EEG CONTROLLED LOWER BODY ROBOTIC EXOSKELETON

Hemanth Modulla - 115608832
Rijuta N. Dighe - 116269407

Overview

- Spinal cord injuries can happen through direct injury to the cord, or indirect injury to surrounding tissue and bone. In complete injuries, there is no function below the point of injury, while in incomplete injuries, there is some function below that point.

- Many a times the victims do not physically lose their legs, but the ability to use them is lost either partially or completely. In such cases, prosthetics does not help. To use prosthetic limbs, the victims will have to go through amputation. In fact a large number of Americans are likely to opt for an elective amputation to go back to ‘normal life’. However, Prosthetics is neither a comfortable nor a viable solution.

- In United states yearly around 13000 people suffer spinal cord injuries. For the first year, people with high tetraplegia can expect to pay about a million dollars for care. Low tetraplegia produces about $769,000 in medical expenses, while paraplegia costs about $518,000. On an average $315,000 is spent per person on mobility aids and care.

- A non invasive, cost effective solution can be very helpful for people with such condition.

Understanding the problems

1. Victims of spinal cord injury who can neither send nor receive signals to legs due to injuries in the spinal cord have to rely on wheelchairs and do not benefit from the advancements in artificial prosthetics.

2. Patients have to go through an elective amputation to use artificial legs for which most of them are rightly reluctant.

3. Existing solutions are either costly or invasive.Existing Non invasive equipment is bulky and not very comfortable.

Project Objectives

- To design a low cost, lightweight, lower body robotic exoskeleton that can be controlled using brainwaves (EEG Signals-Electroencephalography).

- To design a product that helps paralyzed human beings regain their ability to walk

Identifying the customers

The main target audience are people with condition:

- The brain is able to sense touch and other sensations in the body, but is unable to effectively relay a response due to injuries in the spinal cord.
- The victims have not lost their legs physically or those who have partially lost their legs making it difficult to use a prosthetic legs.
- The brain can neither send nor receive signals to an area of the body due to injuries in the spinal cord.
- People with incomplete quadriplegia (tetraplegia), complete paraplegia, complete quadriplegia (tetraplegia), incomplete paraplegia

Such as : Soldiers, Victims of accident…..

Image:http://www.candoability.com.au/cda/blog/

Market Analysis

In United States

- Around 30.6 million people (15 years and older) have difficulties in walking and climbing stairs.
- Around 3.6 million people (15 years and older) use a wheelchair to assist with mobility. About 11.6 million people who used a cane, crutches or walker.
- $3.9 Billion is expected for the power wheelchair market by 2018.
- This is a huge market and is growing everyday.

Market Trends

- Some of the significant market players include Ekso Bionics, ActiveLink (Panasonic Corporation), Cyberdyne, Inc., **ReWalk Robotics** Ltd., Rex Bionics Plc, Lockheed Martin Corporation, Suit X (U.S. Bionics Inc.), RB3D, and Hocoma.
- Investments by key players for the development of new and innovative products is expected to boost the market growth in the coming years.
- For instance, ReWalk Robotics developed an exoskeleton, designed to support the legs and upper body of a disabled person. Similarly, **Ekso** Bionics developed Ekso GT for use in rehabilitation therapy for patients suffering from stroke and spinal cord injuries.
- Furthermore, **Phoenix** by SuitX, is another exoskeleton designed for pediatric patients, suffering from cerebral palsy and spinal injuries, to gain mobility.

Requirements

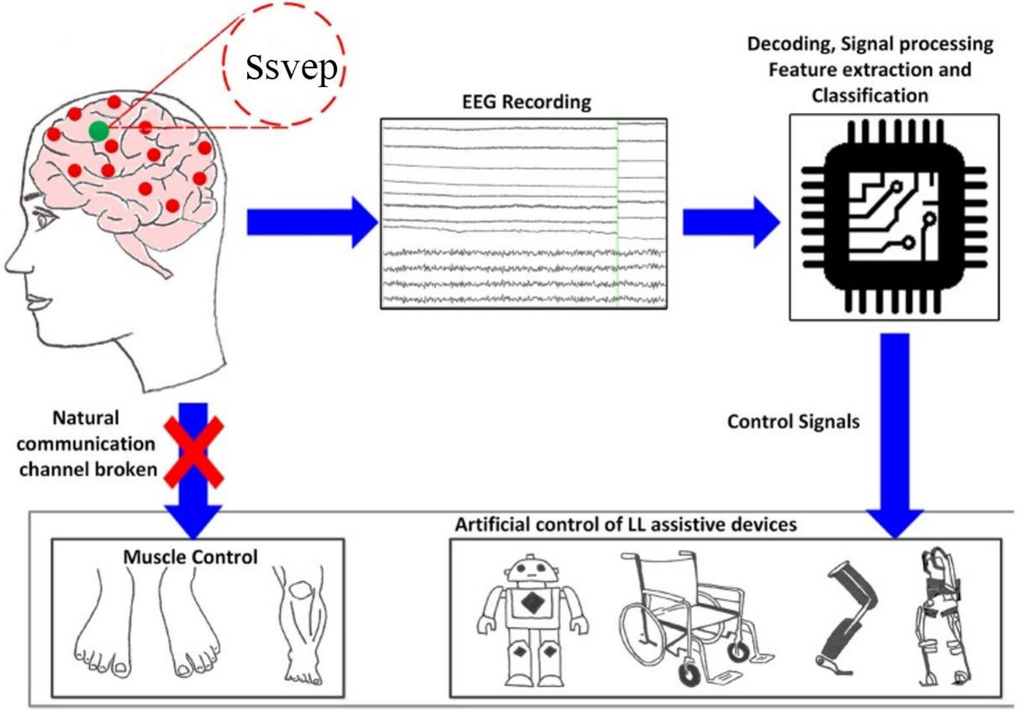
User Requirements:

- Smooth Walk
- Safety (Water, Heat and shock proof)
- User friendly
- Cost effective
- Low maintenance
- Aesthetically good
- Least possible disturbances.
- Fast and good customer service.
- Easy and fast recharge.

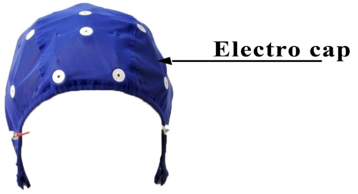
Product Requirements

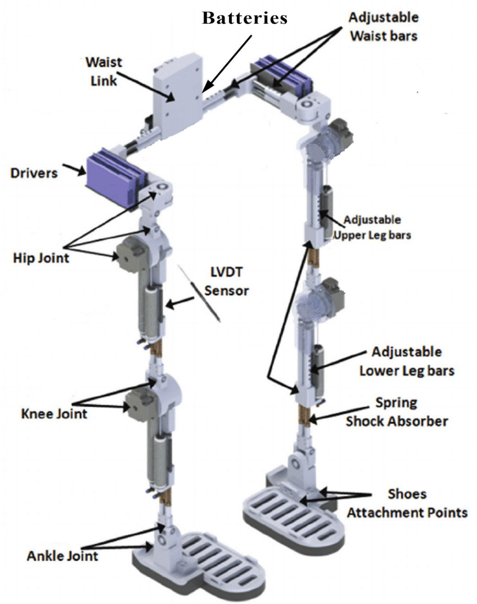
- FDA approval
- Highly accurate
- Profitable
- Ergonomic design, Should be adjustable for different users.
- Light weight
- Environmentally benign.(
- Easy to manufacture.
- Good Battery life.
- Cyber Resilient.

Low Level System Description.



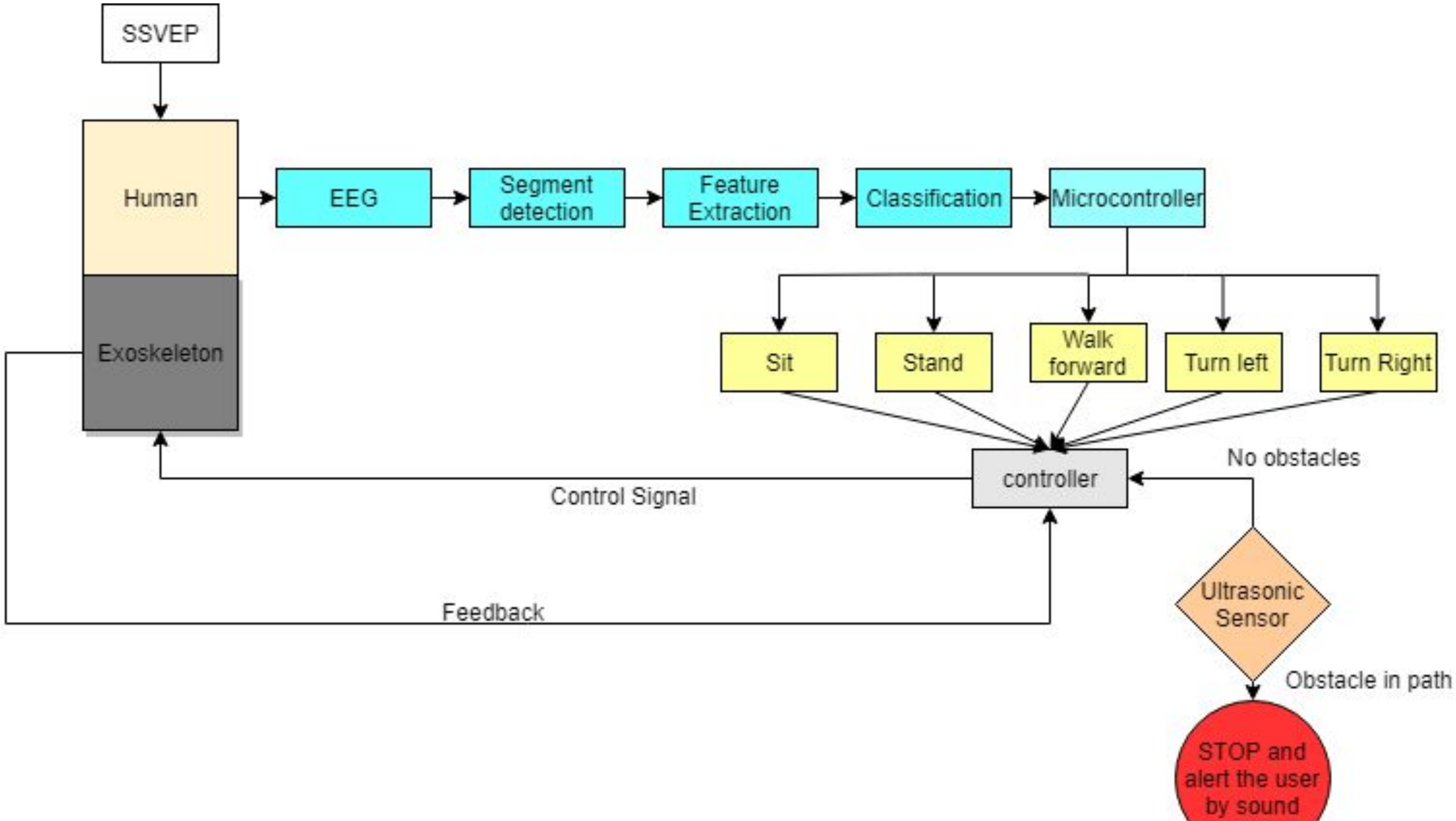
Proposed Solution





- When the user wants to perform an operation he/she will look at the SSVEP board for the respective LED's.
- The Electro cap will catch the signals sent by the brain. The signals will be processed and classified into the following five functions - Move forward, Turn Right, Turn Left, Sit down, Stand stationary. The exoskeleton will be preplanned to perform the given five functions.
- The continulus position feedback will be sent to improve the stability and establish firm balance of the body.
- The height, width and the shoe size can be adjusted according to the requirements. The cap will be customized according to the need.

Flow Chart


SSVEP
Human
Exoskeleton
EEG
Segment detection
Feature Extraction
Classification
Microcontroller
Sit
Stand
Walk forward
Turn left
Turn Right
controller
No obstacles
Control Signal
Feedback
Ultrasonic Sensor
Obstacle in path
STOP and alert the user by sound

The five main tasks

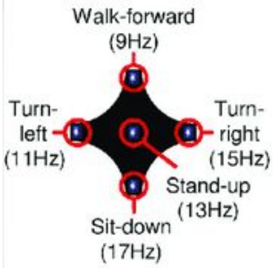
1. STAND: This will be the stationary position.
2. SIT: Lower hip joint. When contact is established with the surface, stop.
3. MOVE FORWARD: Knee joint of left leg up. Knee joint forward. Ankle joint forward. Sense the distance. Waist forward. Both joints down. Alternate movement for both legs.Stop if there is an obstacle.
4. TURN RIGHT: Right ankle joint forward. Right knee joint forward. Left knee ahead of right ankle. Align left ankle. Align waist for Stand position.
5. TURN LEFT: Left ankle joint forward. Left knee joint forward. Right knee ahead of left ankle. Align right ankle. Align waist for Stand position.

Visual Stimulation Unit (SSVEP- Steady state visually evoked potential)

- SSVEPs can be defined as the natural reaction to the visual stimuli at various frequencies . In short, if one look at the flashing light with a specific frequency, visual cortex reacts with EEG signal at the same frequency

- The visual stimulation unit contains five LEDs and a microcontroller Unit. Five multi-chip high flux LEDs (DG-82A83C-001–5/S-3), with a luminous intensity of 6000 mcd, a peak wavelength of 0.26/0.28 nm and a white emitting color.

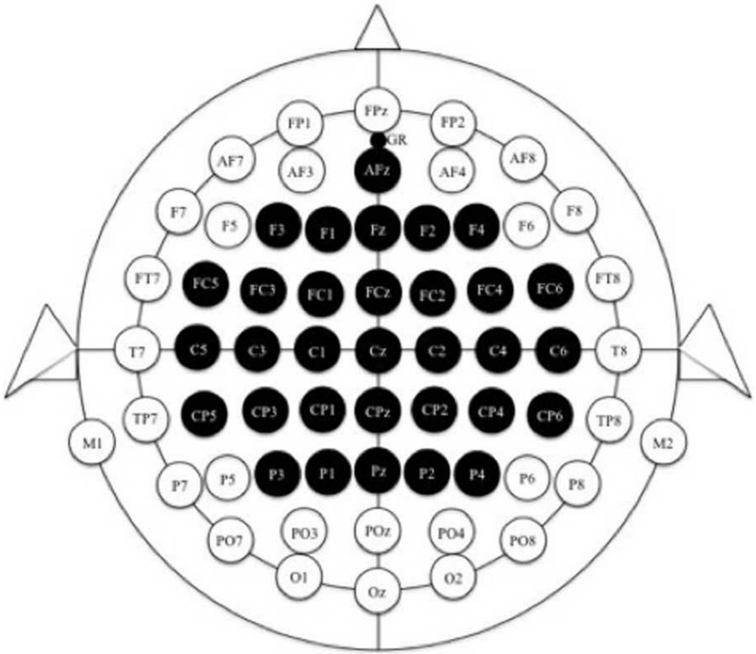
- Their continuous flickering allows a command for walking forward, turning left, standing, turning right, and sitting.



EEG (Electroencephalography)

- A noninvasive EEG based system will be used to control the exoskeleton. Recordings are obtained through the electrodes attached to the scalp surface.

- The EEG data is received through a wireless EEG interface (MOVE system, Brain Products GmbH, 8 Ag/AgCl electrodes is analysed and then the control command is sent to the robotic exoskeleton.



EEG CAP

- Electro-Caps are an EEG electrode application technique.They save time in the acquisition process of multi-channel EEG.
- The Electro-caps are easy to use and can be quickly connected for recording. They are made of an elastic spandex-type fabric with recessed, pure tin electrodes attached to the fabric. The electrodes on the standard caps are positioned to the International 10-20 method of electrode placement.
- The 128-channel Quik-Cap for the SynAmps 2/RT and Neuvo amplifier is a high-density EEG cap with 4 integrated bipolar leads for vertical and horizontal EOG (VEOG, HEOG), ECG and EMG. The cap connects directly to the headbox of the SynAmps 2/RT and Neuvo.

Feature Extraction : Fast Fourier Transform

- FFT) transforms a signal from the time domain into the frequency domain. Basically, any time-dependent signal can be broken down in a collection of sinusoids. In this way, lengthy and noisy EEG recordings can be conveniently plotted in a frequency power spectrum.

- By doing so, hidden features can become apparent. By adding all the sinusoids up after FFT, the original signal can be restored, so no information is lost.

- The library : “FFTW++ library”.

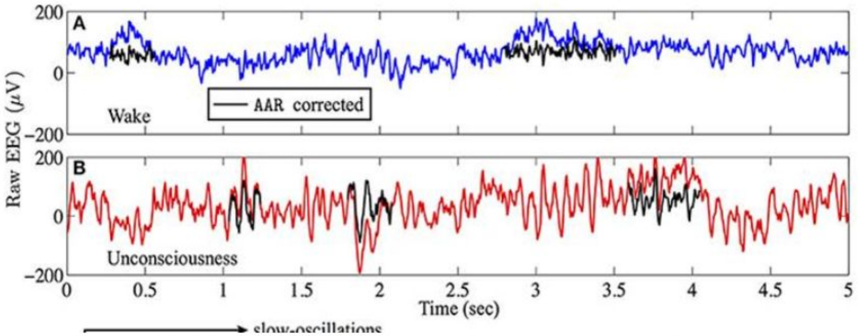
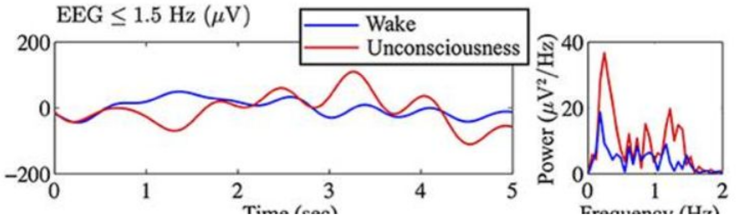
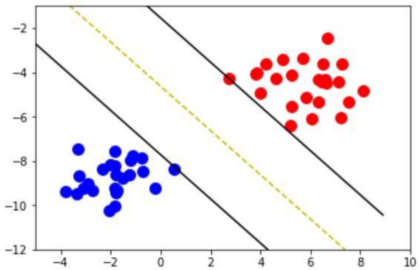


Fig. 1. Raw EEG of an awake person (blue) and propofol-anesthetized person (red). source: Wang *et al* (2014).



Filtered EEGs (<1.5 Hz) of an awake person (blue) and propofol-anesthetized person (red) (left panel) and corresponding FFT spectra (right). source: Wang *et al* (2014).

Classification



SVM - (Support vector machines)

- Though SVM is a linear classifier, it can be made with non-linear decision boundaries using non-linear kernel functions, such as Gaussian or radial basis functions (known as RBF). The non-linear SVM offers a more flexible decision boundary, resulting in an increase in classification accuracy

- The basic of SVM [10] involves the adoption of a nonlinear kernel function to transform input data into a high dimensional feature space, which is more easier to separate data rather than at the original input space.

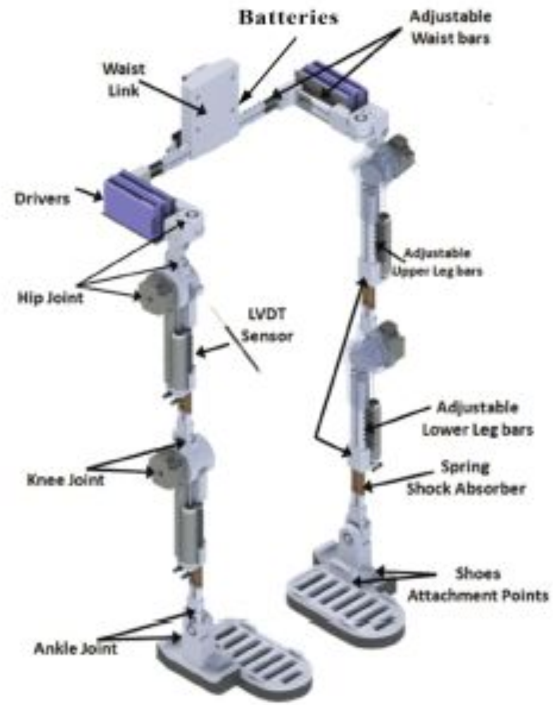
- Comparison to the neural network classifier, SVM classifier has a better training accuracy rate.

- LIBSVM (Library for Support Vector Machines), is developed by Chang and Lin and contains C-classification, ν-classification, ε-regression, and ν-regression. Developed in C++ and Java, it supports also multi-class classification, weighted SVM for unbalanced data, cross-validation and automatic model selection. LIBSVM is used along with radial basis function (RBF) kernel to nonlinearly map data into a higher dimension space.

ExoSkeleton Design

Major components:

- Body(material)
- Motors
- Sensors
- Controller
- Power Supply



Body

- The harness and the supporting le will be made up of Carbon-fibre with metal rods running down for added support.
- The user can wear any shoes as the shoe straps are adjustable.

RE 40 Maxon Motor

Motors :RE 40 motors are chosen

- These motors allow a smooth and no jerky movement, which is one on the major requirements.
- The motor is equipped with powerful 150 W and has an efficiency of more than 90 percent.
- The motors are characterized by good torque behavior, high dynamics, a very large speed range and a long service life.

Specifications: https://www.maxonmotorusa.com/maxon/view/product/motor/dcmotor/re/re40/148866

MicroController

- Raspberry pi 3 is chosen to work on the classifier, feature extraction , user identification and software updates.
- It has high performance.
- It has Bluetooth; it has Wi-Fi; and it has a more powerful CPU/GPU pair.

Battery :The lithium-polymer battery 29.6V is considered for the product.

- Greater energy density is one of the chief advantages of a lithium ion battery.
- In lithium ion batteries, the rate of self-discharge is much lower than that of other rechargeable cells such as Ni-Cad and NiMH forms.
- One major lithium ion battery advantage is that they do not require any maintenance to ensure their performance.

Image : AA portable power corp

Sensors

LVDT (linear variable differential transformer) :A a relatively simple electrical transducer with high resolution and reliability. It is used to determine the position of each actuator.

LVDT	0.1-0.25	0.25	Medium	Medium	Medium
Features	Linearity %	Resolution	Cost	Life	Robustness

Ultrasonic: Maxbotix Ultrasonic Rangefinder - HRLV-EZ1 - HRLV-EZ1

This ultrasonic sensor detects objects from 1mm to 5 meters, senses range to objects from 30cm to 5meters, with large objects closer than 30cm typically reported as 30cm.

Cyber Resilient

Technique	Purpose and Implementation
Adaptive response	Optimize the ability to respond in a timely and appropriate manner: Increasing accuracy of control system.
Analytic Monitoring	Monitor and detect adverse actions and conditions in a timely and actionable manner: Provide an Emergency stop button to stop all actions in case of adversity.
Co-ordinated protection	Implement a defense-in-depth strategy, so that adversaries have to overcome multiple obstacles: Password protection for bluetooth and permission required for wifi connection; hardened kernels to reduce the surface of vulnerability
Dynamic Positioning	Increase the ability to rapidly recover from a non adversarial incident: If the patient stumbles, regain balance immediately
Realignment	Define potential wrong positions beforehand
Segmentation	Define and separate system elements based on criticality and trustworthiness. The system needs to be modular and the individual components need to be balanced without any dependencies..

Additional Features

- The device can be connected to mobile through bluetooth. The user can monitor the brain activity using a mobile application.
- The device will receive updates and other maintenances through the mobile application when connected to Wifi.
- The device will start only when it identifies the user through his/her brain activities. This is done using Raspberry pi.
- The device comes pre trained , however the device needs to be trained for the person before his/her first usage.
- The user can see the connection status , battery percentage and any emergency instructions on a small screen display.

Cost Analysis (Approx. $12,000)

Sr. no	COMPONENT	COST	QUANTITY	TOTAL
1	Exoskeleton body-Material	950	1	950
2	Differential **amplifer** 595-THS4552IRTWT	6.4	1	6.4
3	STM32 L476G-DISCO (Micro controller)	25	2	50
4	CUI Inc. CEP-1110 (sound)	1.48	1	1.48
5	Maxon RE40 24V DC 150W **motor** with maxon GP42 15:1	198	10	1980
6	AKSIM™ OFF-AXIS ROTARY ABSOLUTE **ENCODER**	343.8	10	3437.8

7	lithium-polymer **battery** 29.6V	345	4	1380
8	LED display	10	1	10
9	Raspberry Pi 3	35	1	35
10	Ultrasonic sensor	32.5	4	130
11	LVDT	515	4	2060
12	Eeg cap	352.8	1	352.8
13	Manufacturing cost	1000	1	500
14	Misc	1000	-	1000
	TOTAL			$11893.5

Profitability

- Directly selling it online to users according to customization
- Selling it to hospitals/health-care facilities.
- Renting it to hospitals/healthcare facilities/old age homes.

Future Scope

- Cost Reduction through improvisation of materials.
- Include jumping, running, continuous speed manipulation, climbing up and down.
- Install a camera estimate the surroundings and use a path planning algorithm to predict the path and vary step size and speed.

References

1. https://www.compositesworld.com/blog/post/composites-in-exoskeletons
2. https://bio-medical.com/electro-caps.html?gclid=Cj0KCQiArqPgBRCRARIsAPwlHoWSQra5Hxh0P92Gx-0XN6KcQa662OfuoarQmfhUdsxqfqdV3HstK0AaAuJ0EALw_wcB
3. https://en.wikipedia.org/wiki/Cyber_resilience
4. https://www.google.com/search?q=hardened+kernels&oq=hardened+kernels&aqs=chrome..69i57.7303j0j7&sourceid=chrome&ie=UTF-8
5. https://www.maxonmotorusa.com/maxon/view/product/motor/dcmotor/re/re40/148866
6. Lin, Yuan-Pin, et al. "Support vector machine for EEG signal classification during listening to emotional music." *Multimedia Signal Processing, 2008 IEEE 10th Workshop on*. IEEE, 2008.
7. https://kdsmartchair.com/blogs/news/18706123-wheelchair-facts-numbers-and-figures-infographic
8. https://www.spinalcord.com/types-of-paralysis
9. https://www.rexbionics.com/
10. https://www.maxonmotor.com/medias/sys_master/root/8808028438558/2013-01-en-exoskeletton.pdf?attachment=true
11. https://www.adafruit.com/product/984?gclid=Cj0KCQiA6JjgBRDbARIsANfu58F7hGvyNodoKfOgqrY7O1Q0jdqkrxPg2FUmklQYtfVjedMg8qD55RYaAss5EALw_wcB
12. Blitzwave Library: https://oschulz.github.io/blitzwave/
13. https://www.eparent.com/whats-happening/latest-stats-facts-numbers-on-wheelchairs/