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Low-cost approach towards the design and development of lower limb exoskeleton

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ABSTRACT

From the time the human race have evolved many have faced the difficulty in walking, standing, balancing and so on. About 13.7 percent of the world's population have a motor disability with serious difficulty in walking or paintingbalance making them among the largest minority groups on earth. Through this paper, we will be going to discuss the earlier research and the functions of the exoskeleton. The paper provides an overview of the hardware, sensors, actuators, and controlsystem for the performance of the exoskeleton. 3D prototype of the model is designed and the simulation are performed toachieve a low cost exoskeleton for the medical and defence purposes.

Keywords: *Exoskeleton, EMG Sensors, Robotics*

1. INTRODUCTION

1.1 Motivation and background

Mobility is one of the important traitsof all theadvanced forms of life which helped in the survival and evolution of the organism. Mobility is the vitalability needed for a human to do thedaily chores preserving his/herindependence while doing physical activities. Human locomotor skills require interaction between the nerve, neuromuscular, and musculoskeletalsystems to achieve natural movement, But, due to some unfortunate reasons like injuries, diseases, muscleimpairment, and genetic reasons thelocomotor skills get compromised. Reduced functionality of the body can cause mobility disorders to impact daily life activities. the WHO estimates that approximately 15% of the world's population has some form of disability, of which 2-4% experience significant difficulties in functioning because of locomotor disabilities. The GOI, by census 2011 shows about 2.1% of the Indian population is disabled, of which 27.9%have a disability relating to movement. I Ramendra Verma, myselfdiagnosed with amyotrophic lateralsclerosis (ALS) which is a progressive disease that limits the movement of the body. It is to improve the quality oflife for these people suffering from gait disorders and to help them become more independent by assisting and supporting their locomotion.

Exoskeletons, for example, can playan important role in addressing mobility issues. An exoskeleton is a user-oriented robotic system that replaces or supports limb function. The most successful applications of exoskeletons have been i nrehabilitation and quality of life enhancement, but they can also be found in the military, industry, and medical care.

Lower limb exoskeleton can play a vital role in the defence service as well as it could also assist the soldiers to march through difficult terrain carrying heavy weights on their back by increasing the human strength capability.

2. HUMAN ANATOMY OF LOWER LIMB

2.1 Nervous System

Nerves and nerve cells (neurons) inthe nervous system carry signals to and from the cerebrum and spinal cord to various parts of the body. The nervous system consists of the central nervous system and the peripheral nervous system. The sympathetic nervous system comprises these parts.

i. Sympathetic chain

Along with the two sides of the spine, the sympathetic chain is made up of ganglia that extend from the head to the tailbone. Ganglia are said to be the groups of nerve cell bodies. The sympathetic chain sends signals to the head, neck, lower body, and extremities during the fight-fear-flight response.

ii. Collateral ganglia

The celiac ganglion, inferior mesenteric ganglion, and superior mesenteric ganglion arethree collateral ganglia. They are present in the abdomen of the front spine. Collateral ganglia are responsible for sending messages to the organs in the abdominal and pelvic regions.

iii. Adrenal medulla

Each adrenal gland has an adrenal medulla in its centre. The adrenal medulla contains specialized neurons.

2.2 Hip Joints

Hip joints are ball and socket joints, where the head of the femur bone attaches to the acetabulum of thepelvis.

Motion Available

The hip joint can move 3 major axes, and all of these motions are perpendicular to each other.

- A femoral head is located at the centre ofthe entire axis.
- The sagittal axis allows the forward to backward and allows the motion of abduction and adduction.
- In the longitudinal axis, or vertically along the thigh, rotation can be internal and external.
- The transverse axis permits flexion andextension movement.

2.3 Knee Joints
The knee joint in the human body is considered one of the largest and mostcomplex joints. An extensive network of muscles and ligaments attaches fourbones to form this body part. It iscrucial to understand thebiomechanics of human walking whendesigning exoskeletons and active orthoses for the lower limbs.

2.4 Ankle Joints
Synovial joints are hinged and formedby the articulation of the talus, tibia, and fibula bones.

Motion Available:

- During ambulation, the ankle joint is crucial since it adapts to the surface onwhich one walks.
- Leg muscles are divided into anterior, posterior, and lateral compartments.
- At the ankle joint, plantar flexion, dorsiflexion, inversion, and eversion are all possible movements.

3. EXOSKELETON
Powered human exoskeleton deviceshave been researched since the late 1960s when science- fictional writers first used the word"exoskeleton" to represent a device that enhances wearable performance. There are 3 of 17 seven degrees of freedom in the human leg, including three rotational degrees at the hip,one at the knee, and three at the ankle.

3.1 History of the Exoskeletonand Wearable Robotics Parts

3.1.1 Mihailo Pupin Institute Exoskeleton: The Mihailo Pupin Institute in Belgrade housed Mihailo Vukobratovic and his collaborators who carried out important research in the late 1960s and 1970s relating to exoskeletons that continue to be respected as among the most comprehensive. In their work, they proposed a "kinematic walker," including a water-powered actuator for driving both knees and hips in a kinematic way.

Source: *https://www.mechatech.co.uk/journal/exoskeleton-history-part-4*

Duringthe 1970s, a rumoured "kinetic dynamic exoskeleton" was developed, incorporating pneumatic actuators for hip, knee, and lower leg flexion/expansion, in addition to a snatching/ adduction joint at the hip to provide greater flexibility in frontal planemotion. This idea was subsequentlyaltered somewhat into the "complete exoskeleton" by broadening the connection at the middle to encase the whole chest of the patient, giving more prominenttrunk support.

3.1.2 DARPA Exoskeletons: Close by there was a profound interestcreated which prompted broad examination in the research field ofexoskeletons. The United States concocted its tremendously discussed Defense Advanced Research Projects Agency (DARPA) program which welcomed the research connected withexoskeletons.

Source:*https: //roboticsandautomationnews.com/wp-content/uploads/2016/01eksoproduct.jpg*

DARPA's well-known exoskeletons include BLEEX, Sarcos, and MITExoskeleton. Before examining other exoskeletons in the field of rehabilitation, we will discuss the BLEEX created under this program, Berkeley Lower Extremity Exoskeleton (BLEEX) has been the most notable of the DARPA program exoskeletons. The distinctive component of this task is that it conveys its power source. To be sure, its designers guarantee it to be the main "load-bearing and vigorously independent" exoskeleton.

In BLEEX, there are three degrees of freedom at the hip, one at the knee,and three at the lower leg. Four ofthese movements are activated: hip flexion/expansion, hip snatching/ adduction, knee flexion/augmentation, and lower leg flexion/augmentation. The kinematics and activation necessities of the exoskeleton were planned by expecting the actual wayof behaving like that of a 75 kg humanand using clinical stride examination information for strolling. When you stroll on flat ground, you consume an average of 1143W of water-driven power and 200W of electrical power for the hardware and control, whereas you consume 165W of metabolic energy.

3.1.3 Exoskeletons in Rehabilitation When patients with spinal cord injuries or cerebrum injuries lose motor elements of their lower body limbs due to injury, exoskeletons can dramatically facilitate their recovery and rehabilitation. Patients who have been wheel- led deal with plenty of issues as to their development and manage numerous mental issues.Furthermore, the human body is designed in such a way that it is capable of standing, walking, andmoving around, yet a wheelchair client

loses this ability and is negatively affected.
To conquer such issues, exoskeletons assume a significant part in recovery and empower a wheelchair client to be free of wheelchairs, empowering him to stroll around. As we have already discussed, the Mihailo Pupin Institute Exoskeleton was a trailblazer, yetbecause of the mechanical limitations of that time, it was not considered a truly doable choice. Be that asit may, with propels in innovation, today we see some noteworthy innovative work in the field of exoskeletons and their application in restoration has begun toenter the field of commercialization.

Exoskeletons like the REX,eLEGSTM, HAL, Vanderbilt, MindWalker, and ReWalkTM, are some examples of achievement in the field of the exoskeleton.

Every single one of them has a one-of-a-kind component. Some utilise certain biosignals to work, while some utilise complex calculations with a ton of sensor data. The working principle is based on as responds stride orthosis while utilizing the utilization of a joystick to work. We will presently examine the ReWalk and eLEGS followed by HAL and Windwalker.

3.1.4 HAL-5

For control, the HAL-5 framework uses a variety of detecting modalities including skin surface electromyographic (EMG) anodeslocated below the hip and above the knee, as well as potentiometers for estimating joint flexion points, ground response force sensors, and a spinnerand accelerometer on the rucksack for determining middle stance.

A mobile example-based system and an EMG- based system employ these detecting modalities to decide thesuit's function and work, respectively.

3.1.5 Comparison of different exoskeleton

Characteristics		HAL-5	Rewalk	Rex	WalkON suit
Design					
Control strategy		Predefined gait trajectory & Model based control	Predefined gait trajectory	Positioning control	Predefined gait trajectory
DOF	Hip	3	2	3	2
	Knee	1	1	1	2
	Ankle	1	1	2	2 Passive
Type of sensors		Force Kinematic EMG	Kinematic	Kinematic	Kinematic
Actuation type		Electric	Electric	Electric	Electric
Battery life		1 hour	2 hours 4 minutes	2 hours	Up to 5 hours
Motion performed		Standing and Sitting Walking Climbing stairs Load augmentation	Standing and Sitting Walking on different surfaces Climbing stairs	Standing up Walking Climbing stairs	Standing and Sitting Walking on different surfaces Climbing stairs
Additional support		none	crutches	none	crutches
Wight		12 kg	15 kg	39 kg	30 kg

3.2 development of Exoskeleton

i. Actuators

Actuators transform electric, air, or hydraulic pressure into mechanicalpower for the gadget or machine tomove.

Actuators are utilized in exoskeletons to give the expected actual force tohelp weight, inactivity and size of the exoskeleton gadget and the client loadduring motion. Electric driving actuators are more commonly in lower exoskeleton robots since they are not difficult to control with high accuracy contrasted with water-powered and pneumatic actuators.

Notwithstanding, hydraulic driven actuators are normal in executionexoskeletons, for example, military,industry and burden increase applications because of the high ability to massproportion.

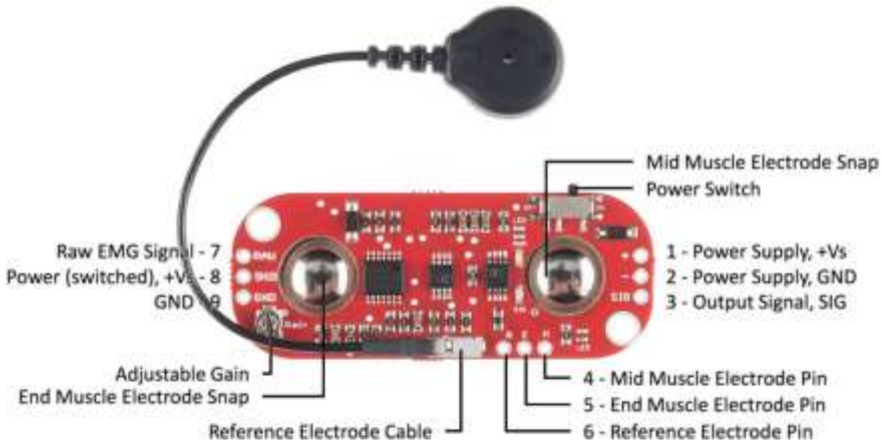
ii. Sensors

Human bio-mechanical information related to movement can be sorted into three classes: kinematic, motor and bioelectric information. The kinematic information addresses body stance and joint points. The motor information addresses the joint forces and cooperation powers.

During human movement, bioelectric information structures the organic signs of movement such as the electromyography (EMG) signal, the electrooculography (EOG) sign, the electroencephalographic (EEG) sign, and the electrocardiographic (ECG) signal.

Sensors are utilized in mechanical technology to refresh the regulator framework with specific internet- based data regarding the state of the framework. In general, Keen control frameworks consist of three layers: insight layer, choice layer, and execution layer. To recognize the stateof the frame, the wearer's position and the general climate, the insight layerin the exoskeleton regulator uses multi- sensor data; primarily point sensors, pressure sensors, and organicsign sensors. Whirligigs ,inclinometers, encoders, precise speed increase sensors, and inertial estimation units are all part of point sensors.

A pressure sensor is used for a variety of purposes, such as identifying strolling stages, weight movement process, and determining the force of connection between human and exoskeleton.



Source: https://cdn.sparkfun.com/assets/learn_tutorials/4/9/1/topSensor.jpg

iii. Motors and Movement of Stepper Motor

A stepper motor is a device based on the electromechanical concept. Electrical power is converted to mechanical power by the motor. Furthermore, it can separate a full pivot into many steps by using a brushless, simultaneous electric engine. As long as the engine is carefully measured to the application, the motor's position can be controlled almost without any input instrument.

iv. Framework

a. Chrome Tube for outline support Chrome Moly items are called so because of the presence of the two components Chromium (Cr) and Molybdenum (Mo). Cr helps in increasing the material's protectionfrom consumption and oxidation and raises the material's solidarity at high temperatures. Mo is known to increase the tractable and creep strength at high temperatures, lessen weakness, and further develop hardenability. In some cases alluded to as "P Grade" materials or just "Chrome".

b. Steel Sheets Plate to help the casing

Iron- based materials such as stainless steel are known for their heatresistanceandlowconsumption. In contrast with other forms of preparation, treated steel has a base chromium content of 10.5%, which gives it greater obstruction than consumption.

c. Fiberglass for bending and strength

Glass fibres are thin strands of glass made upof many fine strands. These items are among the most versatile materials known to man.

Different filaments such as carbon fibre and polymers have virtually identical mechanical properties. In the construction of fibreglass, which is a tough and lightweight material, glass fibre is utilized as a building
material. Properties of fibre glass -High heat resistance

1. Dimensional stability.
2. High tensile strength.
3. Good chemical resistance.
4. High heat resistance
5. Great durability
6. Highly economical

In an exoskeleton, architects will require lightweight materials thatcan endure enormous powers. Materials like steel and aluminium have specific strengths of around 100 to 250 kN-m/ kg, whilefibreglass is around 1,300 kN- m/kg.

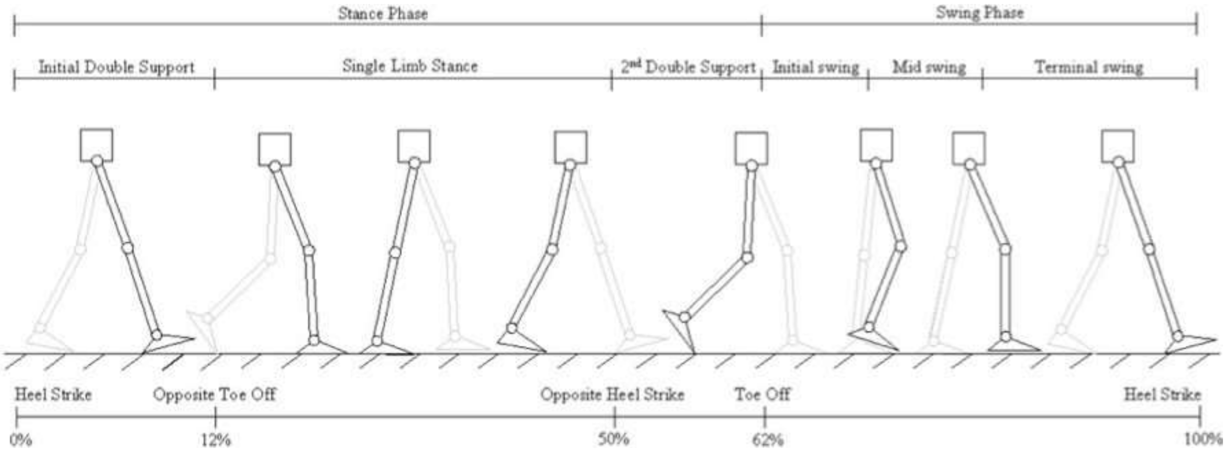
4. DESIGN AND MODEL

4.1 Gait Analysis

Understanding the biomechanics of human walking is crucial for thedesign of lower limbexoskeletons and dynamic orthoses.

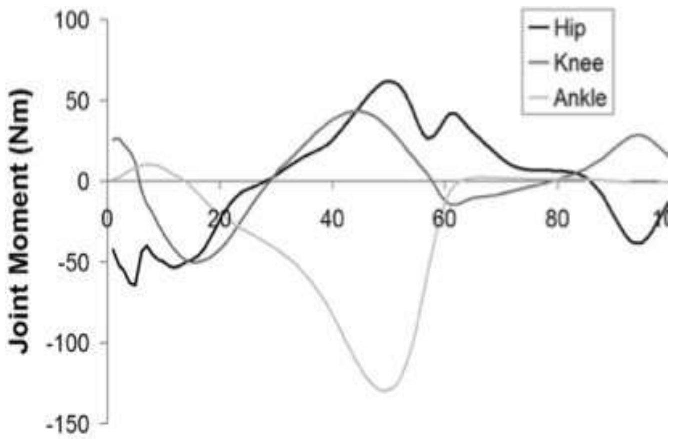
The human walk step cycle is normally addressed as beginning (0%)and finishing (100 percent) at the mark of impact point strike on a similar foot, with impact point strike on the next foot happening at roughly 62% of the stride cycle.

Among the seven degrees of freedom in the human leg, three rotational degrees exist at the hip, one at theknee, and three at the lower leg. In this step, the word flexion (positive heading) and expansion (negative heading) is used to describe joints moving in this plane. In this step, the word flexion (positive heading) andexpansion (negative heading) is usedto describe joints moving in thisplane. Adduction(away from the focal point of the body) and abduction (into the body) are terms used to describe hip movements in the coronal plane. As well as eversion (away from the focal point of the body), reversal is also referred to as the movement ofthe lower leg in the coronal plane. This paper describes the kinematic format of the different exoskeleton and orthosis plans as "revolutionary," with the remaining degrees of freedomof the hip and lower leg described as “revolutionary."

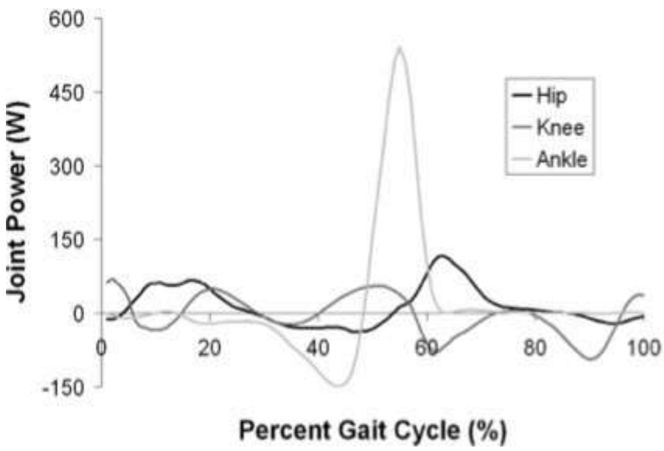


Gait Cycle- Subdivision

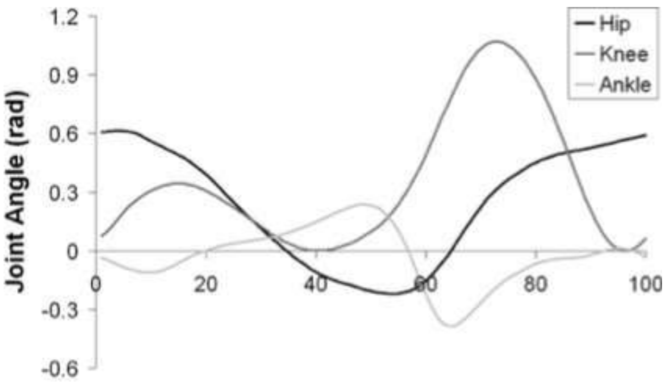
4.2 Graph of Gait Cycle Analysis



Graph of Joint Moment

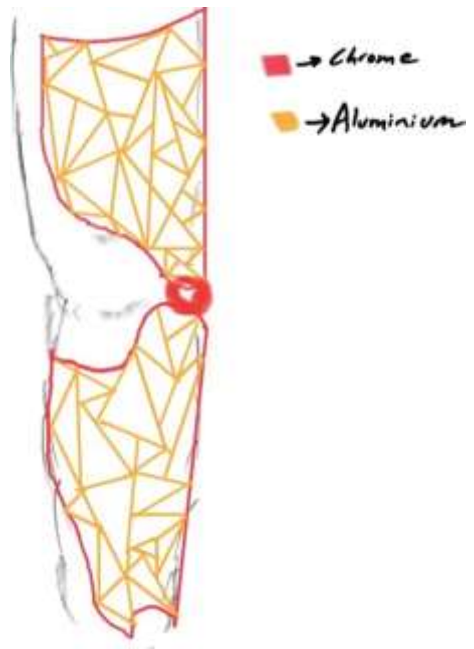


Graph of Joint Power



Graph of Joint Angle

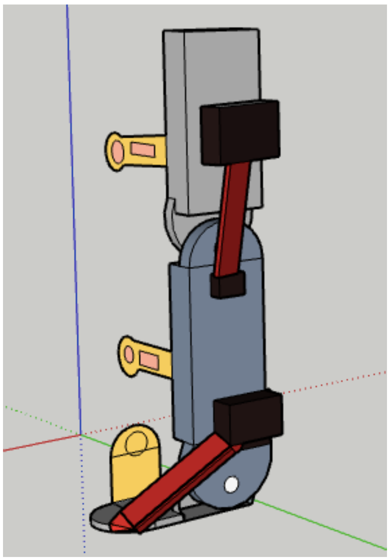
4.3 Designing of the frame work



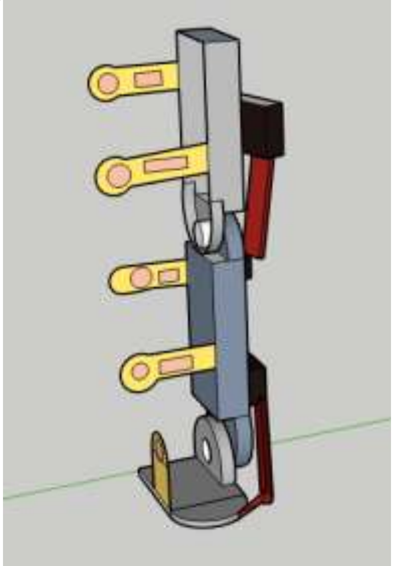
The frame of the exoskeleton body is design using Chrome and Aluminium metal which provide the body strength but keeping it light weight.

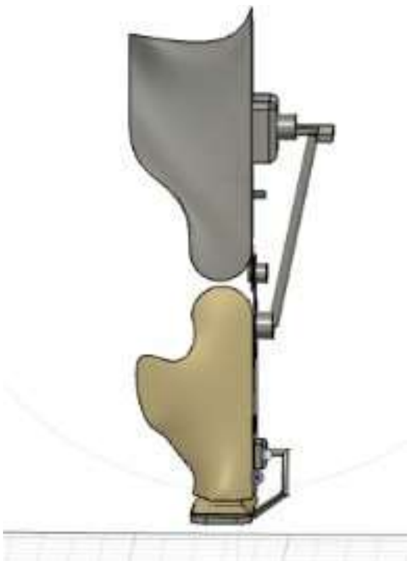
4.4 Model of 3D prototype

i. Prototype I

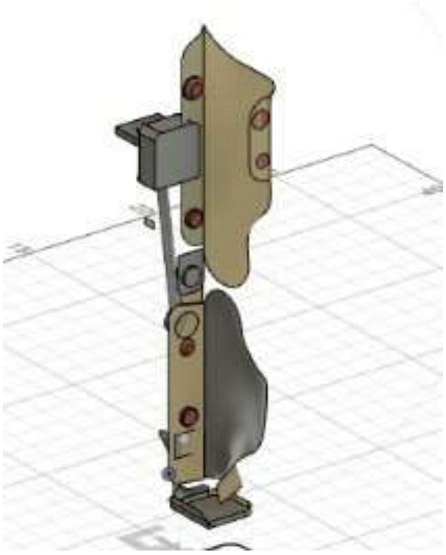


ii. Prototype II



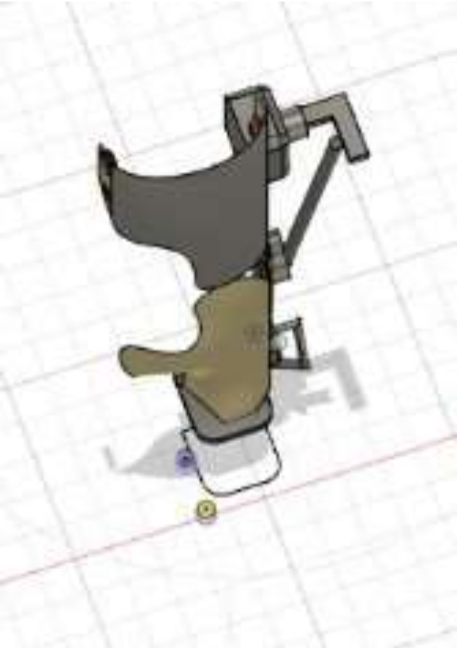


Front View



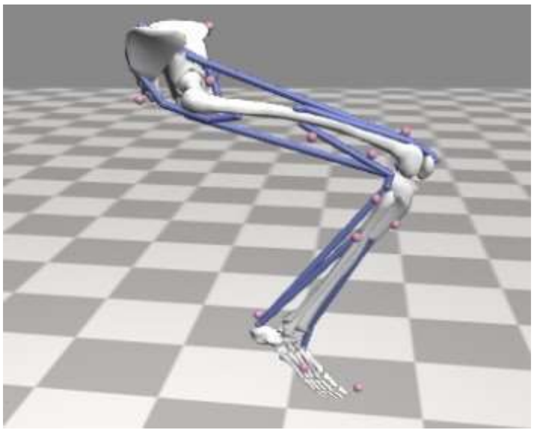
Rear View

Side View

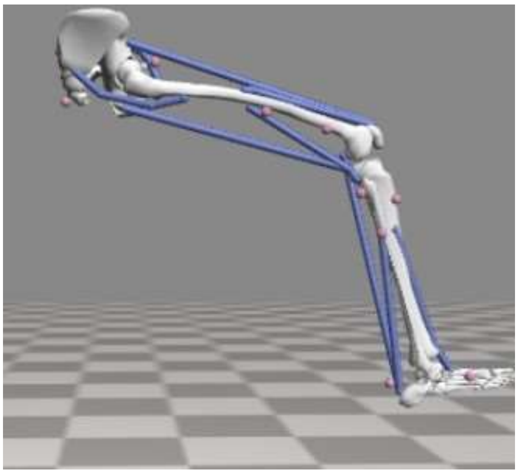


Top View

5. SIMULATION



Hyper-flex Movement



Flex Movement

6. CONCLUSION

This paper is written as an academic project. The paper consist of 3Ddesign, simulation and going through of earlier research. We saw that how people with disabilities faces problems in day to day lives and we decided that how technologies of today can providethem with the assistance in dailylifestyle. In this paper, we have gone through with all the different types of research and design of exoskeleton. Here we tried to develop the exoskeleton framework using robotics as well as machine learning of the lower limb.

We developed the economically friendly framemade of Chrome Molly alloy and carbon fibre with the EMG sensors. This exoskeleton helps the user to balance and provide the strength to the lower limb to stand andwalk.

EMG is attached to the surface ofhuman body monitoring electrode.The EMG sensors reads the signal ofthe nerve of human body and throughthe arduino nano the signal is processed and compared with data setusing python supervised machineleaning and the output generated byarduino nano helps in the movement. The movement of the knee joint isassisted by the stepper motor and theactuator. Actuator provides the moment through hinge joints.

There is also an additional support is provided for the foot to rest with flexible movement using sensors, motors and joints. An additional set EMG sensors at the calf muscles and arduino nano chip are set near ankle.

The 3D design of the prototype was created on Autodesk Fusion 360, showing the cost efficient compact version for the exoskeleton and the simulation for the flex and hyper-flex was preformed on the Opensim software, showing the desired moments. 3D prototype of the modelis designed and the simulation are performed to achieve a low cost exoskeleton for the medical and defence purposes.

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APPENDIX

1. Abbreviations

CAD Computer aided design **CGA** Clinicalgait analysis **CoG** Centre of gravity
CoM Centre of mass
CoP Centre of pressure **DE** Differential evolution **DoF** Degree of freedom **ECG** Electrocardiography
EEG Electroencephalography **EMG** Electromyography **EOG** Electrooculography **FLC** Fuzzy logic control
KAFO Knee-Ankle-Foot orthosis
MIMO Multi input multi output
MISO Multi input single output **MSC.vN4D** MSC. VisualNastran 4D **PD** Proportional Deravitive
PID Proportional Integral Deravitive **PSO** Particle Swarm Optimisation **RMS** Root meansquare
RMSE Root mean square error
RoM Range of motion
SCI Spinal cord injury
SDA Spiral dynamic algorithm
SISO Single input single output

2. Software Used

Autodesk Fusion 360Sketch Up
OpenSim