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Design and Simulation of Under Limb Orthosis for Rehabilitation of Paraplegics

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Abstract: Lower limb orthosis can be used to replace the loss of functioning of lower limb that causes a lot of inconvenience in carrying out day to day activities. However, wheelchair may assist to some extent it might lead to medical issues. Replacing the wheelchair with rehabilitation devices helps in sorting this issue. Various rehabilitation techniques and devices that are developed are reviewed and their specifications and comparisons are mentioned in brief. A lower limb orthosis is designed using solidworks and the design imported into MATLAB using simmechanics is simulated using simscape multibody and the resulting torques for each joint namely hip, ankle and knee joints are obtained.

Keywords: Orthosis, Paraplegia, Rehabilitation, Simulation, Under limb

I. INTRODUCTION

United Nation's World population prospects [1] shows that the population of elderly people ranges to be around 962 million in 2017 and by 2050, the global population of older people will be double its size in 2017, reaching nearly 2.1 billion as shown in Fig[1]. Growing Un-hygienic conditions are being the main reasons for reduced immunity and physical strength in human body. Most of the aged people suffer with lost motor functions and require some external assistance to carry out daily activities. Devices like crutches, wheelchairs are used to assist in their mobility. People suffering with loss of motor function due to spinal cord injury also mostly rely on wheelchair. However, excessively relying on wheelchair may lead to medical disorders like osteoporosis, heart diseases, illness and ulcers[2]. Hence, instead of spending those extra medical care costs we can replace wheelchairs with some rehabilitation devices like exoskeletons or orthotics which reduces the need of external assistance and make the person self – dependent.

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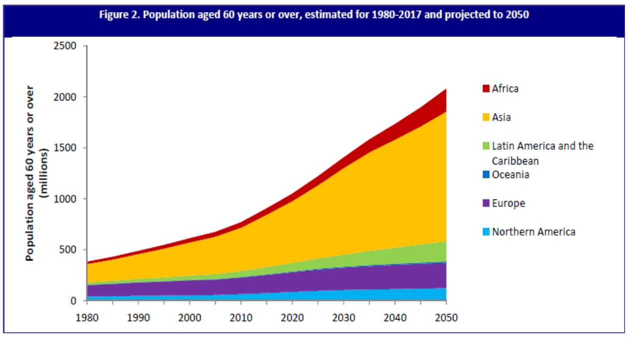

Fig.1. World population prospects[1]

Paraplegia

Paraplegia is a lower limb paralysis and is mostly caused in case of any damage to the brain or spinal cord. When spinal cord injuries to the thoracic occur, signals cannot hop from lower body region to the brain and vice-versa due to the extensive loss of sensation and they suffer with complete inability to feel anything below the waist.

Predominant cause for paraplegia:

Car & motor cycle accidents, Falls, Medical/Surgical Injuries are estimated to be around 72% reasons for the people suffering with paraplegia.

There are many rehabilitation techniques for the people suffering with paraplegia due to Spinal cord injury. At the initial stages of paraplegia, patient rely on a wheelchair for their movement, but using wheelchair for excessive time may lead to medical co-morbidities. Hence rehabilitation devices like Wearable Exoskeletons and orthotic devices are been developing since 40 years. Starting from training a person in virtual reality environment and using a suspended treadmill to over-ground.

walking devices, the technology has been developed. A brief review of devices developed, their purpose and control techniques used and it's future scope is also mentioned in Table[1].

Wheelchair assisted people face major issues related to physical healths as well as mental issues like low esteem and inferiority as they always need an external assistance to take care, also they cannot keep an eye contact while talking to other people. This results in losing their self confidence. Since 40 years, an effort has been put to replace wheelchair with some rehabilitation device through which the patient can walk their own and become self-reliant and unaided.

Many such devices have been developed till date and some of them are commercially available. It started with gait rehabilitation devices through which the patient can be trained to regain his motor functions.

Firstly, the patient is trained through a virtual reality environment (VRE). Later they can be placed on the rehabilitation devices, these devices can be suspended on a treadmill or can be an over ground walking device.

Table- I: Review of Rehabilitation techniques

REHABILITATION TECHNIQUE	PURPOSE OF THE TECHNIQUE	CONTROL METHOD	CONCLUSION	FUTURE SCOPE
WheelChair	Primary substitution of lost motor function for patients suffering with paraplegia due to SCI is a Wheelchair.	Wheelchair can be controlled manually by the patient or through some external assistance.	Excessively relying on wheelchair can lead to medical disorders like heart disease, and ulcers [2].	Using External Orthotic devices instead of wheelchair for Rehabilitaiton.
Virtual Reality Environment	Restoring able body like condition and intuitive control after SCI by training the subject in a VRE.	Recording and analyzing Idling and walking kinaesthetic motor imageries (KMI) and Electroencephelogram(EEG) signals and decoding the signals within a virtual reality environment (VRE).	The simulator satisfied the properties like intuitiveness, robustness, and short training time. The successful implementation of this system shows that integrating EEG with BCI-FES system is feasible [3].	Implementing the KMI and EEG recordings to a real time BCI lower extremity device to enable the SCI affected to regain their motor functions or assist in their walking.
Treadmill Suspended Robotic Orthosis (RoGO).	To interface RoGO suspended over a treadmill with the BCI computer to allow for computerized control.	Cross-correlation analysis, omission and false alarm rates techniques are implemented. EMG control is also employed .	Results prove that restoring brain-controlled ambulation after SCI is feasible. This can be applied to incomplete motor SCI, where it could lead to better neurological results than standard physiotherapy.	Developing BCI-controlled lower extremity prostheses for free overground walking for those with complete motor SCI.
OVERGROUND walking BCI –FES system.	Restoring brain-controlled overground walking after paraplegia due to SCI with NON-Invasive technique.	BCI – FES system is used. BCI states, gyroscope, laser distance meter, and video recording data were used to assess the BCI performance. walking/idling control strategy with muscle reconditioning to facilitate standing and overground walking .	Non-invasive neurorehabilitative therapy in those with incomplete motor SCI can be achieved by modifying the version.	If this noninvasive system is successfully tested in population studies, the pursuit of permanent, Invasive BCI walking prostheses may be justified.

II. REHABILITATION TECHNIQUES

Once the patient is trained with suspended gait orthotics or virtual reality environment, he can be adopted with over-ground walking devices. Over-ground walking devices are the substitutes of wearable robotic devices like Exoskeletons or Orthosis. An orthosis denotes the anatomy of a limb and restores the lost functions and can assist persons with impairments in the limbs. Whereas, Exoskeletons complement the ability of the limbs and can also restore lost functions[4].

There are many developed exoskeletons for lower limb rehabilitation that are published in various journals. Classification is majorly focused on exoskeletons for gait rehabilitation categorized as suspended gait orthosis and over-ground orthosis.

A. Treadmill Suspended Exoskeletons

A treadmill suspended exoskeleton shown in Fig.[2] provides training for gait rehabilitation. Patient with lost mobility is attached to this device through a body-weight support system and is trained till he manages to be equipped with the device. Treadmill type gait training devices do not support moving around to carry daily activities, but they apply forces to the human joints to relearn their lost motor function.

A body-weight supported treadmill system is effective for gait recovery as it reduces the gravitational force on legs. ReoAmbulator and Lokomat, etc. are such devices developed for treadmill based gait rehabilitation through stationery gait training platforms [5].

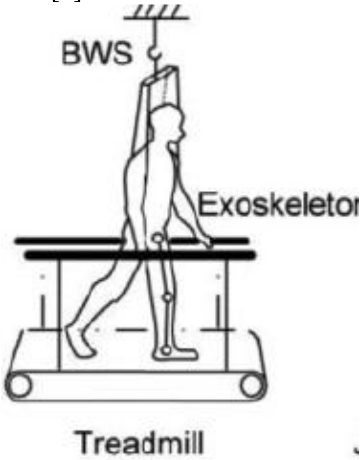

Fig. 2. Treadmill based Exoskeleton [5]

ReoAmbulator:

Also, referred to as AutoAmbulator is marketed by Motorika Ltd.,USA. It has an actuated hip and knee joints and an additional suspension system which keeps the trunk of the person in straight position. It is not much adaptable as it does not have a visual bio-feedback system, also it has only 3 D.O.F at hip and knee joints.

Fig. 3. ReoAmbulator [6]

Lokomat:

This exoskeleton is developed by Hocoma, Switzerland. It is a commercially available device adopted around the world. It has an additional feature of virtual reality environment of visual feedback. Hip and knee joints are powered and driven by DC motors and a ball screw.

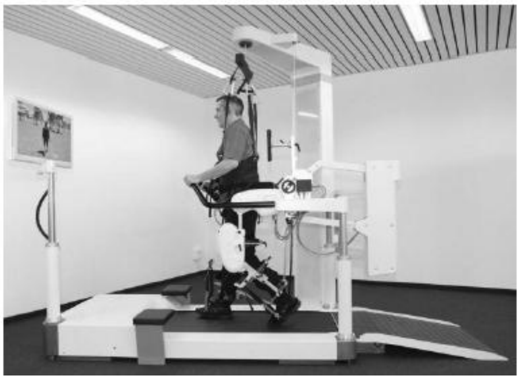

Fig. 4. Lokomat(Hocoma, Switzerland) [5]

ALEX(Active leg *exoskeleton*):

ALEX is a powered gait orthosis which has a force-field controller that controls the forces between the leg and the orthosis and helps it move in a desired path. It trains the subject in about 45 min to make him walk on a treadmill. It uses linear electro actuator instead of series elastic actuation(SEA) . ALEX provides force and impedance control. It has 4 D.O.F in hip for pelvic rotation and a hip brace to which the human is secured, thigh segment has 2 D.O.F and can be adjusted to human length. Shank segment and foot segment has 1 D.O.F with respect to thigh and ankle respectively. Each motor contains Encoders to determine the position of the joint [7].

Back-drivability of the device is obtained by friction compensation that makes the device responsive and offer least impedance.

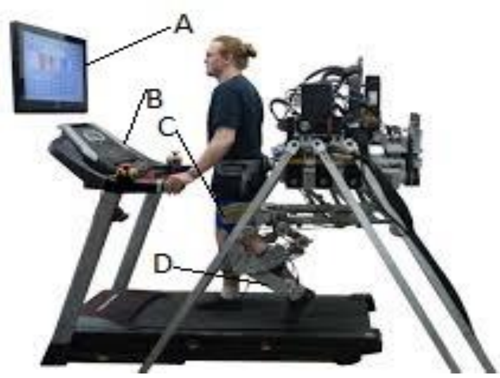

Fig. 5. ALEX(University of DELAWARE) : A. Visual feedback device, B. Treadmill, C. Leg thigh, D. Leg shank.

B. Over-Ground Walking Devices

Over ground walking devices can be a portable lower limb orthosis or a mobile rehabilitation robot. These devices could be referred to as powered Exoskeletons. Several factors are to be considered during their design such as weight, balance and power supply. Over ground exoskeletons can be of a simple portable device which can be worn by a patient directly or it can be associated with a BWS (body weight support) system and a mobile base. BWS system supports the trunk to be in an upright position [5].

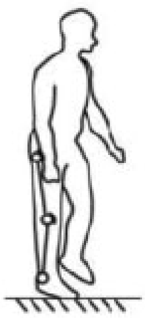

Fig. 6. Portable Exoskeleton.

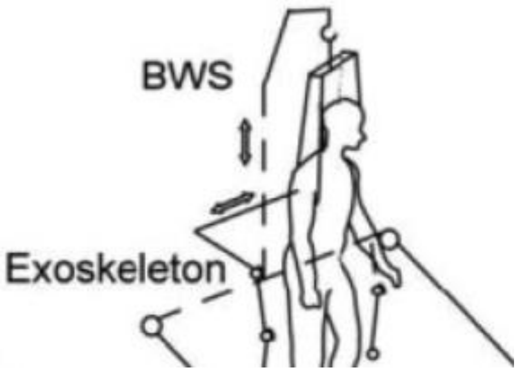

Fig . 7. Exoskeleton with mobile platform.

There are many such overground walking devices available commercially and some of them are explained in brief in Table[2]. All these devices allows the patient to easily put on and take off the device even if the user is in a wheelchair. In addition, some of the key points like cost, battery life and walking speed of the device, etc are also mentioned below:

Table- II: Specifications of Over ground walking devices

EXOSKELETON	WEIGHT	CLUTCH SUPPORT	ACTUATED JOINTS	D.O.F	SENSORS USED	ACTUATORS	CONTROL TECHNIQUE
ReWalk	23	YES	Motorized Hip & Knee joints for both legs	4	Torso tilt sensor, wireless mode selector	DC motors	Position control using trajectory tracking control method.
HAL	15	NO	Motorized Hip & Knee joints , passive control of Ankle	6	Rotary encoders, strain gauges , floor reaction force sensor	Harmonic drive gears, DC servo motors	EMG based control , wireless LAN control , and virtual torque control .
Ekso / eLEGS	20	YES	Hip & Knee joints (f/e), passively actuated Ankle	6	Encoders, Linear accelerometers	Hydraulic Actuators	Position & Impedance control using Finite State Machine method
Rex	38	NO	Hip, Knee and Ankle	6	Encoders, force sensors	Linear Actuators	Non–Invasive brain interface control for data acquisition from brain directly, joystick control
Indego	12	YES	Hip & Knee	4	Potentiometers as Angle position sensors	Brushless DC Motors	FES controlled device, postural information measured control .

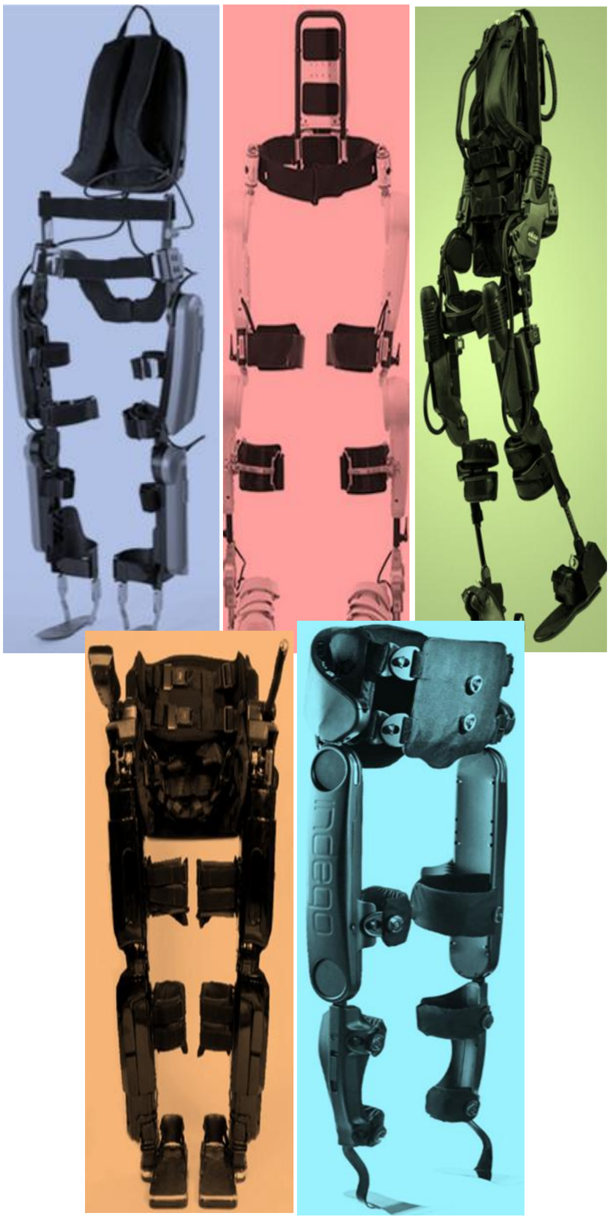

Fig. 8. ReWalk, HAL, Ekso/eLEGS, Rex, Indego [13]

Specifications:

a) ReWalk: Battery life - 2Hr 40Min,
Cost – 70,000 USD,
Walking speed - 2.2 kmph [8],[9]

b) HAL: Battery life – 2Hr 40Min [10].

c) Ekso: Battery life – 6 Hrs,
Cost – 1,00.000 USD,
Walking speed – 3.2 kmph [11].

d) Rex: Battery life – 2Hr,
Cost – 1,50,000 USD,
It has a self balancing system.

e) Indego: Battery life – 1Hr,
Cost – 1,40,000 USD,
Walking speed – 0.8 kmph [12].

III. MECHATRONIC DESIGN APPROACH

Mechatronic approach of designing a lower limb powered orthosis with 8 D.O.F. having four for each leg includes a combination of various sensors, actuators and control mechanisms. Replacing conventional sensors with latest smart sensors can improve the accuracy and precision of the device.

Main objective of this design is reduction in weight of the device and improving its efficiency. This can be achieved by using medium torque- medium speed servo motors. Maintaining user condition monitoring in order to avoid any danger to the wearers' body can increase the widespread use of lower limb orthotic devices.

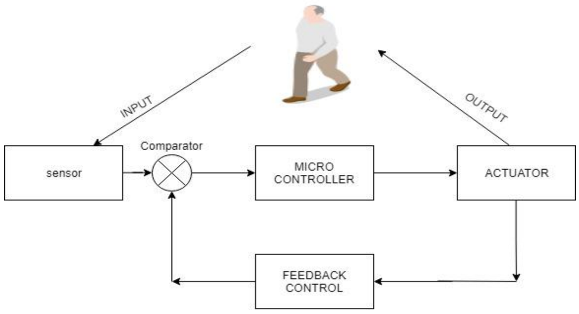

Fig. 9 : Automatic Control System

Wearer's leg motion and position are measured with optical encoder placed at each joint of the leg and the signal is sent to the ARDUINO board that acts as a controller. Based on the input from the sensor, controller controls the actuation of joints. Here, joints are actuated using servo motors. Additionally, the controlling of the device can be done using Brain Computer Interface.

Brain computer interface can be done by implementing EEG(ElectroEncephelogram) signals coming from the brain are extracted and given to the controller. Controller decodes the signals and controls the actuation of the joints.

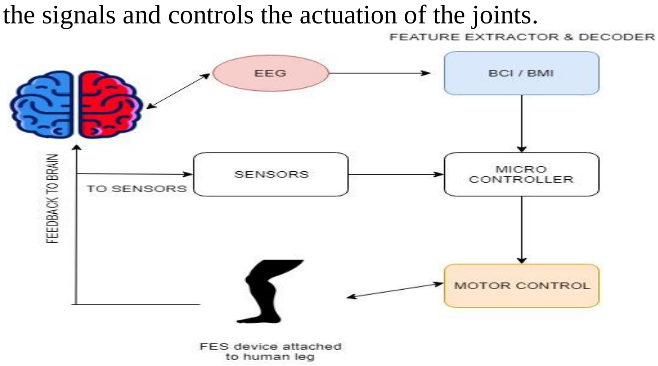

Fig. 10. Brain computer interface system

Design:

A lower limb exoskeleton is specially designed for assisting the people with paraplegia due to spinal cord injury. It has three rotary joints namely Hip, Knee and Ankle joints which can be attached to the wearer's Hip, Ankle and knee joints respectively. It has 2 vests for supporting the waist of the wearer's body. Battery and Controller board can be placed in the racks provided at each vest.

The Length and width of the lower limb exoskeleton can be adjusted according to the wearers' body dimensions with help of the adjustment rods provided at each joint. Clamps are provided at each leg to attach the device to the wearer. Foot system is provided in order to support the foot of the wearer. Servo motors can be attached at the place provided at each joint to give the joint a desired rotary movement.

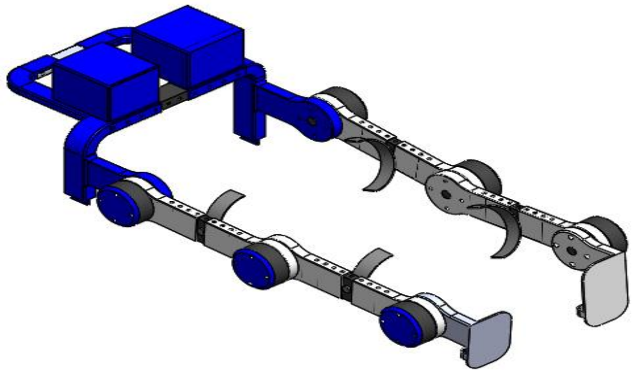

Fig. 11. Isometric View of the proposed design

IV. SIMULATION

Torques for each joint is simulated through MATLAB software. Firstly, the structure is designed using SOLIDWORKS as shown in the figure. Output torque for three joints of each leg namely Hip, Knee and Ankle joints are obtained. These results can be considered in constructing the real hardware.

Solidworks design in imported into MATLAB through simmechanics and the simulink model is shown in the Fig[11]. By using simmechanics explorer, we can run the simulation of the device and verify its motion.

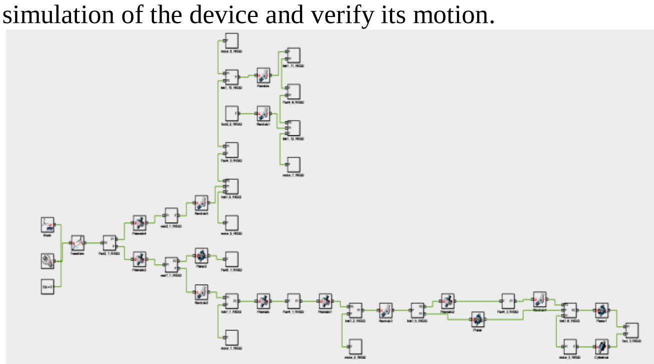

Fig. 12. Simulink Model

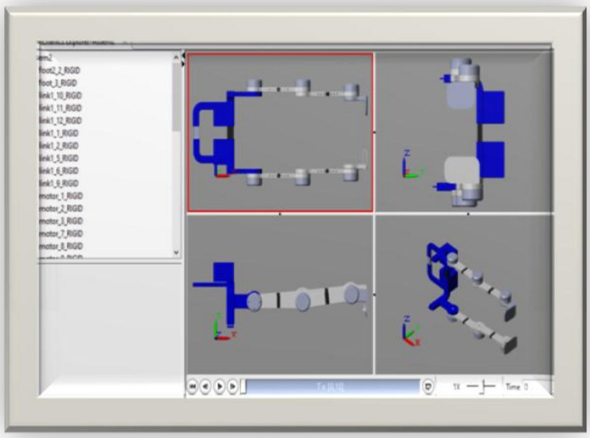

Fig. 13. SimMechanics Explorer view of the design

V. RESULTS

Revolute joints of each leg are provided with sinusoidal input signal in order to calculate the Output torques. Motion for the device is provided by the sensors and the torques are set to automatically compute. Output torques for each joint are realized and are plotted as shown in the Fig.14. Maximum torque obtained is 210 N-m.

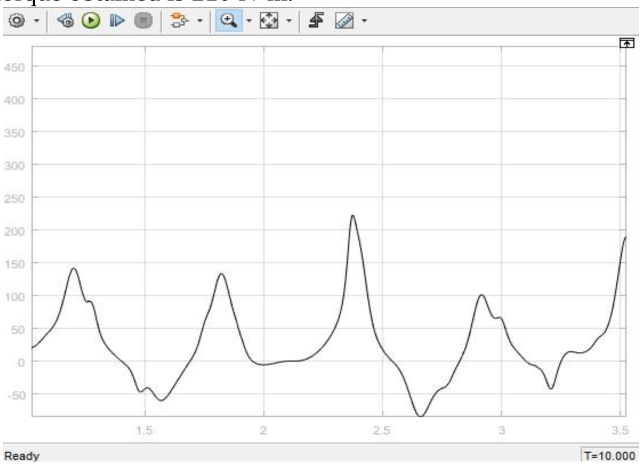

Fig. 14. Hip Torque

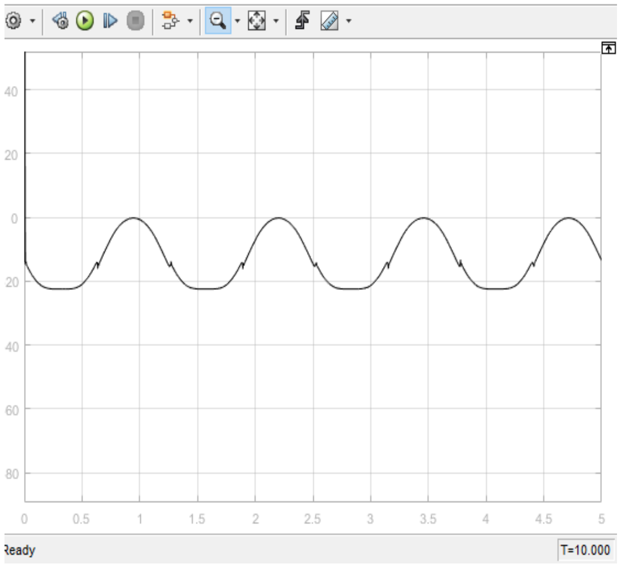

Fig. 15. Knee Torque

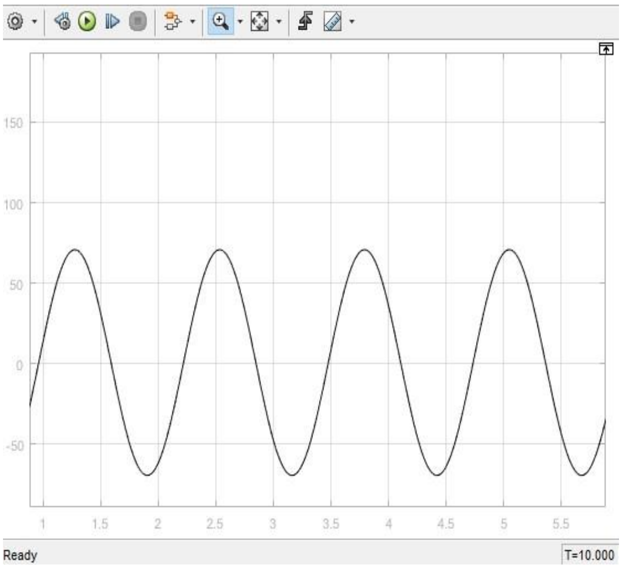

Fig. 16. Ankle torque

VI. CONCLUSION

A new exoskeleton device is designed that can be adjusted according to the wearer's dimensions and has a variable assist. The design is simulated and the torques for each joint is obtained. Maximum torque is obtained at the Hip joint and is 210 N-m. Major concern need to be taken regarding the exoskeleton is minimizing the energy requirements and the metabolic energy expenditure, solving these issues will have a significant impact on advancement of active orthosis. These results can be further implemented for making the device in real time. We can also make the device more portable and more efficient so that these devices can really reduce the metabolic cost during daily activities. The accuracy of the device needs to be further more optimized.

REFERENCES

1. UN Population fact sheets. 'Population ageing and sustainable development', August_2014.
2. Johnson, Renee L., C. A. Brooks, and Gale G. Whiteneck. Cost of traumatic spinal cord injury in a population-based registry. *Spinal Cord* 34, no. 8 (1996): 470-480.
3. Wang PT, King C, Chui LA, Nenadic Z, Do A. BCI controlled walking simulator for a Brain computer interface driven Functional Electrical Simulation device. In: Proc. RESNA Ann Conf; 2010
4. Minchala, Luis I., Fabián Astudillo-Salinas, Kenneth Palacio-Baus, and Andrés Vazquez-Rodas. "Mechatronic design of a lower limb exoskeleton." *Mechatronic Systems in Engineering: Design, Control and Applications of* (2017): 111.
5. Chen, Gong, Chow Khuen Chan, Zhao Guo, and Haoyong Yu. A review of lower extremity assistive robotic exoskeletons in rehabilitation therapy. *Critical Review in Biomedical Engineering* 41, no. 4-5 (2013).
6. Motorika. Retrieved 1 September, 2013, from http://www.motorika.com/?categoryId=91202.
7. Banala SK, Agrawal SK, Scholz JP. Active Leg Exoskeleton (ALEX) for gait rehabilitation of motor-impaired patients. Proceedings of the IEEE 10th International Conference on Rehabilitation Robotics (ICORR); 2007 Jun 13-15; Noordwijk aan Zee, The Netherlands. 2007.
8. g G, Weingarden H, Zwecker M, Dudkiewicz I, Bloch A, Esquenazi A. Safety and tolerance of the ReWalk exoskeleton suit for ambulation by people with complete spinal cord injury: A pilot study. J Spinal Cord Med. 2012;35(2):96-101.
9. Herr, Hugh. Exoskeletons and orthoses: classification, design challenges and future directions. *Journal of neuroengineering and rehabilitation* 6, no. 1 (2009)
10. Viteckova, Slavka, Patrik Kutilek, and Marcel Jirina. Wearable lower limb robotics: A review. *Biocybernetics and biomedical engineering* 33, no. 2 (2013): 96-105.
11. Ekso Bionics. (2012). Retrieved 2 September, 2013, from http://www.eksobionics.com/ekso.
12. Indego Powering People Forward. (2012). Retrieved 1 September, 2013, from http://www.parker.com/literature/Exoskeleton/Parker%20Indego%20Brochure.pdf
13. Rupal, Baltej Singh, Sajid Rafique, Ashish Singla, Ekta Singla, Magnus Isaksson, and Gurvinder Singh Virk. "Lower-limb exoskeletons: Research trends and regulatory guidelines in medical and non-medical applications." *International Journal of Advanced Robotic Systems* 14, no. 6 (2017): 1729881417743554.

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