TEKNOFEST

AEROSPACE AND TECHNOLOGY FESTIVAL

BIOTECHNOLOGY INNOVATION COMPETITION

PROJECT DETAIL REPORT

TEAM NAME

EXONIX

PROJECT NAME

EXONIAL EXOSKELETON (DIŞ İSKELET)

APPLICATION ID

73062

CATEGORY

PROJECT

CONTENTS

PROJECT DETAIL REPORT

1. Project Summary (Project Description)

Paraplegia is a life-changing disability that affects patients' physical and mental health. Paraplegic patients need constant care from their caregivers, as they cannot take care of some of their basic needs by themselves. They need rehabilitation to regain some basic functions of their lower extremity. Our project is suggesting a solution for paraplegic patients by building a brain-controlled lower limb exoskeleton using a brain-computer interface. Due to its ability to replicate human leg movements, the exoskeleton is planned to be used in daily life and for rehabilitation purposes by the patients.

Our team members are from different disciplines divided into 4 main categories as electronics, software and artificial intelligence, mechanics, and physiology. The project has different subsystems that have innovative aspects. Each subsystem is explained in the "Solutions" and "Methods" sections in the report separately.

Keywords: Exoskeleton, Disability, Spinal Cord Injury (SCI), Rehabilitation, Paraplegia, Walking, Kinematic Sensing, Electroencephalogram (EEG), Brain-Computer Interface (BCI), Gait Cycle, 6 Degree of Freedom (DOF), Artificial Intelligence (AI), Machine Learning (ML), Deep Learning (DL), Exoskeleton Joint Torque Estimation, Application Development

2. Problem

Paraplegia is a life-changing disability that can occur for many reasons such as spinal cord injury (SCI), multiple sclerosis (MS), traumatic brain damage, or stroke. In Turkey, 2500 people become paralyzed because of SCI each year (Karacan, et al., 2000). Paraplegia causes paralysis in the lower extremity of the body, which means loss of strength and movement. 80% of the patients suffering from these diseases and incidents have experienced movement impairments on their lower extremities (Langhorne, Coupar, & Pollock, August 2009). 35% of the patients regain basic movement abilities by rehabilitation while 25% lose their walking ability completely (Studenski, Duncan, Pere, & Lai, July 2002). Patients who are disabled from the waist-down are challenged into some problems in their daily lives. Some of the most important problems are for example, not being able to take care of personal care needs by themselves, and not being able to fulfill their basic needs. These are causing permanent difficulties and changes in the lives of patients and their families/close ones. Patients are not able to do their daily activities easily anymore, they need constant assistance from a caregiver. Due to losing control of the lower extremity, patients become isolated from society. Isolation may have some effects such as patients dropping their education, not reaching their potential, not being able to work in a job matching with their levels. These effects are not only affecting patients and their families but also the economy of the country.

Paraplegia is affecting not only physical health but also the psychology of the patients (Migliorini, New, & Tonge, 2009). Psychological problems also cause chronical pain. Studies show that an important number of patients are suffering from depression especially the patients suffering from chronic pain which are also showing worse depression symptoms. 1 in 3 patients describe this as severe pain. Due to chronic physical pain, the quality of life (QoF) of the patients is becoming decreasing.

Neurorehabilitation requires lots of time and physical effort from physiotherapists, especially for walking training. Usually, at the first stages of ambulation, two or more physiotherapists are required to help in training. This is a reason for the limitation of the number of patients to be treated by physiotherapists. Moreover, it will impose an economical burden on health services.

There are some solutions in the literature developed for patients who lost their ability to move their legs. Phoenix is an exoskeleton with motors that control hip and knee movements. An EEG-controlled wheelchair that was created by Rebsamen et al. studied another solution for the same problem (Tariq, Trivailo, & Simic, 2018). Some other suggestions were considered by us, such as using an EMG on patients' legs that is connected to an invasive circuit replicating a neuron which is a communication bridge between the functional and non-functional neurons. The circuit, passing the information from the last functional neuron in the spinal cord to the EMG that is connected to the legs of the patients to execute the intended movement.

Most of the methods in literature can only be used for rehabilitation purposes due to their mechanical design. Most of the products on the market can only be used with crutches. Therefore, there is not enough freedom provided to patients, they would not be able to live their daily lives like they used to. Moreover, they are expensive and cannot be personalized. The EMG-connected circuit also has some problems. Due to its invasiveness, the device may not be able to be introduced to the market for many years. Our proposed project will overcome these problems by keeping certain design principles in mind such as robustness, ease of use, non-invasiveness, budget-friendliness, being highly safe and making innovations in our software. The ultimate goal is to create an independent environment for the patients with lower limb disabilities to do their daily activities like they used to.

3. Solution

3.1. Proposed Project

The purpose of the proposed project is to build a brain-controlled lower limb exoskeleton for patients suffering from spinal cord injury (SCI), lower limb paralysis, paraplegia or any other disability that prevents movement of their legs. To achieve this, an electroencephalogram (EEG) headset will be used to control the wearable exoskeleton via a brain-computer interface (BCI). The exoskeleton will be controlled by mental commands (going forward, turning left-right) via decoded brain signals. The recognized mental commands will activate the high-torque motors on the joints of the exoskeleton, and then replicate healthy leg movements that end up with walking or turning left-right. Our project is aiming to create a user-friendly system that provides rehabilitation training functions in long-term usage.

The exoskeleton can help by monitoring, controlling movement speed, direction, amplitude, joint coordination patterns, and controlled disturbances. It can also help by providing weight support with minimal effort, hence, offers potential for reliable, standardized testing, and goniometry prevention measures (Bryce, Dijkers, & Kozlowski, 2015). Additionally, the exoskeleton will have some features that can help patients to use it and wear it easily. Voice commands will be able to bring the exoskeleton near to patients to wear it by themselves. Additionally, the exoskeleton design will be portable, can be folded into smaller sizes, and lighter than most of the other ones in the market for easy usage. Accelerometers and gyroscopes will be used for the detection of falling and airbags will be activated in that case. Additionally, an application will be developed. If the patient falls, they will be able to press the panic button by using their voice commands or pressing the panic button on their phone. The alert section will give a warning for low EEG signal connection or low battery. Voice commands will work for calling the exoskeleton in a charging station to near the patient or patient alerting their caregiver if they fall.

The proposed project when compared to the other projects in the will be low-cost, easily adaptable, highly accurate, rapidly responsive, and easily personalized.

3.2. Mechanical Design of the Exoskeleton

In the first phase of the project, it is decided to build two different mini prototypes. The first prototype (Prototype-I) will be an EEG-controlled miniature exoskeleton, which will be designed to work with the biomechanics and anatomical model of a miniature leg. In this version of the prototype, movements of the joint (ankle, knee, and hip) will be performed by servo motors. Through these motors, the targeted freedom of movement will be achieved as needed. The aim of creating the Prototype-I is to be able to test the connection between the exoskeleton and the EEG headset, and to test the anatomical compatibility of a human leg (See Appx A).

The second prototype (Prototype-II) will also work with an EEG headset, and it will be larger than Prototype-I. Additionally, it will be a more complex design than Prototype-I. This is due to Prototype II's similarity to a muscular system. In Prototype II, a smoother moving system will be designed by using gears and belts together with a stepper motor. The main goal of creating two different prototypes is to test the interoperability of the electronics planned to be used in the main project. The drawings of the prototypes were made on SolidWorks and Autodesk Fusion 360 and will be 3D printed using PLA+ material. The materials and mechanical elements for the main project will be selected accordingly.

3.3. Software and Artificial Intelligence Implementation

There are some reasons for this project to be a better alternative than existing solutions on both the market and the research, which are software solutions developed by us. It is examined by close to 10 companies that provide software and hardware solutions for recording and processing EEG signals. Due to the massive amounts of customization needed for the project, total control over both the EEG hardware and the software part is needed. For that reason, the OpenBCI for EEG headset and its applications are chosen by us as opposed to companies such as Emotiv that provide BCI systems and EEG headsets which don't allow changes to its hardware and software, hence, works like a black box. What sets OpenBCI apart is all the method's functions, and the API calls are open and easily modifiable. Additionally, there is no license fee so the hardware can be accessed infinitely.

Some socket programming was made to get the data from the EEG into our computers later to be processed and categorized. To further categorize signals, they had to be processed first and noise had to be eliminated. To do this, advanced signals processing techniques were used, feature extraction methods were implemented, and matrix transformations were used. After the signals were processed, multiple models were trained for our project. So far, a 79.37% accuracy rate is reached in the classification of 4 different classes. Detailed explanation is in the "Methods" section of the report.

For the signal processing part, a combination of different technologies was used. Due to having the opportunity to work with OpenBCI, its native open-source library Brainflow was used.

Brainflow is a library intended to acquire, parse, and analyze dynamic signals and other types of data from biosensors. It has implementations on C++, C#, Python and Java. For our project, Python is chosen since all the other scripts implemented are also on Python. Another advantage was having Brainflow, so that it could be accessed by all the API and methods since it was open source. From the figure 1, artificial intelligence implementation workflow can be seen. The flowchart is explained in detail in the "Methods" section of the report.

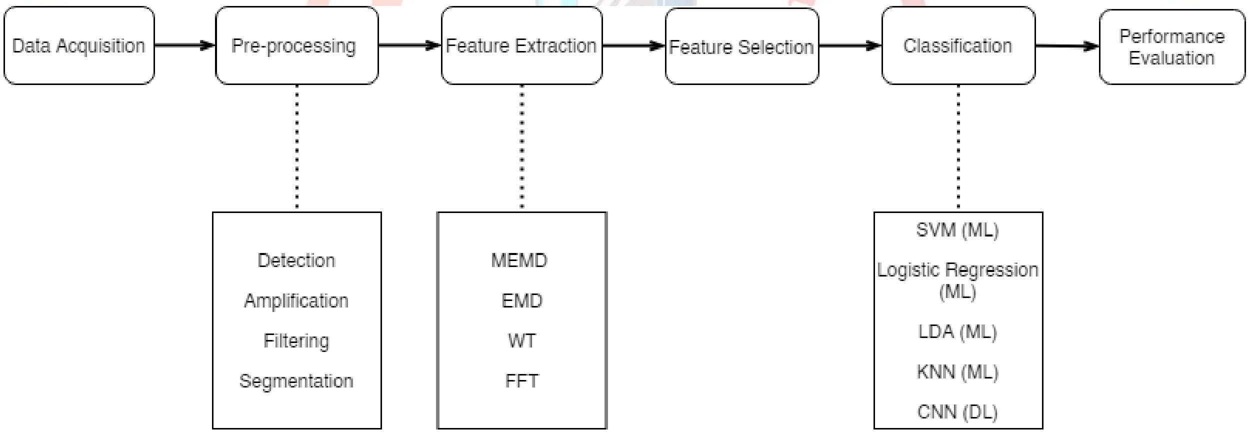


Figure 1 Flowchart of Artificial Intelligence Implementation

3.3.1. Future Aspects of software solutions

Once the real exoskeleton is designed, our team will work on recreating the exoskeleton on the Unity game engine using its physics engine. Once it is complete, state of the art algorithms will be used at reinforcement learning to teach the exoskeleton to walk the way it is supposed to.

3.4. Electronic Components of Prototypes

The OpenBCI Cyton Board is an 8-channel neural interface with a 32-bit CPU. Cyton Board is the most crucial electronic part of this project since it is used to sample brain activity which then be sent to the Raspberry Pi which will be driving the actuators. The PIC32MX250F128B microcontroller is at the heart of the OpenBCI Cyton Board, offering plenty of local memory and excellent processing rates. On each of the eight channels, data is sampled at a rate of 250Hz. It will be powered by 4x1.5V AA batteries since the input voltage is between 3.3V and 12V. Cyton Board uses RFDuino radio modules to interact wirelessly with the Raspberry 4 using the Ganglion Dongle. The Ganglion Dongle is a USB Bluetooth module that has a fast transmission rate and is easy to pair. Gold cup electrodes are ribbon cables with ten passive gold electrodes that allow for high-precision brain signal measurement. Dry EEG Comb Electrodes are attached to the ends of the Gold Electrode Cups to promote wearability. There is no need to apply gel to the head while using these Dry EEG Comb Electrodes. Longer hair may be accommodated by the expanded prongs, which also provide great signal quality. The Electrode Cap Gel is a low-impedance EEG electrode gel that improves the effectiveness of sample brain activity readings.

Raspberry Pi 4B is an affordable and highly versatile single board computer containing all of the components needed for a computer on a single board, including the CPU, memory, IO and many interface devices. Raspberry Pi 4 is distinguished by its popularity, ease of use, low cost and class-leading performance on its CPU and GPU. The Raspberry Pi 4 has an ARM-based 4-core CPU and supports H.265 hardware encoding as well as high bandwidth USB ports. Raspberry Pi 4 can be preferred in cases where microcontroller boards are not capable of realizing the given task, especially if more than one operation is required at the same time, such as detecting 8-channels of sample brain activity and driving actuators.

Servo motors were chosen for the actuator because of their ease of use and fit for the prototype-I. The metal gear in this High Torque MG996R Digital Servo produces 10 kg of stall torque. The MG996R is extremely sensitive, with improved shock resistance and a new PCB and IC control system. This basic servo with strong torque can spin around 120 degrees. This actuator stands out due to its tiny size and ability to provide feedback.

Stepper motors are electromechanical actuators that can change the angular position in steps. How much movement the motor will make in a given signal depends on the step angle of the motor. The higher the number of steps per revolution, the higher the sensitivity of the stepper motor. Stepper motors can be operated many times without any errors, and they are easy to maintain because they have a simple mechanical structure. Since stepper motors cannot be driven directly, they need stepper motor drivers to control values such as torque, speed, and position. For this purpose, A4988 driver modules are chosen for driving stepper motors. Current limiting, overcurrent protection, and 5 micro-step resolutions (Full step, Half step, Quarter step, Eighth step, and Sixteenth step) are all included in the driver. It has thermal shutdown for overheating, as well as low-voltage and high-current safety. The system will run more safely as a result of this.

Single-cell Li-Po battery has a capacity of 5000 mAh and a voltage rating of 3.7 V. Li-Po batteries have a higher current capacity than conventional batteries, making them ideal for high-power projects. Li-Po battery has been chosen since it is a sort of power source that can handle it.

In figure 2, data transmission from EEG components to the exoskeleton flowchart can be seen.

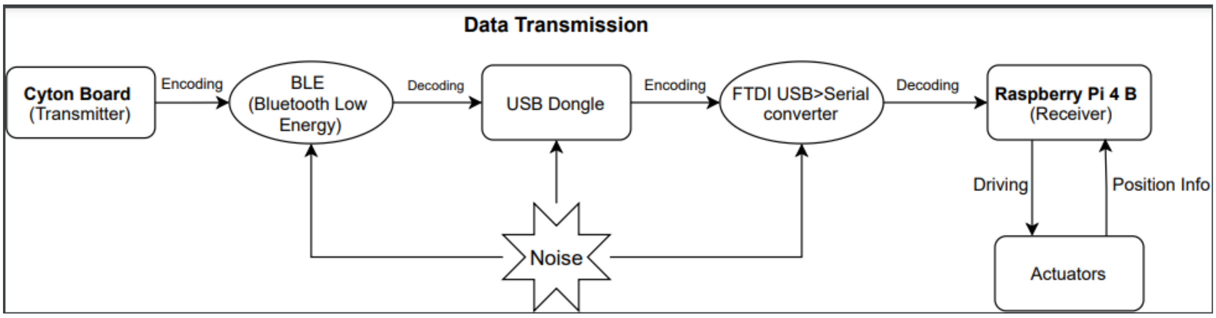


Figure 2: Data transmission flowchart between EEG and exoskeleton

4. Methods

4.1. Artificial Intelligence Implementation and Software Solutions

4.1.1. Data Acquisition

EEG based Brain-computer interface (BCI) has gained popularity in recent years as an alternate communication mechanism between the human brain and an output device (Tariq, Trivailo, & Simic, 2018). The brain acts as a complicated nonlinear system. Thus, contrary to linear methods, nonlinear methods for EEG signal analysis are considered to provide better information for mental commands (Liang, Li, & Shi, 2008). EEG is a well-recognized method of measuring the electrical activity produced by the visual cortex of neuron populations. For our project, an OpenBCI 8-channel EEG headset, which was borrowed from a PhD student from Dokuz Eylül University for a short amount of time, was used. Data from AF7, AF8, Pz, P3, P4, PO3, PO4 and Oz channels on the EEG headset are used by us due to being on the visual cortex on the scalp (See Appx B).

Data from OpenBCI 8-channel EEG device is obtained by the board, broadcasting its IP, mac address and serial number meanwhile our computers were listening with their Bluetooth interface. Once data from the board is obtained, it is sent to the query of the board which consists of IP protocol serial port and timeout. Moreover, data consistency coming from the board and not having sudden changes were made sure.

The first concern using the EEG headset is to make sure diodes are working on the headset. Their function is to transmit highly optimized brain signals. For that reason, a script is already implemented for analyzing Impedance between the scalp and diodes. This script constantly listens for updates in the signals and immediately warns if signals are of poor quality. Therefore, coming up with solutions momentarily is going to be possible.

4.1.2. Feature Extraction and Selection

The main goal of the software part of the project is to be able to distinguish mental commands. There should not be any noise that will confuse the classification models. To have clean data, feature extraction should be applied. One of the feature extraction advantages is reducing the data size. Reducing the data size into manageable amounts while not losing any important information is very important for this project due to being able to obtain faster Machine Learning Classification results. There are some algorithms developed for extracting features on dynamic signals such as EEG signals. Empirical Mode Decomposition (EMD), Multivariate Empirical Mode Decomposition (MEMD) (Akan & Mert, 2014; Flandrin, Rilling, & Gonçalvés, 2004). EMD does not let all the channels be in the algorithm. MEMD is a solution for this problem caused by EMD. There are other methods such as Fast-Fourier Transform (FFT) and Wavelength Transform. All these methods were tried on the data separately. The most successful result was chosen, which was the MEMD algorithm. After feature extraction, feature selection was done on the dataset.

4.1.3. Classification and Performance Evaluation

Due to not being able to own an EEG device, results had to be tested over a small sample space, meaning there might be differences in the results. It is hoped to get more accurate data by obtaining an EEG device and to be able to increase classification accuracy. Having access to an EEG device will yield much more accurate results soon. The given task is a classification problem instead of a regression problem since not determining a value in a continuous line. There are finite classes that stand for individual commands/instructions that will be sent to the exoskeleton as an approach for this part. The goal is to try to classify the right signals into the right classes using supervised learning methods. Four individual classes have been acquired and trained multiple models using different algorithms to get the best possible accuracy and speed since classes will be processed in real-time. SVM (Support Vector Machine) is a non-probabilistic linear classifier, it is extremely robust and fast but dependent on labelled data since it is a supervised learning algorithm. SVM constructs hyperplanes or sets of hyperplanes to classify data using vectors. When SVM is used to classify multiple classes either One Against One (OAO) or One Against All (OAA) will be used. After an evaluation of each method, OAO gave higher accuracy with SVM and was the highest among the other models. The accuracy was 79.37% and it was also faster at predicting than the rest. KNN (k-nearest neighbor) is a non-parametric classification model. A point is predicted by looking at its k-nearest neighbors and selecting the appropriate class by looking at most of its neighbors. For selecting the nearest neighbors, Euclidean Distance is preferred (Sun & Huang, 2010). The accuracy rate was 77.63%. Logistic Regression is a probabilistic algorithm that uses logistic regression to plot features and normalize them to binary range using logarithm of odds and select appropriate classes. Later, the algorithm gives probabilities of the classes depending on the predicting which then will be chosen by the most probable. The accuracy rate was 75.28%. LDA (Linear Discriminant Analysis) is an algorithm that finds linear combinations of features that belong to the same class and is related to regression analysis and analysis of variance. The accuracy was around 73.43%. CNN (Convolutional Neural Networks) is mainly used to analyze images so what sets this example apart is that deep learning methods were used, and raw signal data was encoded as images later being processed by the neural networks; due to the limitations, such as not having enough computational power and a big enough dataset, it was the least successful method out of all the methods with a 49.45% accuracy rate. Its architecture consists of 4 hidden layers and a final SoftMax layer. Further experimentation and research with different layer architectures are still ongoing to this date.

4.1.4. Changing from Python to C++

C++ is much faster than Python. Therefore, if our proposed project is going to be at maximum efficiency, in the future codes in C++ will be implemented for the real deployment of the project. Additionally, processing power and battery power will be used less. Hence, the exoskeleton's the cost will be decreased and the efficiency will be improved.

4.1.5. Mobile and Web Application

The software solution provided by us will have two applications, one is for both Android and IOS, and the other is a web application at the website exonixtech.com which is created by us. The mobile application will be implemented in Flutter. With Flutter, developed codes can be used in both IOS and Android. Moreover, our team members have experience with it. There will be three important functionalities inside the mobile application, which are alerts, the panic button and voice commands. Alerts will notify selected individuals or organizations if the safety of the individual who is inside the exoskeleton is in danger. These situations can be falling over, or system failure. Additionally, it will notify individuals about the signal quality of EEG in real-time. Voice commands will be having the most important functionality of our mobile application. In case of a not present EEG device, out of battery, or malfunctioning, the exoskeleton will be used via voice commands. The system will use hot words which means there will not be a need for trying to understand the entire speech but rather hot words. Therefore, instead of going through thousands of words classification of the voice data, maximum 4 groups of classes will make it more responsive and faster. The panic button will be there so if the individual wants to get some aid in any situation it will be accessible to push. A web application will be there so that people can also use the functionalities of the mobile application from a website and there will also be information, tutorials, and the help desk inside the website.

4.2. Mechanical Principles and Design

4.2.1. Gait Cycle

Gait cycle is the duration between an initial contact of a heel to the ground and it's second contact with it. The cycle consists of 8 different phases which all define a mode of movement (See figure 10 in Appx C). The first phase of the cycle is the Initial Contact (IC) phase in which a heel starts contacting the ground. After the IC phase, comes the Loading Response (LR) where the initial heel is grounded for a forward movement, and the knee becomes flexed for absorbing the bearing of the movement. In the Mid-Stance (MS) phase, the body moves forward by using the fixed heel-foot combination to carry the limb and trunk forward. In the Terminal Stance (TS) phase, the movement depends on a single limb support while the other limb becomes lifted, and the center of gravity is shifted forwards. TS phase is followed by the Pre-Swing (PSW) phase where both limbs contact the ground. In this phase, the first leg starts to swing forward by flexing the knee muscles and using a toe pivoted motion. In the Initial Swing (ISW) phase the first leg begins swinging, while knee and hip flexion carry the leg in a forward motion. The Mid-Swing (MSW) phase starts after ISW and continues the leg movement until it reaches the limit of the shank. To complete the Gait cycle, the movement ends with the Terminal Swing (TSW) phase where the foot strikes the ground and prepares the movement for the next gait cycle (See Appx C figure 10).

4.2.2. Kinematics

The kinematic calculations in our prototype model give the relationship between the movements of the joints. In human walking operations, there are seven DOFs (Degrees of Freedom) (See Figure 11, Appx C). However, for the exoskeleton project, only DOFs of hip, knee and ankle will be used. For the hip and knee joints DOF of flexion and extension will be used while for the ankle joint it will be dorsiflexion, our prototypes have 6 DOF.

Angle nomenclature of the model is as seen in Appendix C, figure 12. In the model, the distance between the hip joint and the knee joint is l_1, distance between the knee joint and ankle joint is l_2 and distance between the ankle joint and the toe tip is l_3. Accordingly, the kinematic equations were calculated as 3 DOF for the right leg in this way (See Appx).

$$x_d = l_1.\cos(\alpha_{right}) + l_2.\cos(\alpha_{right} + \beta_{right}) + l_3.\cos(\alpha_{right} + \beta_{right} + \gamma_{right}) \quad (1)$$

$$y_d = l_1.\sin(\alpha_{right}) + l_2.\sin(\alpha_{right} + \beta_{right}) + l_3.\sin(\alpha_{right} + \beta_{right} + \gamma_{right}) \quad (2)$$

$$z = -d \quad (3)$$

The calculations of our dynamic model will be made using the Euler-Langrange method. (Kanjanapas & Tomizuka, 2013) (Minchala, Palacio-Baus, & Astudillo-Salinas, 2017)

4.2.3. CAD Design and 3D Printing

The designs were made using SolidWorks CAD and Autodesk Fusion 360. In the design process, the ratios between the leg lengths of different people were taken as a basis and designed to be adjustable within a certain size range. Prototypes are going to be printed from Anycubic Chiron Large Plus 3D Printer because of the designed parts sizes (the 3D printer is cost-effective and has a large printing area). Revisions continue corresponding with the analyzes made on the designs done on ANSYS Workbench (See Appx A fig. 4 and fig. 5).

4.2.4. Production

Our prototypes will be produced by the 3D printer using PLA+ material. The reason for choosing PLA+ is due to being healthier when compared to ABS and being more durable than PLA. During production, nozzle temperature will be 210 °C, bed temperature 65 °C, layer height 0.12 mm. Depending on the part to be printed, the infill density can be 20% or 100%.

Prototype designs are modelled for 3D printing via SolidWorks CAD and Autodesk Fusion 360. Strength and deformation analysis of the parts were also made using ANSYS Workbench Static Structural.

4.3. Communication

OpenBCI Cyton Board has a Bluetooth wireless connection which is provided by RFDuino modules. An RFDuino radio module is included inside the Cyton Board. The RFD22301 RF Digital Bluetooth low energy SMT radio module has an ARM Cortex M0 microcontroller (RFDigital, 2013). BLE (Bluetooth low energy) is a kind of wireless communication optimized for short-range communication. In that it allows devices to interact with one another, BLE is quite similar to Wi-Fi. The RFD22301 acts as a "device" for the Cyton board when communicating with the Raspberry Pi 4 over BLE. BLE is designed for circumstances where battery life is more important than fast data transmission rates.OpenBCI provides an RFDuino

USB dongle that connects to the Raspberry 4 to get the greatest data speeds (OpenBCI, 2021). that serves as the RFDuino "Host" on the Raspberry 4. While compared to a Bluetooth 4.0 BLE connection, better data speeds can be attained when utilizing this USB dongle. The "Host" RFDuino USB dongle is linked to an FTDI USB>Serial converter, which is set to appear to the computer as a standard serial port running at 115200 baud using the standard 8-N-1 protocol.

5. Innovative Aspects

Our software part will have multiple important innovations. Our first innovation will be integrating an application to exoskeleton and EEG to use it as a bridge. Voice commands will be put into the application so it will increase the reliability of the exoskeleton. Receiving security and device information via the mobile application will allow the user to instantly access information such as battery status, and EEG signal quality. All sorts of data from the motors on the exoskeleton will be collected. This data will be used for improving our mechanical design. Moreover, any problems will be determined with the exoskeleton. Therefore, in case of an emergency, the caretaker of the patient will be notified. Implementation of the classification models on C++ is planned. Therefore, it will increase overall performance greatly.

Due to our exoskeleton’s carbon fiber and waterproof structure, it is relatively light and strong. It also has an adjustable structure for each user. When the device is not in use, it can go to the charging station by itself using voice commands and can be fold into smaller size. Due to its removable and pluggable batteries, it can be used at outside for longer time without being connected to a charger.

There are similar devices in the market such as ReWalk and NeuroRex. They can be used in daily life and have rehabilitation functions; however, they can only be used with crutches or does not have mental command functionality. Our exoskeleton design overcomes this problem by replicating a human leg movement more realistically way and has a better stability. Hence, creates a better walking experience for the user. Additionally, similar devices’ mobile applications are not comprehensive like ours (no voice commands, panic buttons, alerts for the caregiver, rehabilitation levels).

6. Applicability

The project is built on two emerging technologies, EEG and the exoskeleton. Non-invasive EEG devices in the market, which will be used by us, the noise still has not been reduced to the desired levels and sufficient quality signal data cannot be obtained continuously. While working in this field, the developments in EEG technology is being followed by us. EEG technology is evolving, even though it is a slow process, soon enough it will be possible soon to make our project suitable for daily and continuous use.

For the exoskeleton part, a design consisting of 16 DOFs will be built, 7 on the left leg, 7 on the right leg, and 2 on the trunk. Due to the balance and complex movement system, it is predicted that the study can pass to the test phase within 3 years.

For the signals received from the EEG to be interpreted by artificial intelligence correctly, different datasets should be created. Tests should be performed with data from people having different characteristics. A two-year work schedule is envisaged for dataset studies, training, and tests.

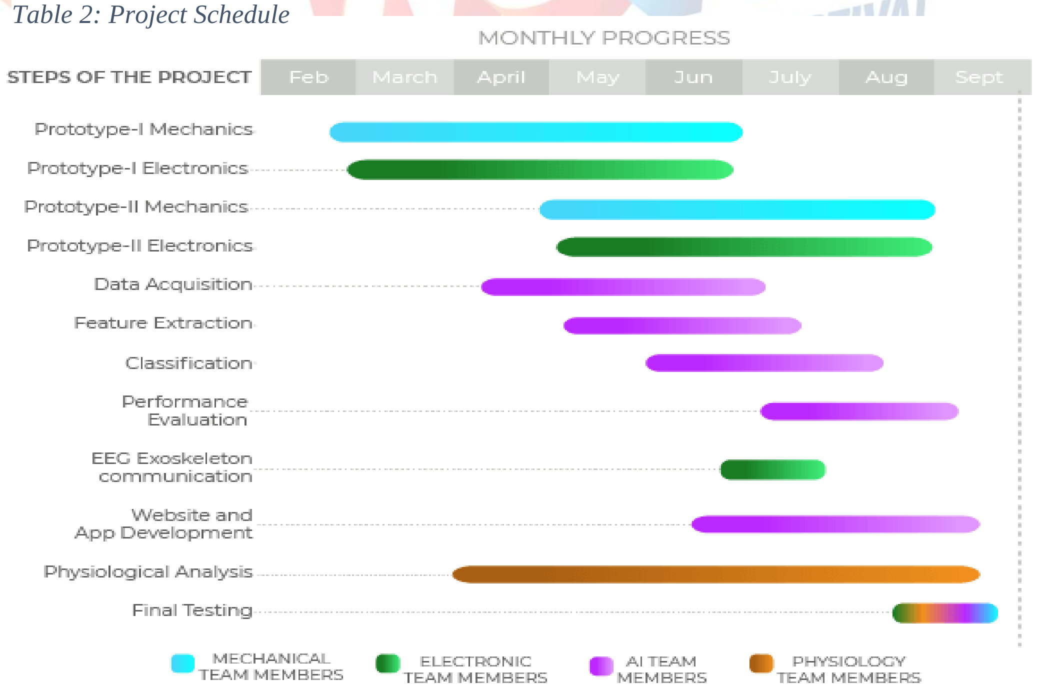
The launch date of the project has been determined as 2026. Based on our competitors, research, and academic studies, this is the first study in this field that provides the ability to walk without any support and in accordance with physiology. Moreover, it aims to be suitable for daily use. The preliminary preparation phase for the technologies that are used by us or will be used has been completed. Our hope is that after our project goes on the market; it will be a new hope for many patients in the first year of the project.

7. Estimated Cost and Project Scheduling

Table 1: Estimated Cost of the Project

	Product	Unit Price	Quantity	Total	Status	Purchase Date
Prototype I	Tower Pro MG996 RC Servo Motor	₺ 32.13	6	₺ 192.78	Owned	-
	eSun PLA+ filament	₺ 174.95	1	₺ 174.95	Owned	-
	3,7V Lipo Battery 5000mAh 35C	₺ 172.48	1	₺ 172.48	Owned	-
	Raspberry Pi 4 8GB	₺ 954.97	1	₺ 954.97	Owned	-
Prototype II	17HS4401 Nema17 Step Motor	₺ 61.39	6	₺ 368.34	Owned	-
	Step Motor Driver	₺ 7.60	6	₺ 45.60	Owned	-
	eSun PLA+ filament	₺ 174.95	2	₺ 349.90	Owned	-
	3,7V Lipo Battery 5000mAh 35C	₺ 172.48	1	₺ 172.48	Owned	-
	Raspberry Pi 4 8GB	**₺ 954.97**	**2**	**₺ 1,909.94**	**Requested**	**31.07.2021**
EEG	**Cyton Biosensing Board**	**$ 499.99**	**1**	**₺ 4,274.91**	**Requested**	**15.07.2021**
	Gold Cup Electrodes(x30)	**$ 39.99**	**1**	**₺ 341.91**	**Requested**	**15.07.2021**
	Dry EEG Comb Electrodes (x30)	**$ 29.99**	**1**	**₺ 256.41**	**Requested**	**15.07.2021**
	Electrode Cap Gel	**$ 19.99**	**1**	**₺ 170.91**	**Requested**	**15.07.2021**
Common	**Anycubic Chiron Large Plus 3D Printer**	₺ 6,702.25	**1**	**₺ 6,702.25**	**Requested**	**15.07.2021**
	Creality Ender 3 Pro 3D Printer	₺ 2,000.00	1	₺ 2,000.00	Owned	-
	IMAX B6AC Charger	**₺ 444.02**	**1**	**₺ 444.02**	**Requested**	**15.08.2021**
	Lipo Safe Bag	₺ 115.70	1	₺ 115.70	Owned	-
		Sub Total=		₺ 18,647.57	**USD Exchange Rate= 8,55 TL**	
		Requested Total=		₺ 14,100.37		

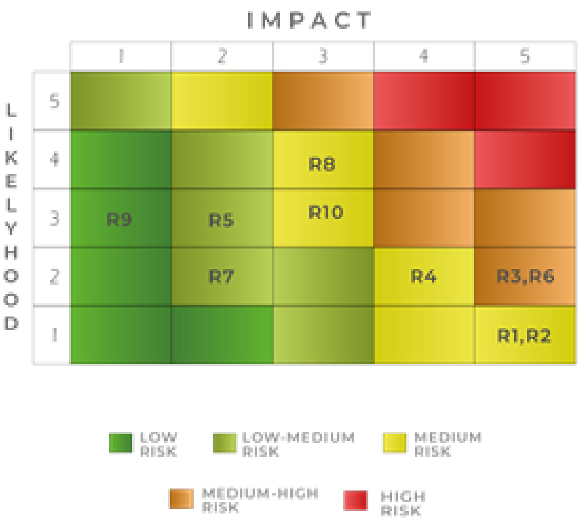
Table 2: Project Schedule



8. Target Audience of the Project Idea (Users):

The target audience of the project is people who have suffered a trauma such as a stroke or an accident or who are congenitally incapable of moving below the waist. While these people had a certain social life and physical freedom before the trauma, they later became dependent on other individuals around them. Likewise, people born with paralysis have never experienced the feeling of being free and going wherever they wish to. Therefore, the target audience of the project is individuals over the age of 6 who have lower-limb paralysis, regardless of a certain economic class.

9. Risks



NO	RISK	PLAN B
R1	Patient falls down	Accelerometer and gyroscope can sense the problem and airbags open, from the application caregiver recieves notification
R2	Fire risk	Battery housing protection will be designed in a fire and explosion-proof way
R3	Engine Failure	Mechanism can be stopped via voice commands or emergency stop and immediate seperation from exoskeleton will be activated
R4	Patient becomes imbalanced	In high interference inputs, the exoskeleton provides balance by controlling the upper body with its waist connection
R5	EEG not functioning	The exoskeleton can still function by using application's voice command feature
R6	EEG electrode oxidation	A user manual can be prepared to explain the proper usage of EEG
R7	EEG-exoskeleton communication failure	-Fail safes can be put in place that will compensate the package losses -Cabled controller can be used
R8	Exoskeleton electronics failure in rainy day	Electronics and engines can be designed in a closed system for water-proofing
R9	Patient's leg measures changes	Exoskeleton design with adjustable leg length
R10	Slow mental command processing	Better trained decoding algorithms

Figure 3. (a) Risk Matrix, (b) Risks and Solutions

10. Resources

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APPENDICES

Appendix A

Figure 4. Prototype-I design

Figure 6. Prototype-I design with a human leg model

Figure 5. Prototype-II design, view from back

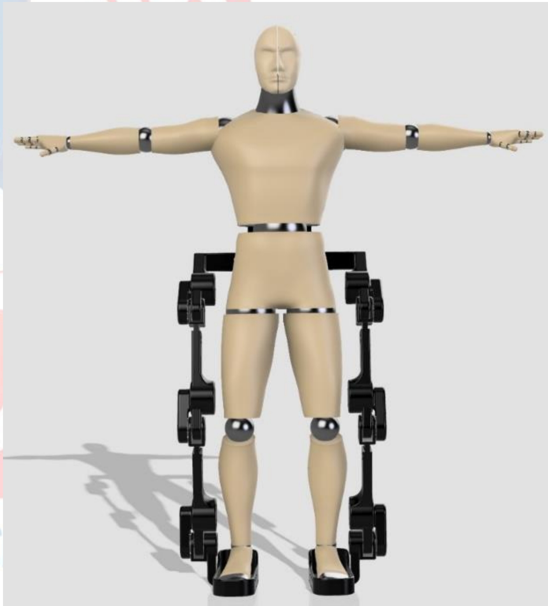

Figure 7. Prototype-II design with a human model

Figure 8. Prototype-II design view from top

Appendix B
EEG Channels of the Visual Cortex

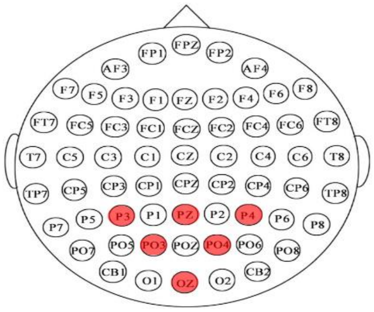

Figure 9. EEG channels of the visual cortex (Zheng & Lu, Sept. 2015)

Appendix C
Mechanic Design

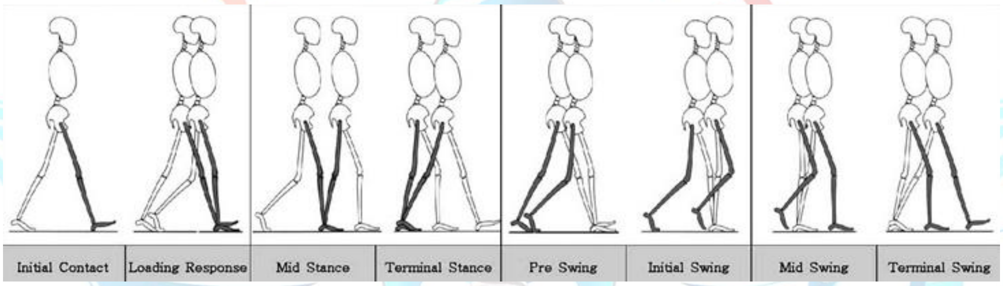

Figure 10: 8 Phases of a Gait cycle (Kanjanapas & Tomizuka, 2013)

Joints	DOF	Range of Freedom
Hip	Flexion/extension	$-120^o \leq \theta \leq 65^o$
	Adduction/abduction	$-30^o \leq \theta \leq 40^o$
	Rotation	$-30^o \leq \theta \leq 30^o$
Knee	Flexion/extension	$-120^o \leq \theta \leq 0^o$
Ankle	Pronation/rotation	$-15^o \leq \theta \leq 30^o$
	Dorsiflexion/toe flexion	$-20^o \leq \theta \leq 50^o$
	Varus/valgus	$-30^o \leq \theta \leq 20^o$

Figure 11: 7 DOF Exoskeleton for dynamic analysis

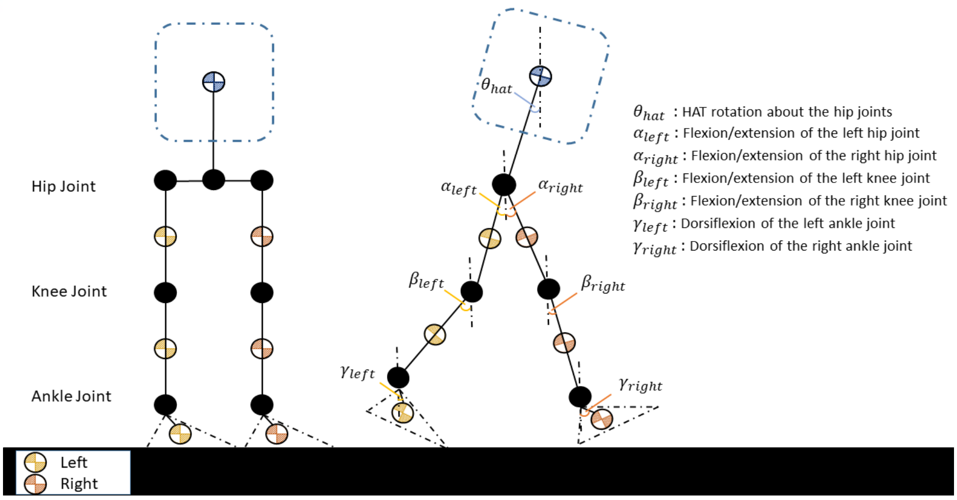

Figure 12: Seven DOF for humans with hip, knee and ankle joints (lower limb)