IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684, p-ISSN: 2320-334X
PP 58-62
www.iosrjournals.org

Bionic Exoskeleton: History, Development and the Future

Habib Ali[1]
[1]*Department of Biomedical Engineering, J.B Institute of Engineering & Technology, Hyderabad, India*

ABSTRACT: *As researchers have begun to explore the various challenges related to building exoskeletons, which was once a science fiction, it has today progressed to be a part of the commercialized product family. In this review paper we touch upon the history of exoskeletons, their design and development, the future of exoskeletons and how they can become a part of our day to day life. This paper provides a brief overview on exoskeleton design, control mechanism and challenges, thereby bringing food for thought and throwing light on the future of exoskeletons.*
Keywords: *Bionic, exoskeletons, gait, nanotechnology, rehabilitation, robotics, walking, wearable, 3-d printing,*

I. INTRODUCTION

Inspired by science fiction [1]-[2], that has very persuasively been brought out in books and movies, researchers have, for quite some time, put in efforts to make an effective exoskeleton which can be used for assistance. In this paper we discuss about the history and development of exoskeletons, but before we do that, let us define what an exoskeleton means. For the purpose of this review, we shall consider an exoskeleton to be an active mechanical device which is anthropomorphic in nature, and can be worn by a person and can act as an assistive device. In this paper, our focus is more on exoskeletons for the lower extremities and exoskeleton as an assistive device for rehabilitation. This is mainly because when we take a look around us, we realize that a small accident might lead to devastating results such as fractures, brain injury, spinal cord injury or at times even death. In worst case scenario, a person becomes a victim of paraplegia, which may lead to loss of locomotion. Such persons may never be able to walk again. As we attempt to uncover the major developments in the field of exoskeleton technology, we shall briefly touch upon performance augmenting exoskeletons followed by exoskeletons for rehabilitation. Then we provide some food for thought as to where we can put in efforts to speed up development and on how bright the future of exoskeletons is.

II. HISTORY AND DEVELOPMENT

Most of the early work related to exoskeletons were concept studies that were put on the drawing board, but never actually built or tested. The earliest mention of a device resembling an exoskeleton was Yagn's running aid [3] patented in 1890, shown in Fig 1. It was a simple bow/leaf –spring operating parallel to the legs and was intended to augment running and jumping Fig 2. Each leg spring was engaged during the foot contact to effectively transfer the body's weight to the ground and to reduce the forces borne by the stance leg. During the aerial phase, the parallel leg spring was designed to disengage in order to allow the biological leg to freely flex and to enable the foot to clear the ground.

In the late 1960s, General Electric Research (Schenectady, NY), with Cornell University and financial support from the U.S. Office of Naval Research, constructed a full-body powered exoskeleton prototype [4]–[5]. Dubbed "Hardiman" (from the "Human Augmentation Research and Development Investigation"), the exoskeleton, was an enormous hydraulically powered machine (680 kg, 30 DOFs), that included components for amplifying the strength of the arms (including hands but without wrists) and legs of the wearer. It proposed to amplify the human strength drastically (25:1) [6].

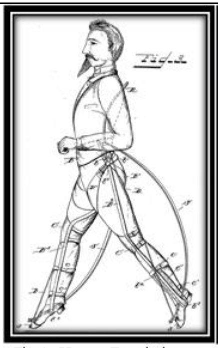

Fig 1. Yagns Exoskeleton

Fig 2. Hardiman

Fig 3. Mihailo Pupin Exoskeleton

2.1 Mihailo Pupin Institute Exoskeleton

The pioneering work done with exoskeletons by Miomir Vukobratovic and his associates at the Mihailo Pupin Institute in Belgrade in the late 1960s and 1970s is one of the most extensive to date [7]–[8].They started with the "kinematic walker," featuring a single hydraulic actuator for driving the hip and the knee, which were kinematically coupled. In 1970, the so-called "partial active exoskeleton" was developed, which used pneumatic actuators for flexion/extension of hip, knee, and ankle, as well as an actuated abduction/adduction joint at the hip for greater stability in the frontal plane. This concept was later modified slightly into the "complete exoskeleton" by extending the attachment at the torso to enclose the entire chest of the patient, providing greater trunk support. More than 100 clinical trials were performed with this device, and a number of patients with varying degrees of paralysis mastered walking using the complete exoskeleton with support from crutches. The total weight of the "complete" exoskeleton, after incorporation of lighter valves, was 12 kg. This value does not include the power source and control computer, which are not located on the device. Later a set of three piezo-ceramic force sensors were soon incorporated into the sole of the "complete" exoskeleton foot for use in determining the location and magnitude of the ground reaction force, which, in turn, was used for control of the device. In order to address the problem of being energetically autonomous, a version of the exoskeleton actuated by dc motors was developed. Although the limitations of the then motor, battery and computer technology marginalized the true portability of the device, this new actuation scheme offered further improvements such as smoother motion and better tracking ability. Fig.3.

2.2 DARPA Exoskeletons

Alongside there was a deep interest developed which led to extensive research in the field of exoskeletons. The United States came up with its much talked about Defence Advanced Research Projects Agency (DARPA) program which invited heavy funding for research related to exoskeletons. BLEEX, Sarcos, MIT Exoskeleton are some of the popular exoskeletons under DARPA. We shall discuss the BLEEX developed under this program before we discuss the other major exoskeletons in the field of rehabilitation.

Berkeley Exoskeleton (BLEEX)

The most prominent of the DARPA program exoskeletons has been the Berkeley Lower Extremity Exoskeleton (BLEEX). The distinguishing feature of this project is that it carries its own power source. Indeed, its developers claim it to be the first "load-bearing and energetically autonomous" exoskeleton. BLEEX has 3 DOFs at the hip, 1 at the knee, and 3 at the ankle. Of these, four are actuated: hip flexion/extension, hip abduction/adduction, knee flexion/extension, and ankle flexion/extension [9]. The kinematics and actuation requirements of the exoskeleton were designed by assuming the physical behavior similar to that of a 75 kg human and utilizing clinical gait analysis data for walking [10] - [11]. It consumes an average of 1143W of hydraulic power during level-ground walking, and 200W of electrical power for the electronics and control, while a similar sized human consumes 165W of metabolic power.

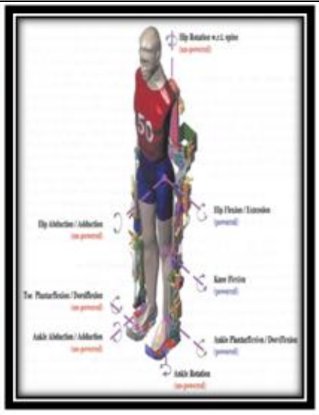

Fig 4.BLEEX [10] Fig 5.BLEEX Degrees of freedom [9]

BLEEX was designed with linear hydraulic actuators since they were the “smallest actuation option available” based on their “high specific power (ratio of actuator power to actuator weight)” [10]. However, a further study determined that electric motor actuation significantly decreased power consumption during level walking in comparison to hydraulic actuation. Later they developed a hybrid hydraulic–electric portable power supply. The new device with this power supply was approximately half the weight of the original exoskeleton (~14 kg), due to the implementation of electric actuation with a hydraulic transmission system.

Exoskeletons in Rehabilitation

Exoskeletons play a major role in the rehabilitation of patients affected by spinal cord injury, or brain injury who have lost motor functions of the lower limb. Patients who have been wheel-chaired face a lot of problems with regard to their movement and also deal with many psychological issues. Also the human body is physiologically designed in a way such that it can stand, walk and move around, but a wheelchair user loses this ability and leads to having a negative impact on the body. To overcome such problems, exoskeletons play a major role in rehabilitation and enable a wheelchair-user to be independent of wheelchairs, enabling him to walk around. As we have discussed earlier, the Mihailo Pupin Institute Exoskeleton was a pioneer, but due to technological constraints of that time, it wasn’t a very feasible option. But with advances in technology, today we see some ground-breaking research and development in the field of exoskeletons and their application in rehabilitation has started to enter the field of commercialization. Some such exoskeletons are the ReWalk^{TM}, eLEGS^{TM}, MindWalker, HAL, REX, Vanderbilt exoskeleton. Each one of them has a unique mechanism. Some use certain biosignals to operate, while some use complex algorithms with a lot of sensor information. Some work as reciprocating gait orthosis while some employ the use of joystick to work. We shall now discuss about the ReWalk and eLEGS followed by HAL and MindWalker.

Fig 6. From left-right, Vanderbit Exoskeleton, eLEGS, ReWalk and Rex

ReWalk

The ReWalk enables people with lower limb disabilities to carry out routine ambulatory functions (stand, walk, climb stairs etc.). It can be used by people with disabilities such as spinal cord injury, brain injury, stroke, multiple sclerosis, cerebral palsy and other severe walking impairments. The ReWalk comprises light wearable brace support suit, which integrates DC motors at the joints, rechargeable batteries, an array of sensors and a computer-based control system. It can be snugly fitted onto the body and worn underneath the clothing, if desired. Upper-body movements of the user are detected and used to initiate and maintain walking processes. User stability and safety during ambulation is secured by concurrent use of safety aids such as crutches for walking and railing for stairs [12].Based on a study [13], it was found that after training, subjects were able to independently transfer and walk, without human assistance while using the ReWalk, for at least 50 to 100 m continuously, for a period of at least 5 to 10 minutes continuously and with velocities ranging from 0.03 to 0.45 m/sec (mean, 0.25 m/sec). Some subjects reported improvements in pain, bowel and bladder function, and spasticity during the trial. All subjects had strong positive comments regarding the emotional/psychosocial benefits of the use of ReWalk. Most subjects achieved a level of walking proficiency close to that needed for limited community ambulation. ReWalk holds considerable potential as a safe ambulatory powered orthosis for motor-complete thoracic-level spinal cord injury patients.

eLEGS

eLEGS stands for "Exoskeleton Lower Extremity Gait System". eLEGS is another hydraulically powered exoskeleton system, and allows paraplegics to stand and walk with crutches or a walker. The computer interface uses force and upto 40 sensors to monitor the user's gestures and motion, and uses this information to intelligently interpret the intent of the user and translate it into appropriate action. It has a reinforced carbon frame which acts as a substitute for bone strength and uses 4 electromechanical motors. It weighs 45 pounds (20kg) and has a maximum speed of 2 mph (3.2 kph) and a battery life of 6 hours. It is suitable for users weighing up to 220 pounds, who are between 5ft 2in and 6ft 4in tall and can up-heave themselves from a wheelchair into a chair. It allows the user to walk in a straight line, stand from a sitting position, stand for an extended period of time, and sit down from a standing position.

HAL

HAL has been designed to support and expand the physical capabilities of its users, particularly people with physical disabilities. There are two primary versions of the system: HAL 3, which only provides leg function, and HAL 5, which is a full-body exoskeleton for the arms, legs, and torso. HAL 5 is capable of allowing the operator to lift and carry about five times as much weight as he or she could lift and carry unaided. The third HAL prototype, developed in the early 2000s, was attached to a computer. Its battery alone weighed nearly 22 kilograms (49 lb) and required two helpers to put on, making it very impractical. CYBERDYNE's newer HAL-5 model weighs only 10 kilograms (22 lb) and has its battery and control computer strapped around the waist of the wearer. When a person attempts to move their body, nerve signals are sent from the brain to the muscles through the motor neurons, moving the musculoskeletal system. [15] When this happens, small biosignals can be detected on the surface of the skin. The HAL suit registers these signals through a sensor attached to the skin of the wearer. Based on the signals obtained, the power unit moves the joint to support and amplify the wearer's motion. The HAL suit possesses both a user-activated “voluntary control system" and a “robotic autonomous control system" for automatic motion support. The HAL-5 Type-C could support a patient with paraplegia to walk [16] The estimation algorithm based on the floor reaction force was investigated through the walking support experiments for a patient with a sensory paralysis on both legs. The cycle of reference walking patterns was adjusted for the patient and the walking support based on the reference walking was achieved, synchronizing with a patient’s intentions estimated by the algorithm. The algorithm successfully estimated mobility corresponding to a patient’s intention, but it did not stabilize a patient’s body posture and he had to maintain his balance using a walking frame with his hands.

MindWalker

The Mindwalker (or Mind-controlled orthosis) project proposed that the damaged spinal cord be bypassed altogether by routing brain signals directly to a robotic exoskeleton in a bid to get patients back on their feet. The system uses BNCI (brain-neural-computer interface) technology, which can convert either EEG signals from the brain, or EMG signals from patient’s shoulder muscles, into electronic commands. The electronic commands are then used to control an exoskeleton attached to the user’s legs. MindWalker provides two solutions; the first is based on a technique referred to as “steady-state visually evoked potential,” which essentially involves the use of flickering visual stimuli to induce correlated EEG signals. These EEG signals are then used to trigger exoskeleton movement commands such as “stand,” “walk,” “faster,” or “slower.” The second approach involves processing EMG signals generated by the user’s shoulders in order to exploit the natural arm-leg coordination of human walking to convert arm-swing patterns into control signals for the exoskeleton. The MindWalker system also utilizes an innovative “dry” technology to read the EEG signals [17].

III. THE FUTURE OF EXOSKELETONS

As we come to the end of this review, we notice a large number of designing constraints. Exoskeletons are yet to meet high efficiency, intelligent power management, lighter weight and improved mechanical design such that they can be incorporated as clothing. With the invasion of 3-d printing, rapid prototyping provides new perspective to the mechanical design, where the subject is constantly growing (children) like the WREX [18]. Also the other aspect which has been highly neglected is the cost. Present day exoskeletons cost around 100k $ which cannot be afforded by average middle class families or people in lesser developed countries, which makes this necessity to be a luxury.

The future involves more work in the materials used to build the exoskeleton, its design and better user control. We can also not deny the role of nanotechnology to help engineer exoskeletons that provide spinal bridges which helps change the path of neural signals. As we move towards an age where cyborgs may soon be a reality, we should work towards designing exoskeletons that become an integral part of a person's appearance, and penetrate into life of people with obesity, weak muscles and old patients and also work for people affected by muscle spasticity. Thus it is very important to understand the human leg morphology, gait, neural control which would lead to analogous efficient design of exoskeleton [19]. Exoskeletons that help climbing stairs, running, jumping and compromising any terrain will be an area of research in the future.

REFERNCES

Edward S. Ellis, The Steam Man of the Prairies (1868).
R. A. Heinlein, Starship Troopers. New York: Putnam, 1959.
N. Yagn, "Apparatus for facilitating walking, running, and jumping,"U.S. Patents 420 179 and 438 830, 1890
K. E. Gilbert and P. C. Callan, "Hardiman I prototype," General Electric Company, Schenectady, NY, GE Tech. Rep. S-68-1081, 1968.
B. R. Fick and J. B. Makinson, "Hardiman I prototype for machine augmentation of human strength and endurance: Final report," General Electric Company, Schenectady, NY, GE Tech. Rep. S-71-1056, 1971.
N. J. Mizen, "Powered exoskeletal apparatus for amplifying human strength in response to normal body movements," U.S. Patent 3 449 769, 1969.
M. Vukobratovic, D. Hristic, and Z. Stojiljkovic, "Development of active anthropomorphic exoskeletons," Med. Biol. Eng., vol. 12, no. 1, pp. 66–80, 1974.
M. Vukobratovic, B. Borovac, D. Surla, and D. Stokic, Scientific Fundamentals of Robotics 7, Biped Locomotion: Dynamics Stability, Control, and Application. New York: Springer-Verlag, 1990.
H. Kazerooni and R. Steger, "The Berkeley Lower Extremity Exoskeleton,"Trans. ASME, J. Dyn. Syst., Meas., Control, vol. 128, pp. 14–25,Mar. 2006
A. B. Zoss, H. Kazerooni, and A. Chu, "Biomechanical design of the Berkeley Lower Extremity Exoskeleton (BLEEX)," IEEE/ASME Trans. Mechatronics, vol. 11, no. 2, pp. 128–138, Apr. 2006.
A. Chu, H. Kazerooni, and A. Zozz, "On the biomimetic design of the Berkeley Lower Extremity Exoskeleton (BLEEX)," in Proc. IEEE Int.Conf. Robot. Autom., Barcelona, Spain, 2005, pp. 4345–4352.
Zeilig, Gabi; Weingarden, Harold; Zwecker, Manuel; Dudkiewicz, Israel; Bloch, Ayala; Esquenazi, Alberto. 2012 Safety and tolerance of the ReWalk™ exoskeleton suit for ambulation by people with complete spinal cord injury: A pilot study: Journal of Spinal Cord Medicine, Volume 35, Number 2, pp. 96-101(6)
Esquenazi, Alberto MD; Talaty, Mukul PhD; Packel, Andrew PT, NCS; Saulino, Michael MD, PhD . 2012. The ReWalk Powered Exoskeleton to Restore Ambulatory Function to Individuals with Thoracic-Level Motor-Complete Spinal Cord Injury. American Journal of Physical Medicine & Rehabilitation: Electronic edition, 5 September
Evan Ackerman, Berkeley Bionics Introduces eLEGS Robotic Exoskeleton,IEEE Spectrum, 9 October 2010.
Kawamoto H, Taal S, Niniss H, Hayashi T, Kamibayashi K, Eguchi K, Sankai Y. Voluntary motion support control of Robot Suit HAL triggered by bioelectrical signal for hemiplegia. Conf Proc IEEE EMBS.2010;2010: 462-6. doi:10.1109/ IEMBS. 2010.5626191.
Kenta Suzuki, Gouji Mito, Hiroaki Kawamoto, Yasuhisa Hasegawa and Yoshiyuki Sankai (2010). Intention-Based Walking Support for Paraplegia Patients with Robot Suit HAL, Climbing and Walking Robots, Behnam Miripour (Ed.), ISBN: 978-953-307-030-8, InTech, Available from: http://www.intechopen.com/books/climbingand-walking-robots/intention-based-walking-support-for-paraplegia-patients-with-robot-suit-hal
MINDWALKER: Going one step further with assistive lower limbs exoskeleton for SCI condition subjectsBiomedical Robotics and Biomechatronics (BioRob), 2012 4th IEEE RAS & EMBS International Conference on 24-27 June 2012 Page(s):1794 - 1800
MAGIC ARMS- 3D Printed 'Exoskeleton' Lets a Little Girl Lift Her Arms and Play – Laserlines press release October 2012.
DOLLAR AND HERR: LOWER EXTREMITY EXOSKELETONS AND ACTIVE ORTHOSES: CHALLENGES AND STATE-OF-THE-ART IEEE TRANSACTIONS ON ROBOTICS, VOL 24 NO 1 February 2008