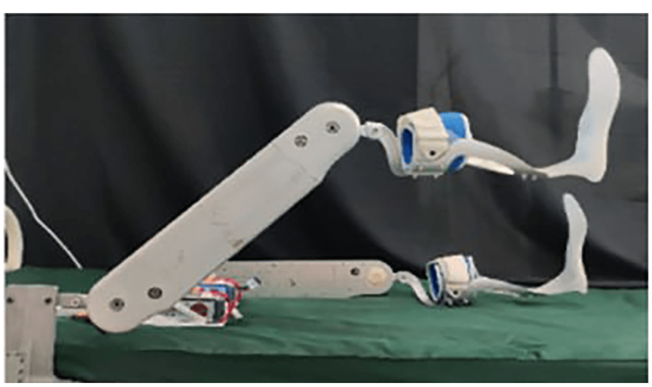

Fig. 6. The prototype of the lower limb exoskeleton [6].

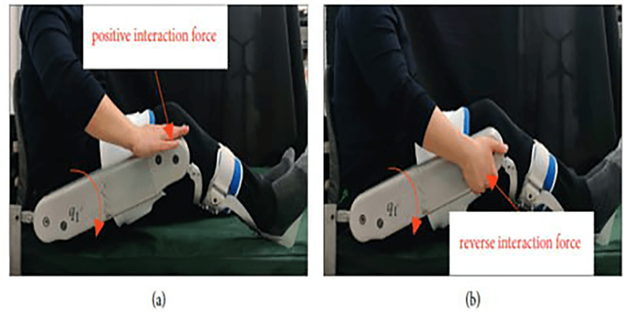

Fig. 7. Force of external interaction. (a) Positivity as a driving force. (b) The force of reversal interaction [6].

orthosis [16]. It utilizes computer-controlled motors (drives) built within the gait orthosis at each hip and knee joint (Fig. 8). To achieve a perfect connection between the speed of the gait orthosis and the treadmill, the drives are precisely matched with that pace. It remains one of the pioneering systems of its kind and has completed most clinical trials [17].

The LokoHelp (LokoHelp Group) gadget is made to assist gait following brain damage [18]. The LokoHelp (Fig. 9) is positioned in the center of the treadmill's surface, parallel to the walking direction, and fastened to the front of the device using a straightforward clamp. It also provides a means for the sufferer to support their weight. Clinical research has been done to evaluate its feasibility and effectiveness [18].

The ReWalk from ARGO Medical Technologies Ltd. is a wearable, motorized, virtually robotic suit that can be used for therapeutic purposes. ReWalk is made up of a battery pack that can be recharged, several sensors, a computer-based control system, and a thin brace support suit with DC motors

Fig. 8. Lokomat system (picture courtesy of Hocoma) [7].

Fig. 9. Loko Help gait trainer “Pedago” (picture courtesy of Loko Help Group) [7].

Fig. 10. Wearable ReWalk system (image courtesy of ARGO Medical Systems Ltd.) [19].

at the joints. Walking activities can start and continue thanks to the user’s upper-body movements being detected. Clinical trials for the gadget are now being conducted at Moss Rehabilitation Hospital in Philadelphia. A wearable robot called the Hybrid Adaptive Limb (HAL) was created for many purposes, including task assistance and rehabilitation. There are two versions of it (two-leg and complete body) [19], (shown in Fig. 10).

Researchers have created a new automated intelligent gait planning technique that is based on the gait century model and a finite-state machine (FSM) model, in addition to the exoskeleton system. The underlying FSM model is defined using the minimal jerk approach and the inverted pendulum model. Exoskeleton robots from the Shenzhen Institute of Two other participants, one paraplegic and one nonparaplegic, wore technological advancement (SIAT) to evaluate the effects of the suggested gait and provide surface electromyogram (sEMG) data for analysis. 33 volunteers took regular walks so that their gaits could be compared to the desired gait [20]. A gait planning approach based on the inverted pendulum model to address the COG transition problem, an online trajectory calculation, and an augmentation of the planned gait to satisfy electromechanical restrictions makes up the four components of the proposed technique. The key locations and associated problems are identified using the gait planning model. The joint criteria are used in the trajectory calculation to connect the important sites to continuous gait trajectories. The intended trajectories are subject to mechanical and electrical restrictions as a result of the optimization [20].

The exoskeleton robot from Shenzhen Institutes of Advanced Technology, Chinese Academy of Science [21], shown in Fig. 10, is utilized in this investigation. Each leg’s ankle, knee, and hip joints each have three degrees of freedom (DoFs) in the SIAT exoskeleton shown in Fig. 11, which is utilized in this investigation. Each leg’s ankle, knee, and hip joints each have three degrees of freedom (DoFs) in the SIAT exoskeleton. Every joint allows for flexion and extension (F/E) motions. A Swiss Re 50 MAXON DC motor and a rocker mechanism power the dynamic hip and knee joints. When the exoskeleton makes contact with the ground, the passive, compliant springs in the ankle joints disperse the shock and strain. The SIAT’s exoskeleton weighs about 27 kg.

Fig. 11. The SIAT exoskeleton [21].

The blue points are where the Delsys wearable sensors are positioned. These sensors gather the sEMG signal from the arms and send it over the wireless channel to the Delsys Trigno system. The computer's USB port is used to connect the Delsys Trigno wireless device. After pattern classification and gait planning on a computer, the CAN bus is used to drive the exoskeleton robotics. The Chinese Academy of Science's SIAT created the exoskeleton robot [7].

The development of a novel robotic device for post-stroke lower limb rehabilitation in bed-confined patients is discussed by researchers Calin Vaida and colleagues. Fig. 12 illustrates a step-by-step method for creating a cutting-edge, effective robotic system for lower limb rehabilitation. The first step in this process is to determine the movements that need to be done when the patient is in a bed. receiving rehabilitation treatment. Then, the precise motion amplitudes of the pertinent anatomical joints are established [22] [23]. The targeted hip, knee, and ankle joints' motion amplitudes in healthy volunteers were examined (keeping in mind that to choose the task (operation workspace) for the therapeutic activities, the exercises begin with lower amplitude and frequency and increase to values that characterize the condition.

RAISE is a straightforward robotic bed device that can be attached to almost any bed. A dual robot arrangement is feasible because of the symmetry of the right and left leg solutions (Fig. 13). The employment of an external device with sensor systems for both native muscle movement and joint relative intensities as well as systemic variables makes it possible to adopt any human-robot communication technique, including mirrored schemes. Because each stage of rehabilitation [22] has a distinct HRI with medical relevance, the robot can be used for each one. Anthropometric information about the patient can be taken into consideration with RAISE's customizable link lengths without degrading performance.

Gao et al. [24] devised and implemented a master-slave con-

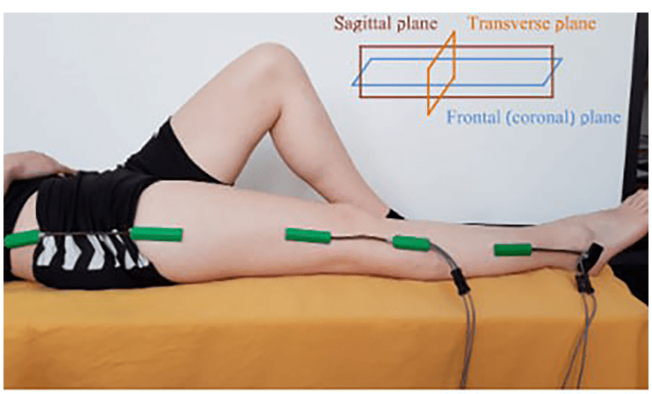

Fig. 12. In which the goniometers are placed on the lower limb [8].

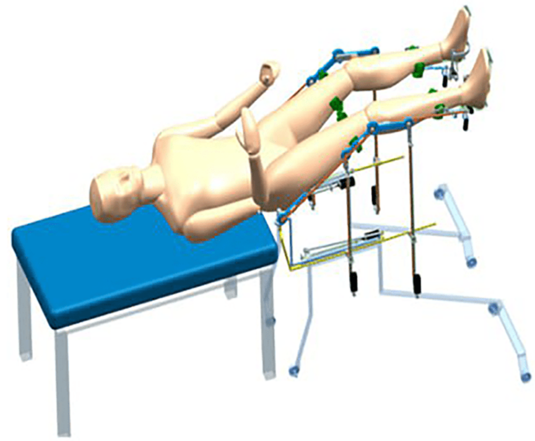

Fig. 13. Mirrored CAD rendering of the RAISE system mounted on a patient [8].

trol system in an intention-actuated exoskeletal robot to support user mobility and lower extremity rehabilitation simultaneously. In this study, the movement of the wheelchair and exoskeleton is called ”slave motion,” and the user's will is called ”master motion.” This gives the user the feeling that he or she is driving the wheelchair.

who have uneasiness around the instruments and equipment used in the medical industry may benefit from the master-slave motion control system. The rehabilitative motion workout is conducted using a single motorized bicycle action [24]. Based on that kinematic design, the Beijing Institute of Technology's Intelligent Robot Institute (IRI) created a prototype of the intended robotic system, complete with all of its components and key control systems (BIT) (shown Fig. 14). The rehabilitation motor is attached to the wheelchair's right board, where it is also connected to the exoskeletons. In general, a rocker cycle powered by a single actuator cannot be maintained by inertia alone. However, the proposed crank-rocker system can operate normally for the following reasons: On the one hand, while the user is seated in the wheelchair, the weights in their legs create inertia, allowing the mechanism to travel past the dead center point [24].

Testing was done to determine how the results from the pedal pressure sensor and the exoskeleton motor motion features relate to one another in order to confirm that When pedal pressure data is employed as actuator feedback and information for the full control system, the exoskeleton motor motion features can satisfy the control requirements. 10 healthy men between the ages of 23.1 and 3.4, ranging in weight from 70.5 to 12.3 kg, and standing at 175 cm tall were asked to take part in the study. A still picture version of a video of the testing is shown in Fig. 15. A rehabilitation exercise performed by one person in a single cranking motion is shown in the picture [24].

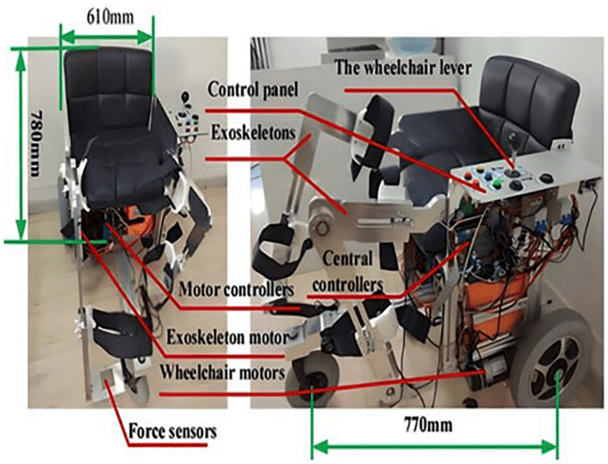

Fig. 14. The IRI at the BIT is proposing a new model of the bicycle intention-actuated exoskeletal rehabilitation robot [9].

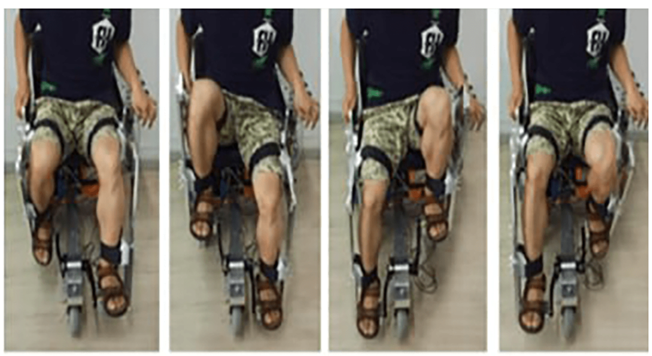

Fig. 15. 15. Pictures taken from a video of the experiment in one crank circle [9].

Goergen et al. [25] advanced a novel, straightforward, and affordable pneumatic robotic system for the rehabilitation of the lower limbs. By carefully controlling the pressures inside the chambers of pneumatic cylinders, we can safely manage the force and run the robot for rehabilitation. This paper covers the development of a rehabilitation robot using an approach that combines mathematical modelling with the phases of the design process [25].
A mathematical model of the kinematic transfer between the angular motion of industrial robot joints and the linear motion of a pneumatic actuator is also included. The physiological rehabilitation of patients with lower limb difficulties is advised to use this gadget. Identify the Fig. The recommended rehabilitation robot has one design. 15. Links 0 (fixed chair/fixed base) and 1 (charged with lower limb movement), which are connected by rotating joints and moved by linear actuators, respectively, make up the system, (shown in Fig. 16).

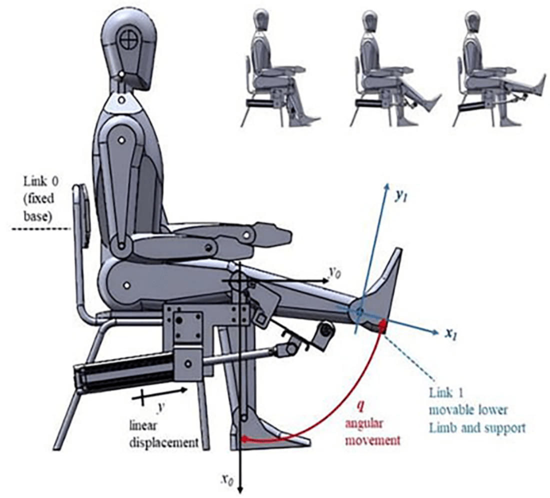

Fig. 16. Robot prototype concept for lower limb rehabilitation using a representation of the geographic coordinate system in sands [10].

Honda started conducting research on Stride Management Assist in Japan in 1999, as shown in Fig. 17. This tool aids in the recovery of walking abilities in the sick or old. A driving device is positioned on each side of the pilot's hip to assist in elevating the leg, and the user may change the leg's angle and pace to suit their preferences. In addition to the first generation, Honda debuted the second generation of its Body Weight Support Assist products in 2008 [26] [27]. Its primary goal, as shown in Fig. 17, is to reduce the labour intensity of prolonged squatting work (b).
The ankle's joints may move. Robots are made with passive joints and an energy storage and release mechanism that benefits the user. Three mutually orthogonal rotating pairs, one revolving pair coaxial with the knee, and a spherical pair all work together to give mobility for the hip, knee, and ankle in this design [28]. Fig. 18 shows the first, optimal structural design.
Designers might use the Swiss Maxon RE50 tried to brush DC motor select a motorized screw, then start moving joints through the connecting rod to mimic the extension and flexion of muscles. Researchers finally created a lower limb exoskeleton robot prototype using the findings stated above [28], whose 3D model is displayed in Fig. 19.
Every joint's maximal angle lies entirely between the body's typical moving joint angle and neither higher nor lower, and all of them are based on configurable design and security requirements [29].
After analyzing and troubleshooting, the exoskeleton robot prototype was finished. Users can dress it up whatever they

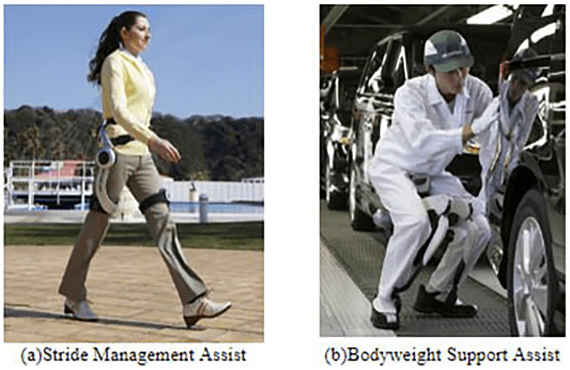

Fig. 17. Honda walking assist devices [11]

want, and its total weight, including the battery, is 28 kg. After just one minute of practice, the pilot can finish donning the robot. They were able to assess the mechanical design and controlling strategy of the robot and ensure that it functioned as intended by having a healthy patient wear the exoskeleton and move around in it. Fig. 20 depicts a pilot wearing the prototype who is 80 kg and 180 cm tall [28], (shown Fig. 20).

De Rossi et al [30] provide a novel and alternative way of evaluating the degree of interaction between a lower-limb gait treatment exoskeleton and the user. They provide a dispersed measure of the standard communication stress over the full region of contact between the user and the device in place of employing a grid condition to determine the eventual consequences of the communication strength. An elastic silicone touch sensor is positioned to take this measurement between the limb and regularly utilized connecting cuff. The benefit of this strategy is that it makes it possible to quantify stress through dispersed communication, which may be useful for controlling or assessing rehabilitation therapy. The suggested method also doesn't affect how comfortable the interface is, is affordable to construct, and can be used to link cuffs of various sizes and shapes [30].
Hocoma is used by both the Lokomat exoskeleton [31] and the LOPES lower-limb exoskeleton [10]. The aforementioned solution offers several advantages, such as the propensity to increase the area of contact, which lessens communication pressure and strain on that user limb; it adapts to the shape of the leg (which changes during gait due to muscle contraction); and it only needs a small range of sizes to fit the majority of users. A load cell is commonly positioned at the point where the cuff and the exoskeleton connection cross to monitor the communication force between the human and the robot [32], (shown in Fig. 21). In this paper, we provide a different approach to contact sensing that makes use of a regular pressure measurement applied uniformly over the whole area where the user and belt touch.

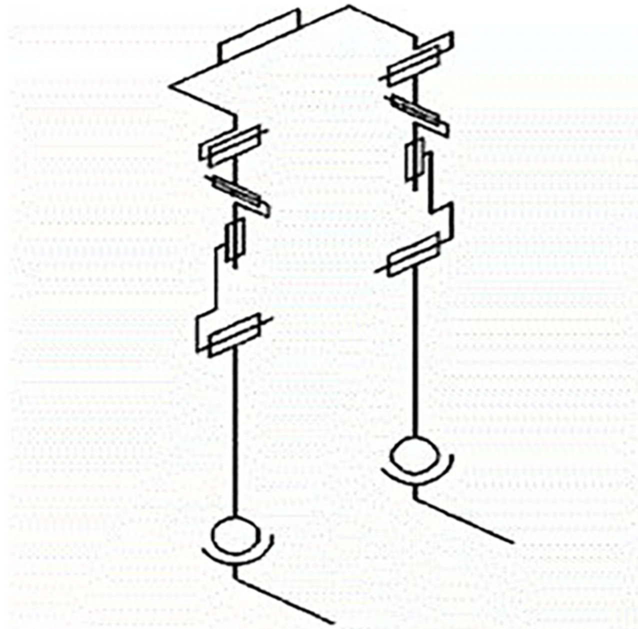
Fig. 18. Design for the mechanically enhanced exoskeleton [11]

The ease of communication is unaffected by the silicone structure of the sensor coming into touch with the leg. This frame, which also contains the composite signal/power line connector, enables quick and simple changes to the distribution of sensors along the belt. Ten to twelve sensors are the most that may be employed per connected cuff because of the limitations of the pad's burden. We sensorized a cuff with six Skillsets pads, three in the front and three in the rear, to test our theory. We attached the sensorized cuff to one of the six connections of the LOPES gait rehabilitation exoskeleton. The cuff is seen being fitted on a healthy individual in Fig. 22. The patient was required to use a treadmill at a constant pace of 4 km/h [30].
One of the leading businesses developing exoskeletons to increase human efficacy is Lockheed Martin. The HULC (Human Universal Load Carrier) exoskeleton technology was donated by Berkeley Bionics (now called Ekso Bionics). The BLEEX-based HULC allows soldiers to carry big loads over long distances. The US Army tested an early exoskeleton prototype and found that it altered gait patterns by increasing metabolic energy expenditure and reducing midfrequency of movement [33] [34]. Though the HULC design has improved, unlike many other exoskeletons still in development, there are no quantitative evaluations of the auxiliary tool that are accessible to other researchers. In a recent news release, Lockheed Martin unveiled FORTIS, a nearly comparable exoskeleton

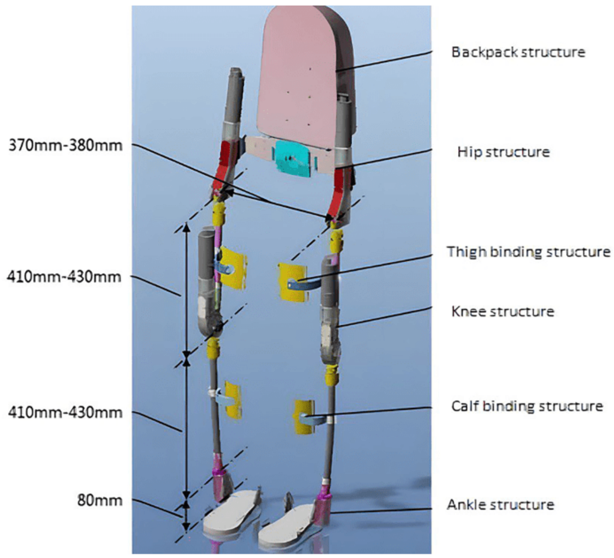

Fig. 19. The suggested exoskeleton robot's 3D model [11]

Fig. 20. Prototype wearable display [11].

Fig. 21. The sensorized fastening belts and the Lopes exoskeleton for lower-limb rehabilitation [12].

Fig. 22. During a gait rehabilitation assignment carried out by the LOPES [12].

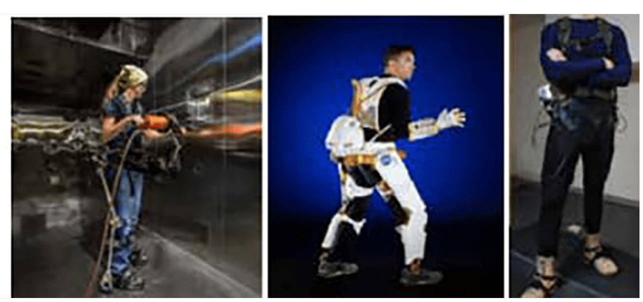

Fig. 23. Lockheed Martin created the FORTIS exoskeleton (left) for commercial use [13].

(shown in Fig. 23). It was developed specifically for use in shipyards [35]. The FORTIS gadget enables the user to handle and move heavy tools more easily by utilizing Equipois' ZeroG arm. Although FORTIS does not have a propeller-like HULC, its ability to redistribute weight to the ground can enhance conditions and reduce fatigue.

In the future, this device may be used as an exercise trainer in space. Under DARPA's Warrior Web application, the Wyss Institute is creating a soft exosuit (shown at right) [13].

For those with damaged spinal cords, Parker-Hannifin is marketing the Indego exoskeleton (shown in Fig. 24). Bilateral agreements between Indego start at the knee and hip joints and extend to the waist, which is the location of a battery pack. Therefore, the design of the Indego exoskeleton is more understood than it would be for exoskeletons created in an industrial contesting employs a joint-level controller that may be operated in either of two modes: either PD mode, which employs high gains to try to impose a specified joint-

Fig. 24. Exoskeletons have been created for a variety of assistive uses in populations with disabilities.

angle trajectory [36], or PD mode, which does not. When the controller is in impedance mode, it successfully mimics a spring-damper mechanism [37]. At the upper level of control, each individual controller is guided by a finite-state machine. Changes between modes like sitting, standing, and walking are controlled by the state machine [37]. The flexibility of the Indigo system makes it stand out since it allows for easy movement of smaller sections when not in use. For the time being, there is not enough performance data to determine its main limitations.

The Hybrid Assistive Limb (HAL) exoskeleton was created by Cyberdyne (left) to help people with impairments. This covers both independent and cooperative arm and leg support. One of the few commercial gadgets that can be operated by brain signals from the muscles is HAL (EMG). The HAL system has been widely used in clinics throughout Asia and Europe. Clinics all over the world utilize the Ekso exoskeleton (middle) mostly for rehabilitation purposes. Patients recuperating from a lower limb handicap, such as spinal cord damage, can benefit from gait training with the Ekso [13].

Numerous wearable robotic devices have been proposed to provide more adaptable and customized forms of support to a range of users in order to get past some of the limits of conventional AFOs (ankle-foot orthoses). This proposal involves the design of a soft robotic ankle-foot orthosis (SR-AFO) exosuit to aid in plantarflexion during gait rehabilitation in patients with aberrant gaits brought on by stroke or other illnesses. Fig. 25 shows the SR-AFO exosuit, which is constructed with legal materials. The SR-AFO exosuit helps with the late stance of the walking stride by compressing the actuator to lift the rear end of the foot higher. As a result, there is reduced stress placed on the user's muscles during plantarflexion [38].

Soft robots are systems that are capable of autonomous behavior and are generally made of biologically inspired materials. Biological systems frequently take advantage of softness and bodily compliance since they tend to seek simplicity and exhibit a lower level of complexity in their interactions with the environment [39].

A soft robotic ankle-foot orthosis (SR-AFO) exosuit that employs soft pneumatic actuators to enable dorsiflexion, inversion, and eversion was developed to prevent footdrops (IE). The sock-like structure, which was designed to fit over the user's running shoes, was based on the thin-film contracting actuator idea. The IE actuators underwent additional testing [38].

Exoboot [40] is a motorized exoskeleton system created by the Universities of North Carolina and Carnegie Mellon (Fig. 26). The carbon fibre exoskeleton system weighs roughly 500 g. The energy required to walk is reduced by more than 7% when springs are employed as energy storage. Over more advanced exoskeleton robots, traditional exoskeleton robots have several benefits. However, work on sophisticated exoskeleton robots has only recently started and is still an exciting topic [41].

IV. Conclusion

The current developments in exoskeleton control methods for lower limb rehabilitation are the main subject of this study. Robotic exoskeletons with sensing, control, and other characteristics for lower limb rehabilitation also have bionic, robotic, informational, and control qualities. As a result, they have emerged as a major hub for multidisciplinary study in the realms of science, medicine, and other disciplines. Many devices have been developed as a result of significant advancements in mechanical design and control system design in recent years. However, there is still a significant research void in the area of fusing people and robots. It should be natural for the wearer (human) and robot to merge into one. Work cooperation between the human body and the robot is necessary for rehabilitation training to be effective.

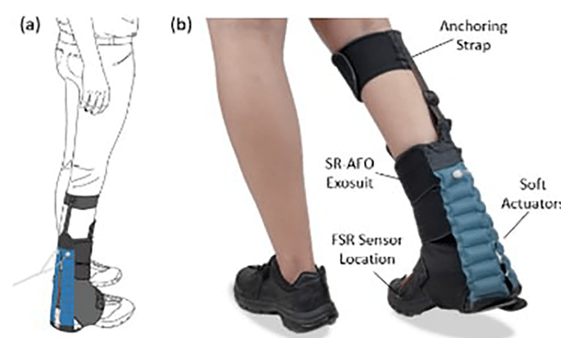

Fig. 25. representation of the SR-AFO (A) depicts an exosuit for flexion and extension, while (B) depicts the rear aspect of the actual equipment worn by an users [14].

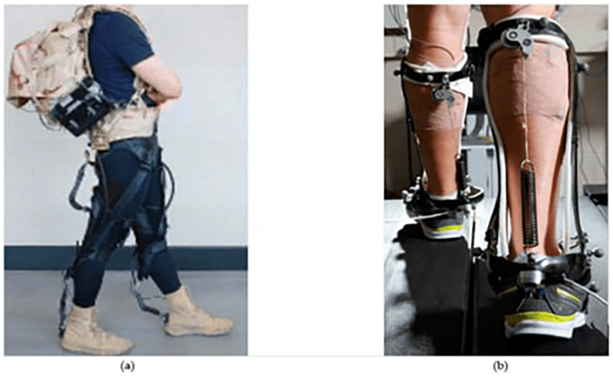

Fig. 26. Advanced exoskeleton robot. (a) Soft exoskeleton robot [15] (b) Unpowered exoskeleton robot Exoboot [16].

V. Future Work

In conclusion, it can be claimed that the use of exoskeletons in the rehabilitation and treatment of patients with neurobiological damage, motor neuron disease, and other illnesses is now very positive; nevertheless, the following areas may use them better:

- Go on a diet. The entire lower limb exoskeletons must be as light as feasible to allow the patient or therapist to manage the balance or transport the apparatus, even though they are designed to lay on the ground when in use. This is crucial for partial exoskeletons since the user may occasionally need to support them while they walk. In both scenarios, it's crucial to consider both the exoskeleton's weight and its distribution on the body. To prevent greater inertia that would increase motor utilization and give the user the impression that the gadget is heavier, most of the weight should be kept as near to the trunk as feasible.

- Price the equipment less. Exoskeletons have the potential to benefit many individuals, but because of their expensive price, they are out of reach for some therapeutic settings or hospitals with little funding and obtaining them for home usage is harder. More individuals will be able to use the gadget when the price drops.

increased independence In hospitals and rehabilitation facilities, exoskeleton autonomy is a secondary concern because batteries can be changed quickly and efficiently. On the other hand, when it's intended for personal use, it turns into a crucial component since, like other portable electronic equipment, it must be used regularly for at least one day.

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