Analysis of Exoskeleton Suit in Clinical and Home Use

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Abstract. The two most common causes of immobility that cause significant problems in everyday life are SCI and stroke. Recent research suggests that robotic exoskeletons may be able to help patients regain their motor function. This paper will evaluate existing exoskeleton suits, compare their functionality, and analyse their benefits and drawbacks compared to conventional rehabilitation equipment. It will also discuss the challenges it is encountering. It is discovered that the exoskeleton suit still requires more useable applications and precise design to meet clinical and domestic use.

Keywords: Exoskeleton suit, Clinical, Stroke, Robotic exoskeleton.

1. Introduction

Spinal cord injury (SCI) and stroke are two major neurological diseases that cause motor disorders of the upper and lower extremities, and the mobility of limbs varies according to the degree of injuries. Although some muscles may still function in some ways, this does not necessarily mean that they have direct control over the limb, which can limit activities of daily living (ADL) [1,2]. Extremity disability will severely affect the autonomy and quality of life as well as burden families and society [2]. It has been demonstrated that beginning inpatient rehabilitation interventions as soon as the injury occurs will make them more conducive to comprehensive functional recovery [1].

The gradual reduction of the rehabilitation duration has been linked to shifting economic healthcare models, which suggests that the use of more advanced technologies would increase efficiency [1]. A feasible measure is to introduce robotic rehabilitation equipment, wearable exoskeleton, also called powered exoskeleton or exoskeleton suit, or just exoskeleton for convenience.

The term ‘exoskeleton’ originates from the colloquial name for an arthropod’s shell, which is a rigid stratum corneum that protects the interior body and can also cooperate with muscles to complete a variety of movements, like the skeleton in vertebrates [3].

A potential method for rehabilitation is provided by wearable exoskeleton technology. The mechanism is directed by the notion of brain plasticity and human motor learning, and patients will achieve improvement or even recovery of motor function by progressively regaining the capability of motion control through repetitive motion and feedback simulation [4]. With the aid of an exoskeleton, patients can acquire basic abilities like grabbing, walking, climbing stairs and sitting down, which dramatically enhances the quality of their everyday life [5].

This paper will firstly examine two main variations of the powered exoskeleton, including their working principles and operations, before analysing its benefits and drawbacks in comparison to currently available conventional rehabilitation equipment, it will also discuss its emerging problems, and finally, it will discuss its challenges and prospects, along with any improvements that are practical to make.

2. Exoskeleton Review

The powered exoskeleton can be categorized by how they operate. The following section will review conventional exoskeletons which detect human movements using traditional pneumatic or hydraulic drive systems [1] and novel exoskeletons whose sensors are attached to the human body to pick up signals so that the machine can recognise and implement the natural posture or action that the user wants to make [6,7].

2.1. REX, ReWalk, Ekso and Indego

Figure 1 depicts the four main market leaders in the exoskeleton industry in 2017, REX, ReWalk, Ekso and Indigo, the first two have two models each, one for rehabilitation clinics, and another one for personal use and it can be customized [8]. The above four exoskeleton examples are intended to assist leg function, however, there are more applications that can be found to improve hand capabilities.

The traditional pneumatic or hydraulic drive system is triggered by the initiation of movement of the user, Gardner et al. [8] state that the sensors will then collect the activity information and pass it to the processor, which subsequently causes the matching mechanical components to produce energy to accomplish the motion.

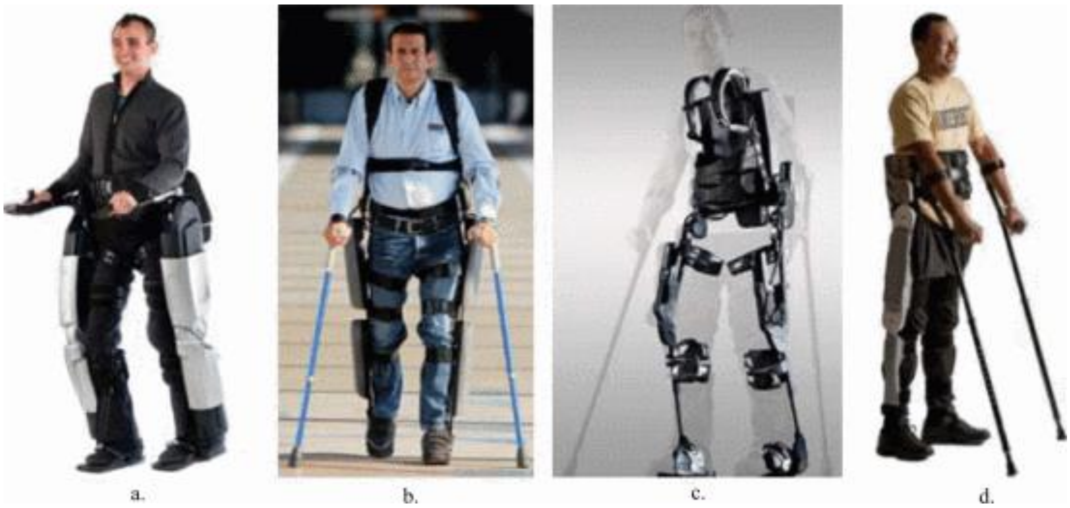

Figure 1. Medical exoskeletons: a. Rex, b. Rewalk, c. Ekso, d. Indegoya [8].

The exoskeleton may be controlled primarily in two ways. First, when a user wants to move, they can make a minor trunk movement that will trigger the sensor located on the chest strap, causing the initiation of the movement. The tilt sensor would examine the trunk angle to determine the hip and knee displacement [8, 9]. For instance, leaning backwards or forwards could cause the patient to sit or stand. Second, the exoskeleton can be operated by a joystick; depending on the exercise chosen by the user, the exoskeleton will manipulate in a variety of directions; some of the exoskeletons would require extra walking aids such as crutches, for stability. According to statistics by Gardner et al. [8], the four exoskeletons have an average height restriction of between 1.5 and 1.9 m and a weight restriction of about 100 kg.

2.2. HAL

The robotics company Cyberdyne and Japan's Tsukuba University are developing the hybrid assistive limb (HAL). There are two primary versions: HAL-3 (shown in Figure 2), which only gives leg functionality, and HAL-5 (shown in Figure 3), which is otherwise a full-body exoskeleton.

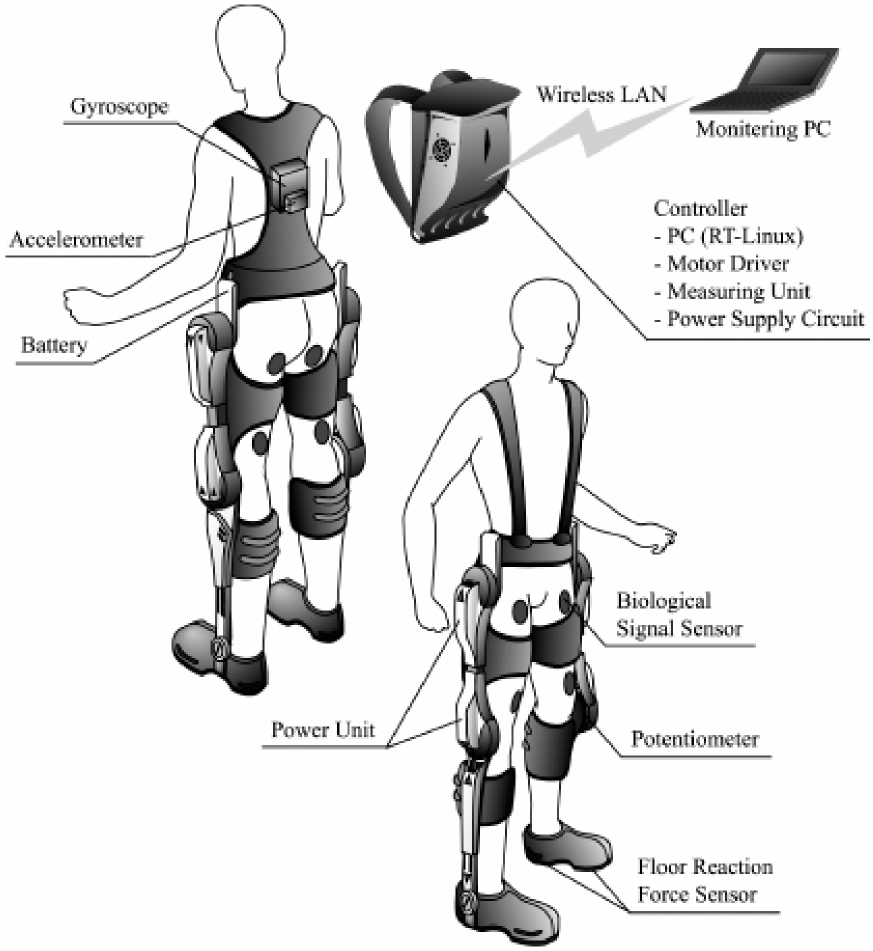

Figure 2. Configuration of HAL-3 [6].

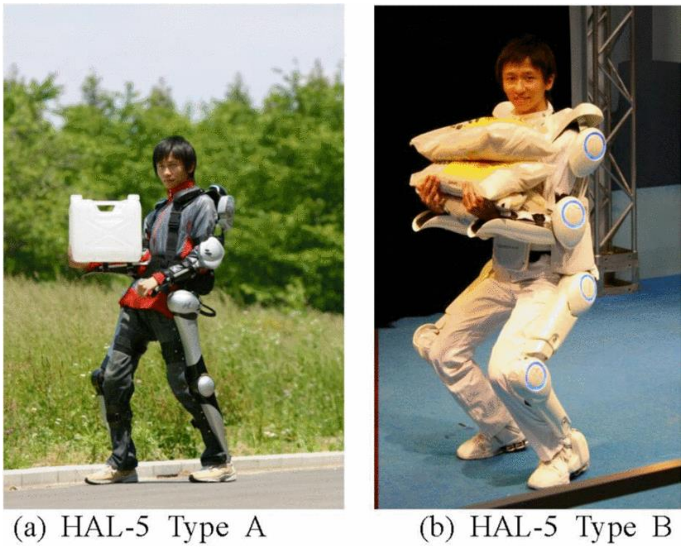

Figure 3. Holding tank (a) and rice bag (b) in HAL-5 [7].

Since the brain will send electrophysiological signals through nerves to the muscles when the user tries to move, HAL then works by picking them up by the sensors, and the servo motor will be activated to launch the corresponding actions they have learnt through the information contained in the signals [10].

When compared to conventional exoskeleton robots, HAL-3 provides two extra functionalities. Firstly, the paraplegics will walk using only their legs, swinging, balancing, and switching support legs by the reference walking pattern taken from a healthy person. Secondly, the robot should be able to guess the user's intention while walking if there is a lag between the interfaces [6].

Compared to HAL-3, HAL-5 will assist both the upper and the lower limb movements. It has two control systems, voluntary and autonomous, that would interact with each other to enhance users' capabilities. The autonomous mode will be engaged once the motion has been executed. In addition to the basic voluntary functionalities of HAL-3, it handles another case where the user cannot properly transmit bio-electrical impulses, namely the absence of ability in the spinal cord or brain. Moreover, the user will not burden with the weight of the exoskeleton robot since it is supported by HAL-5 itself [7].

3. Comparison with Traditional Rehabilitation Equipment: Advantages and Disadvantages

The burgeoning exoskeleton technology is gradually replacing the traditional ones, but the translation is not always easy. This section will discuss the advantages and disadvantages of exoskeleton sssss in comparison to traditional rehabilitation equipment successively, to explore why this technology has not yet become the mainstream clinical rehabilitation method despite its advancement over traditional ones.

3.1. Advantages

Due to a lack of human resources, traditional rehabilitation may have a major issue with patients receiving insufficient training. Since each patient will have a different level of injury, the majority of traditional rehabilitation sessions are tailored to their needs. However, this results in a shortage of therapist resources and makes it impossible to guarantee that each patient will receive an equal and appropriate level of care, which will hurt their long-term recovery. this requires the therapist to be present with the patient all the time during the session to give them instant guidance; however, it would cause a shortage of the therapist's resources and it cannot be assured that each patient could have an equal and proper tender, thus resulting in a negative influence on their long-term recovery period and quality of life [1].

While this dilemma may be improved with the exoskeleton suit. The exoskeleton alone can provide the patients with adaptive and task-specific training once its program is set, as well as feedback. This effectively reduces the dependence of patients on the therapist and alleviate the shortage of medical personnel.

3.2. Disadvantages

Despite the advantages over traditional rehabilitation, exoskeleton still confronts several dilemmas, including weight and size restrictions, high costs, and a paucity of the practical application of exoskeleton suits in clinical settings. One significant element that restricts the use of the limb is the weight and bulk of the exoskeleton [11]. For example, the user must bear the weight of the suit themselves, a suit that is too big may restrict and interfere with daily activities, and a heavier suit requires more power to operate. Although this may be eased by replacing it with soft exoskeleton suits that will make it easier for a user to wear and lightweight to save more power, it faces the problem of not being able to support more weight. Additionally, exoskeleton suit is so expensive that the government hospital is unlikely to adopt them on a broad scale, nor could every family able to afford one. The cheapest one mentioned in Section 2, ReWalk, would cost about 70,000 dollars [8]. Besides, customizing every exoskeleton for different patients owing to their unique degrees of injuries or body shapes would be an extravagance [5], and violate the initial intention of inventing this technology, which was to help ease financial strains and reduce the cost of health care [11]. Furthermore, the lack of appropriate practical applications for exoskeletons hinders their further development. There is still a gap between laboratory research and clinical or home use [12], which results in a lack of investigation of clinical practices [1]. As a result, it is challenging to make helpful, adaptive, or practical improvements in this circumstance.

4. Discussions and Prospects

Based on the current clinical and home applications, there are some existing limitations and obstacles to exoskeleton, this section will discuss 2 essential domains: domain of freedom (DOF), user interface (UI) and human-machine interface (HMI), then it will propose possible future improvements or research directions.

4.1. DOF

DOF is one of the most essential tasks to consider in exoskeleton design since there are various delicate grasping, bending, stretch or twist tasks of hands or legs. According to the investigation records, most of the exoskeletons have at least one DOF of each unit [1]; however, it is declared that hand exoskeletons have around 15 DOFs, that is 2 to 3 for the thumb and 3 for each other finger, otherwise the hand would not have enough strength to support the motion [13], this indicates that only one DOF is insufficient to meet the needs of ADL. Thus, implementing more than 2 DOFs for each unit other than the thumb would make movements more flexible. Increasing the number of DOFs; however, may cause the exoskeleton to have a larger size and more complexity. Therefore, the engineers need to balance the number of DOFs with the exoskeleton's size, weight, portability and design complexity, on the premise of satisfying the fundamental functions.

4.2. UI and HMI

A qualified exoskeleton should have a sound user interface to exchange information between the user and the rehabilitation robot. An external interface is required to extract the user's intent since the robotic system cannot observe the human command signals [1]. The interfaces contain a graphical user interface (GUI) and mechanical switches where users can directly touch the screen of buttons to transfer information without being hampered by external interference; embedded sensors that are worn on users' bodies to detect their motion and surrounding objects; moreover, there are voice-controlled and vision-based interfaces but may be obstructed by the environment. It is crucial to implement different kinds of combinations of UI to provide a more controllable exoskeleton suit and can offer more precise estimation by the same time.

HMI is also an advancement in UI that bridges intuitive communications and control. It imitates the human neuromusculoskeletal system by using a neuromechanical model human hand or leg, extracting electromyography (EMG) signals and converting them to joint torque [14]. However, recent HMI cannot make users control the exoskeleton completely voluntarily. Compared to commercial bionic limbs which apply multiple DOFs, they are less progressed in functional recovery because bionic technology is more mature since it has experienced tremendous progress in control based on surface EMG [12].

Future research could pay more attention to voice- or vision-based controls, even eye-tracking systems can be implemented to assist in grabbing things. There is also research abothe ut transfer expertise from bionic arms to exoskeletons, which records and processes bioelectrical information to build interfaces between the human neuromuscular system and wearable exoskeletons.

5. Conclusion

To conclude, the paper reviewed 2 kinds of exoskeletons, conventional exoskeletons mostly based on sensors and actuation systems, and novel exoskeletons based on biological signals and machine prediction. Then it compares exoskeletons with traditional rehabilitation equipment, finding that it could ease the problem of shortage of therapists and is more accurate in controlling, but faces difficulties in weight, size, cost and practical application. Finally, it discussed the DOF, UI and HMI domains where exoskeleton still exists some challenges and gave some workable` solutions based on current research. It is important to note that the exoskeleton is not the only one in the rehabilitation team. There are also other members including but not limited to case managers, surgeons, physical medicine, patients and their family. The exoskeleton cannot accomplish such a huge work without the contributions of other roles, for example, the patients would be motivated by their family's encouragement.

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