Design Practicum (**IC-201P**)

EXOSKELETON FOR MOTION ASSISTANCE

CLOSURE REPORT

Team Member	**Discipline**
Neelotpal Dutta (**B16106**)	Mechanical Engineering
Nikhil Gupta (**B16023**)	Computer Science Engineering
Gaurav Kumar (**B16057**)	Electrical Engineering
Parimal Kumar (**B16136**)	Civil Engineering
Garvit Mathur (**B16096**)	Mechanical Engineering
Ritwik Saha (**B16110**)	Electrical Engineering

Mentor - Dr. Arpan Gupta

Abstract

In this project closure report, we are elaborating our journey through various stages of designing and implementing Exoskeleton for motion assistance, specifically targeted towards military use during our course Design Practicum (IC-201P). The report would try to reflect every intricate details of the project, including initial thought processes, design stages, CAD models, electronics and electrical components used along with the algorithm and electrical circuits. Initial cost estimates, R&D expenditures, final product cost is also mentioned in the report. It will also walk the reader through business opportunities with this product, future prospects, and how we can extrapolate the design to achieve other functions not there in the current final design.

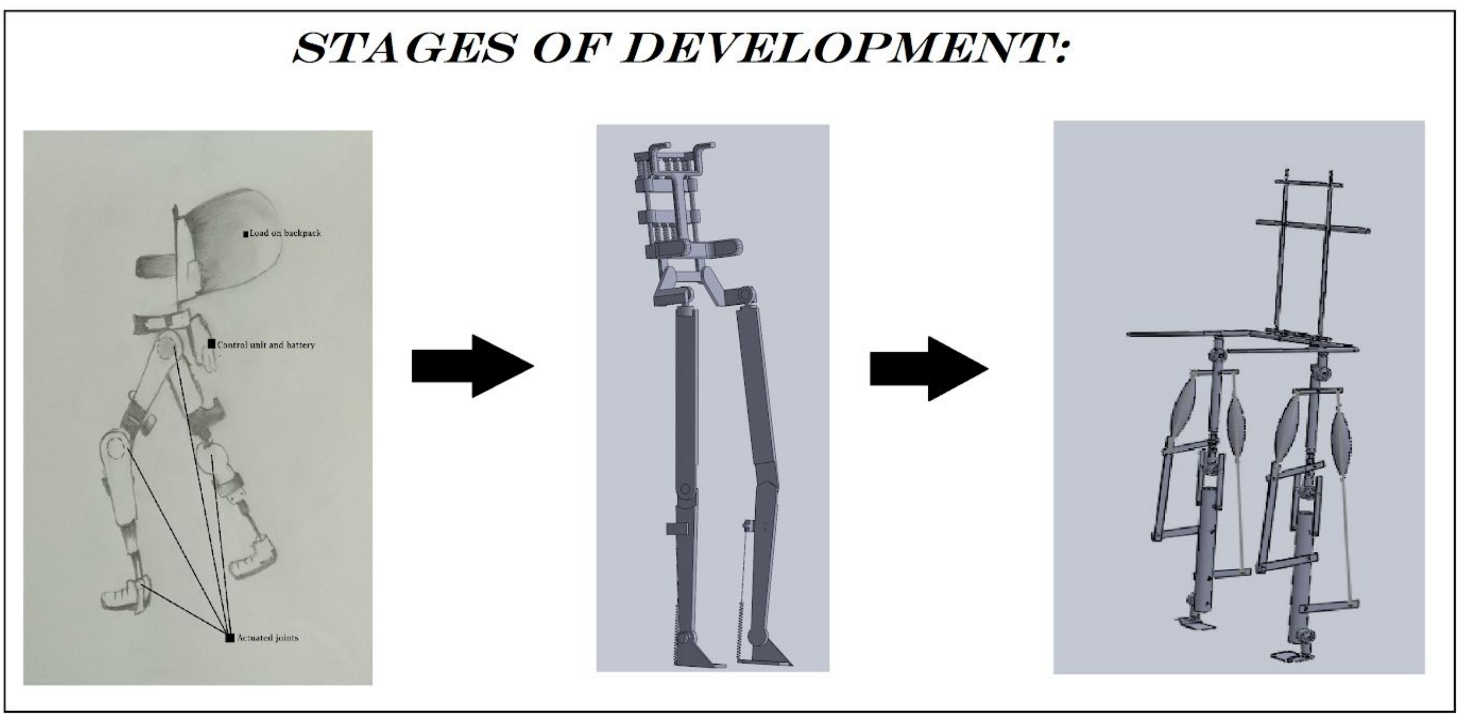
The Problem

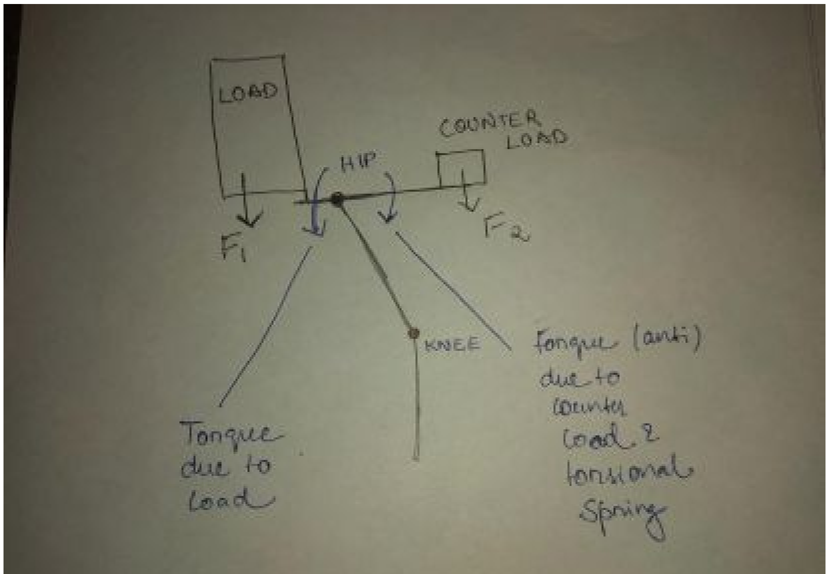
- The Military is currently undergoing a huge influx of developments, but lacking a working prototype of exoskeleton to be used for assisting our jawans, to lift heavy load on or off the battlefield.
- Current implementations of exoskeleton are too costly to be used extensively. Their prices range from tens of thousands of dollars, to even millions (as developed by DARPA).
- We aim to develop a exoskeleton which can meet the requirement of assisting a soldier to lift 40 Kgs, without hindering the movement and cost around ₹30,000.

The Challenges

- The exoskeleton should complement the movements of the wearer, and not hinder it. It should move the way the user wants.
- It should be able to carry 40 Kgs. In other words, it should transfer maximum load to ground, without affecting the gait cycle of user. For this part, extensive mechanical design is required to transfer load to the ground.
- As, the load is put on the back side of the body, measures are to be taken, so as to minimize torque on the upper body.
- All these challenges are to addressed while devising a cost effective solution.

The Mechanical Design

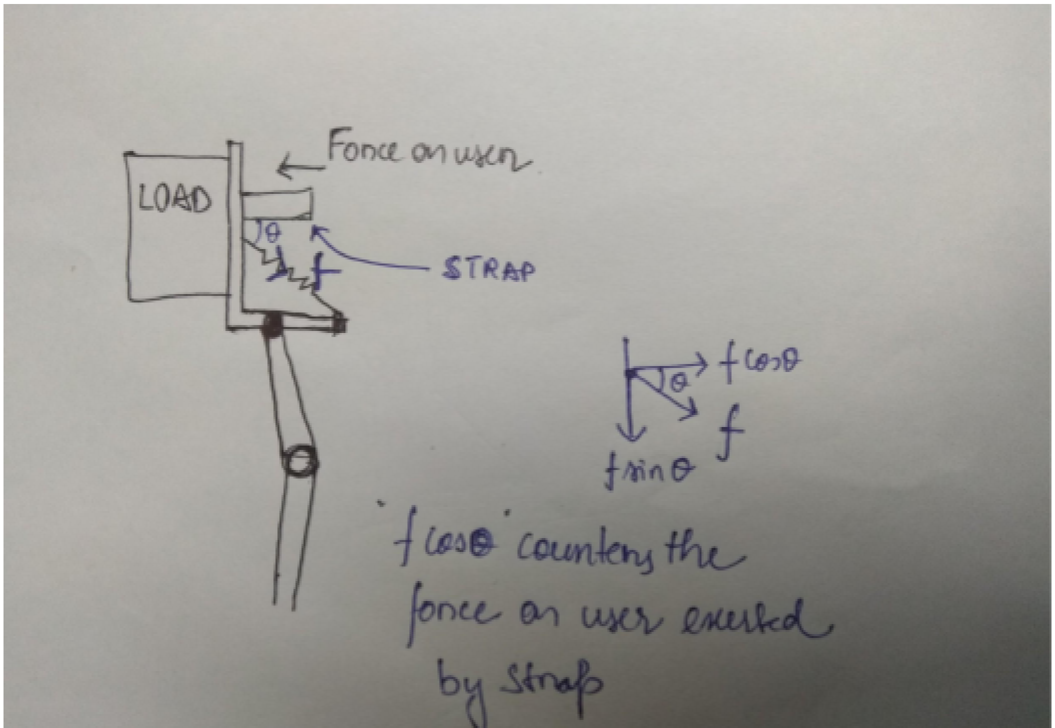




Torques on the hip joint

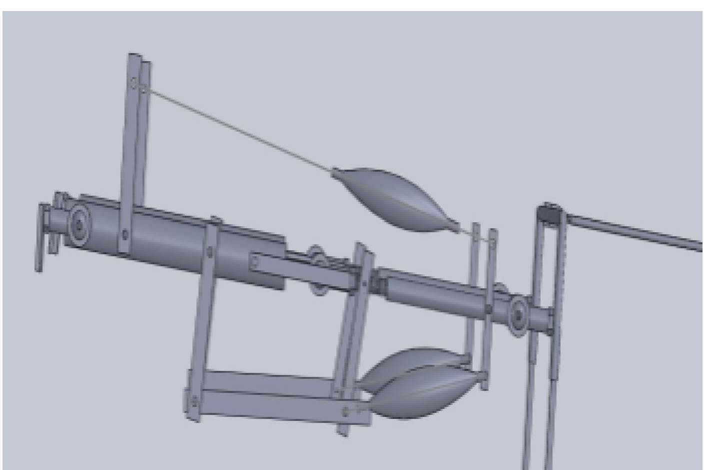
- The main objective of the mechanical design is to build a structure which can transfer the load of the backpack to the ground.
- Having 40Kg on back produces a downward force as well a torque about hips joints. To reduce this torque and preventing a backward pull on body due to weight of the bag, a counter torque mechanism has been used in this model. The torque has been countered by two means.
- Firstly, the structure is extended about hip joint to such a length such that keeping some load in front can counter the torque about hip. Also, it increase load capacity of the user by 50%. We use this space for keeping all our battery or power system instruments. Secondly, we installed torsional springs on hip joint - below hip structure and on legs. When a force is applied on hips it tend to rotate the spring by pressing it downward and in reaction an upward force is applied by spring to hip producing torque in direction opposite to that of the backpack.

- These two mechanisms combine reduces the torque due to weight on hip and lead all forces on leg structure in downward direction.



Action of linear spring

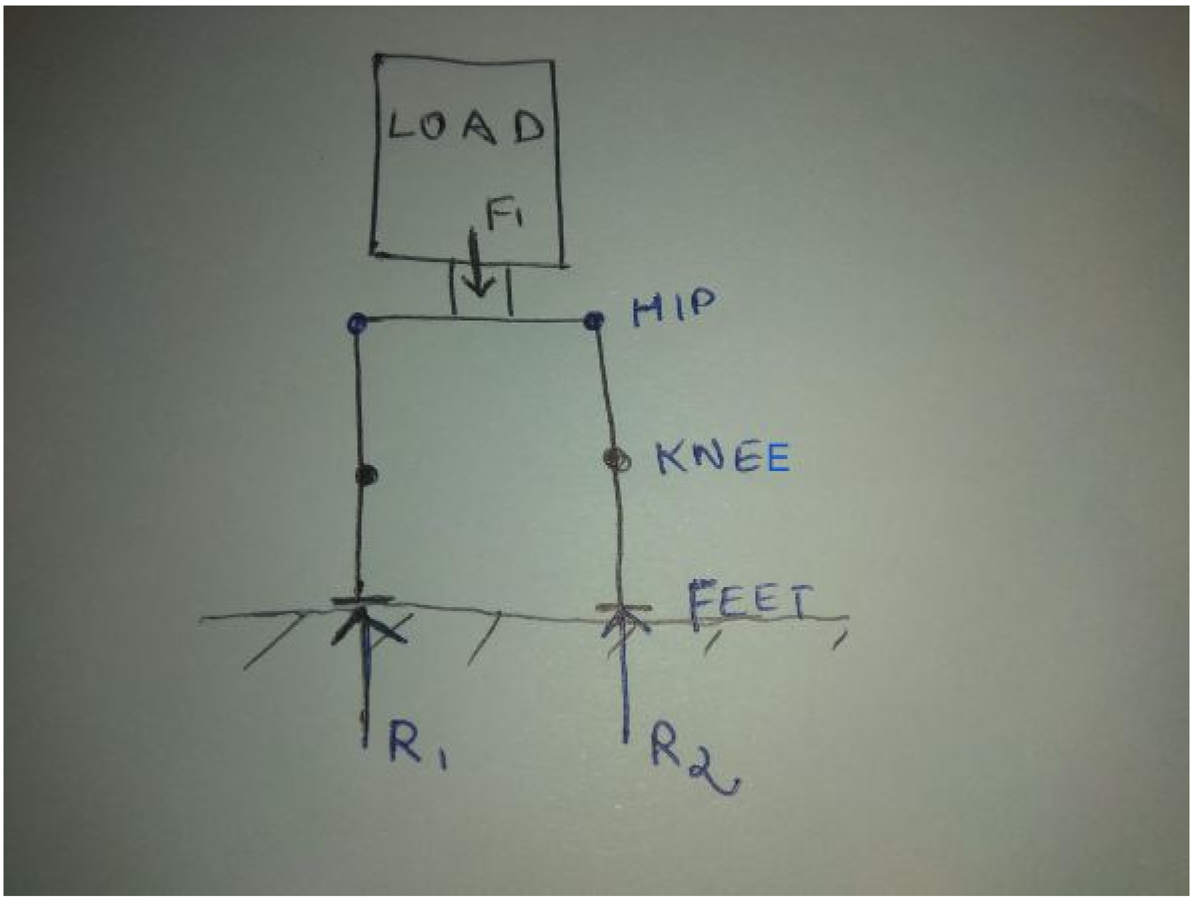
- The backpack is attached to the structure at the back (which can rotate about the hips) and is connected to the user using straps. But the load tend to pull the user backwards. So a pair of linear springs is used to counter this force. As it is connected at the hips, the torque on the user due to the reaction force of the spring is zero.


Pneumatic actuator mechanism

Now, all force get directed down towards ground. The load also exerts torque at the knee joints thereby restricting the free movement. So we use the artificial muscle actuators at the knee to help counter the load torque.

- Thus most of the load is transferred to the ground through the external structure (exoskeleton).

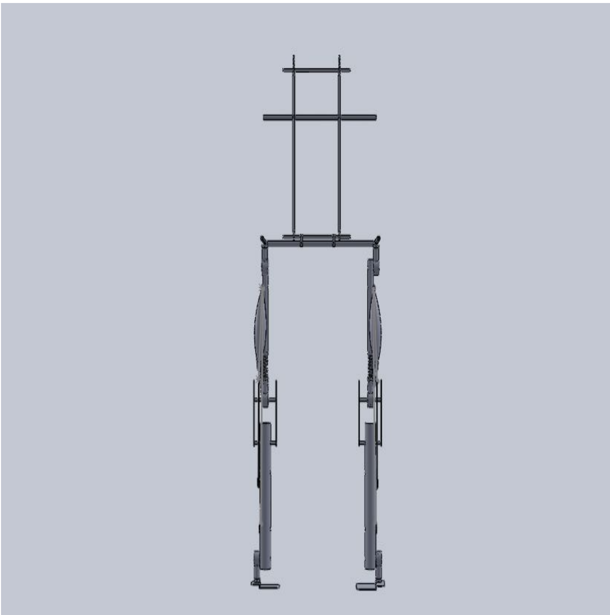
- The force goes to the metallic plate which is installed inside shoe, which transfers the load coming from above to ground.

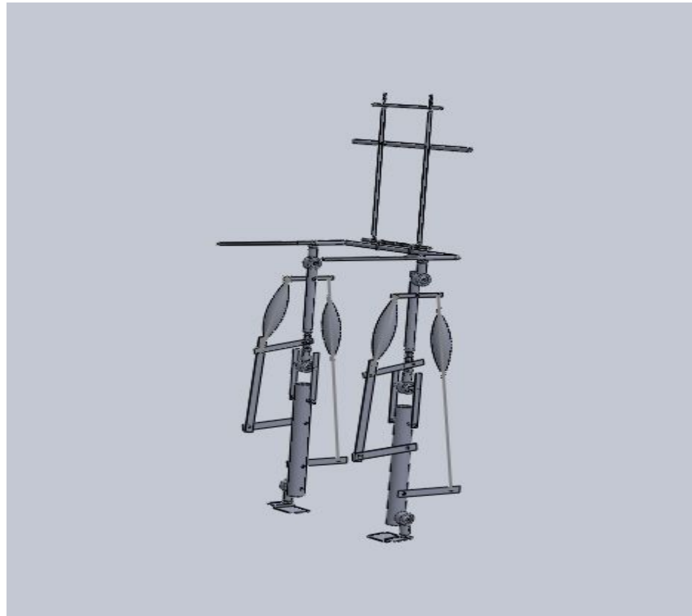


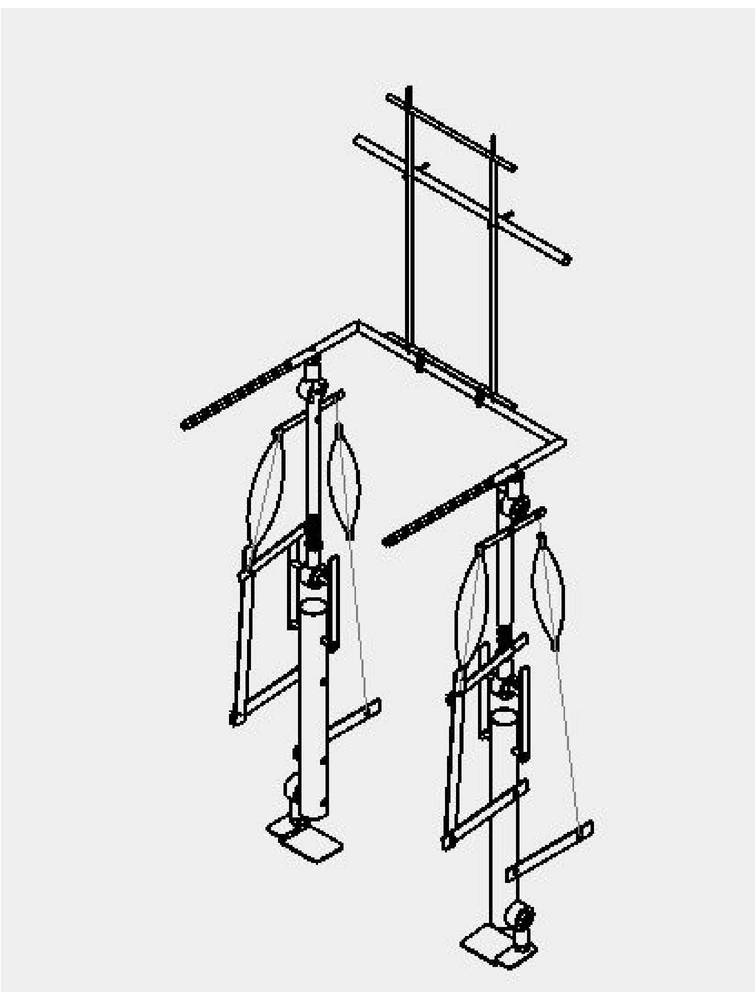
Pneumatic Actuator Muscles

Instead of using motor or traditional actuator in our product we used pneumatic actuator muscles.
It consist of two main components, Latex tube and nylon sleeves. Latex tube is fitted inside the sleeves. The latex is inflated with air using the compressor and the nylon sleeve restricts its longitudinal expansion. The radial expansion leads to the decrease in the length and hence mimics the activity of the natural muscles.

CAD model of the existing prototype:





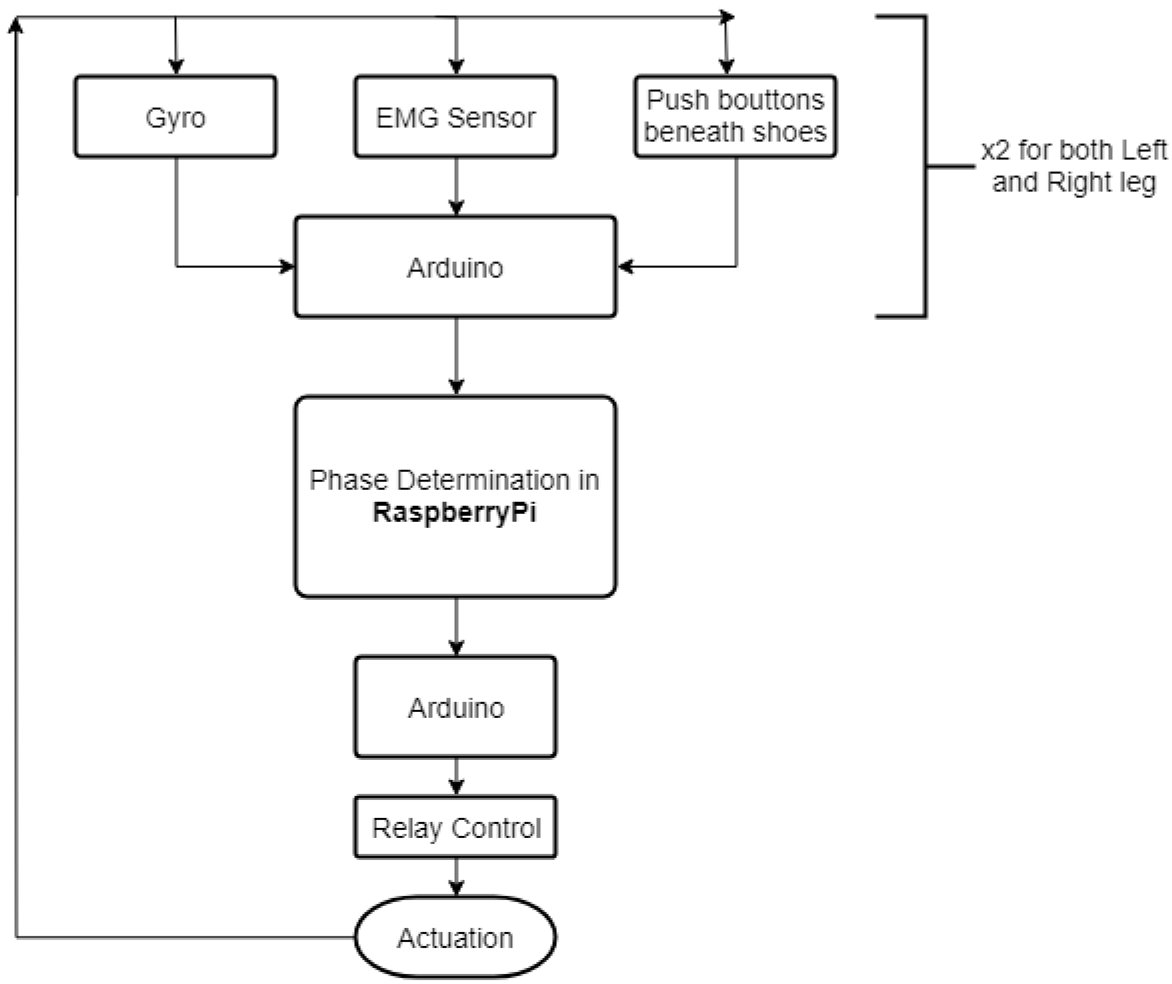


The Electrical Design

Initially, Machine Learning was intended to be used to predict next movement. However due to non-deterministic nature of the predictions, as well as very little time for training, and not very reliable sensors, the idea of using ML was dropped and a more algorithmic way of controlling movement was devised.

Also, in the initial design, piezoelectric sensors were incorporated which were later dropped from the final product, due to its unreliability. Instead, an array of four buttons on the shoe sole was used, which gave us an idea of the phase in which the foot was currently in.

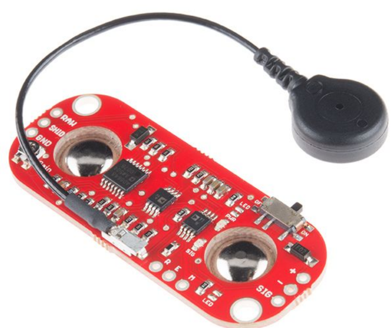
Given below, is a simplistic flowchart, to help grasp the crux of the electrical design. After this, a much more deeper dive to the intricacies in the electrical design would be taken.

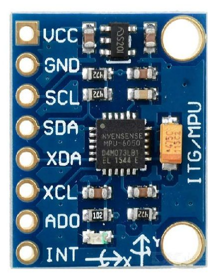


❖ Electrical Sensors and Components

- **ElectroMyoGraphy Sensor (EMG) :** The sensor provides an amplified, rectified and enveloped signal of the actual electrical signal given out to muscles, by our body during contraction or relaxation. It gives an analog reading in form of voltage (0-5V) which can be extracted through a microcontroller, which in our case is an arduino mega.
- **Gyro Sensor :** The microcontroller can be coded to extract Roll, Pitch and Yaw values from the Gyro Sensor (MPU-6050). However, our design is concerned with only the pitch value as our calf as one one degree of freedom relative to our thigh.
- **Push Buttons** : An array of 4 push buttons were placed beneath the sole of of each shoe. If the buttons is pressed, it would generate a high signal allowing the microcontroller, to detect its high state. It is very crucial to know the current phase of walking, the push buttons play a major role in it. 4 push buttons are arranged in such a way, so that the first one is at the heel and the last one at the toes, leaving two in between. When the user first lands on his heel, the first button gets activated, and in due course of time all buttons are activated. After that the foot slowly leaves contact from the ground. In this stage, the first button is released initially, followed by second, third and fourth. Thus, the combination of currently pressed push buttons will give us the phase of the foot.

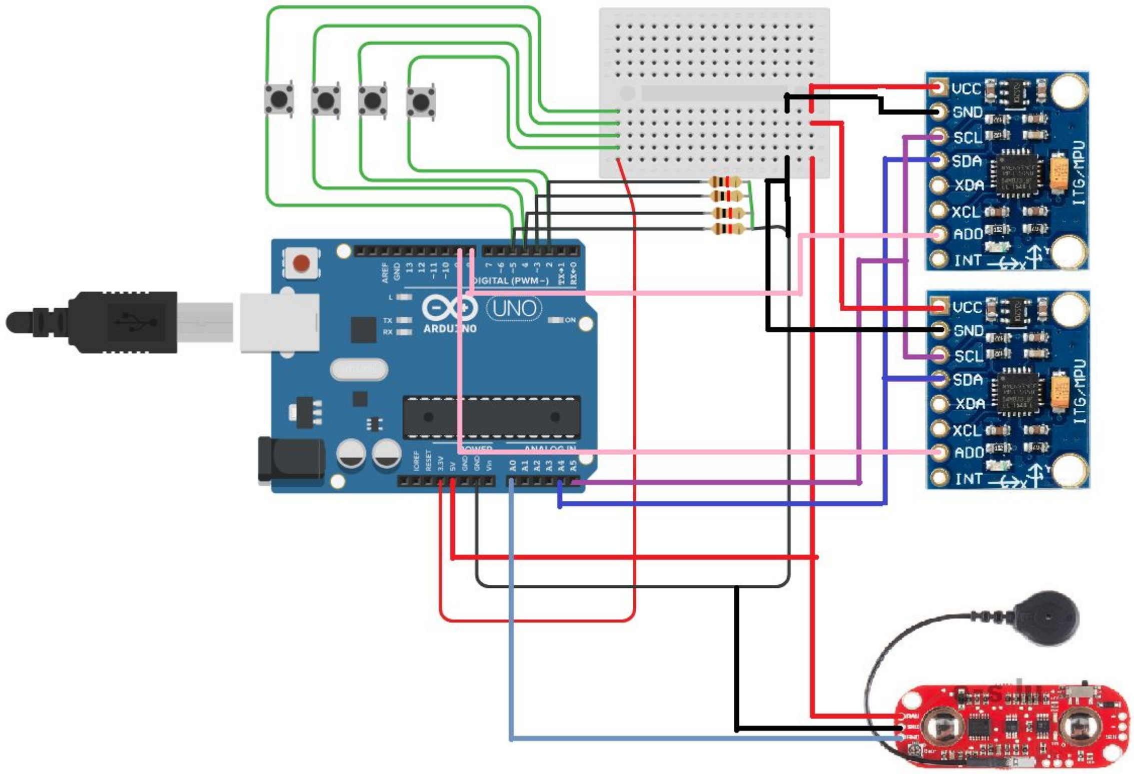
Given below is **EMG** Sensor, **Gyro** Sensor, and **Push Button** from left to right.





- **Arduino Mega :** 3 of these microcontrollers were used. Two of them, were used to collect EMG, Gyro, and Push Button readings for both left and right leg and the third one was used to control relay switches which were further used to control solenoid valves. The function of solenoid valves would be discussed extensively in the section of Mechanical design.
- **RaspberryPi :** It acts as a mediator between 2 arduinos providing sensor values and the arduino controlling relay switches. All the calculations regarding the next movement and gait cycle is conducted by the Pi.
- **Relay Switches :** The Relay Switches act as an interface to control the 24 Volts / 12 Volts by using the microcontroller's high or low that ranges from 0 to 5 Volts. We used these switches between the Arduino and 24 Volts supply and compressor's 12 Volts supply.

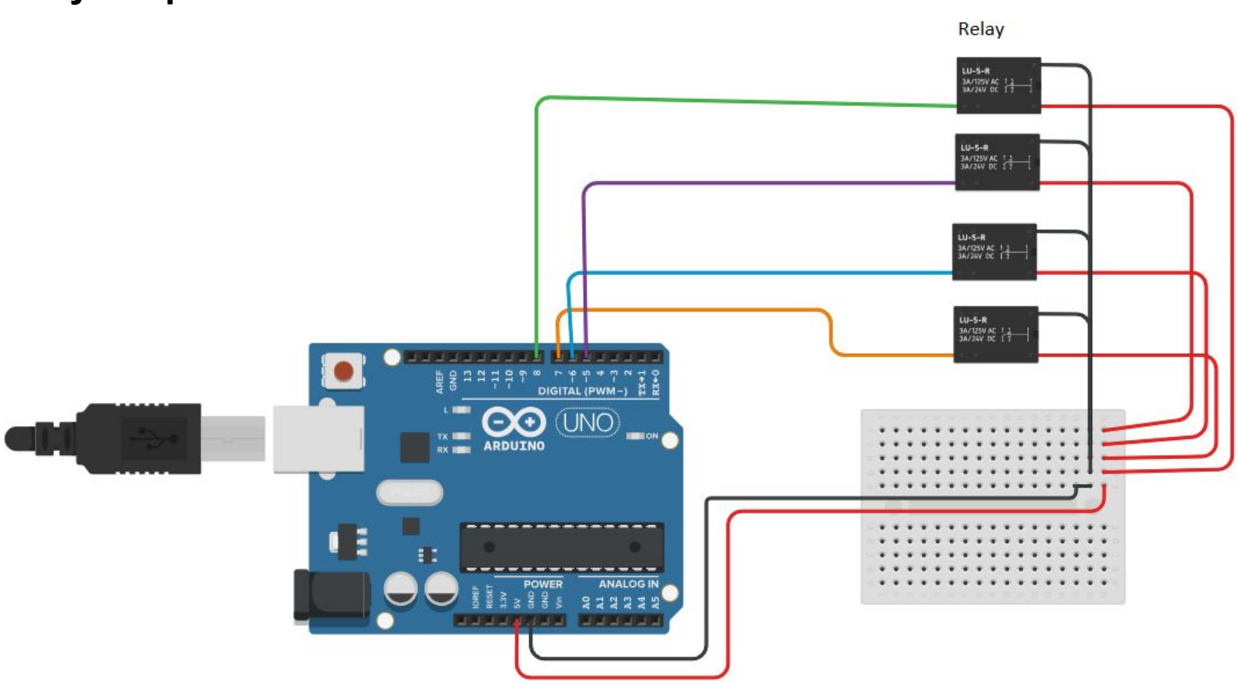
❖ Sensor Input Circuit



➢ The above circuit takes input from all the sensors and passes on values to RaspberryPi. The circuit is replicated for both left and right legs.

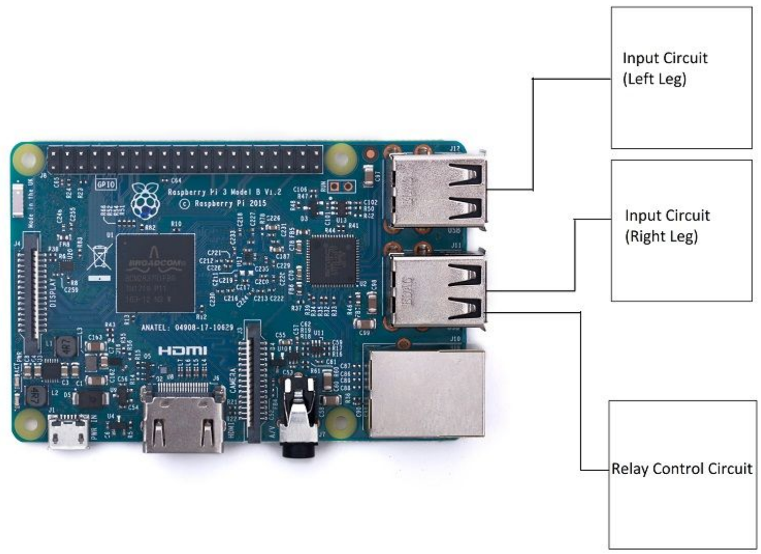
➢

❖ Relay Output Circuit



➢ This circuit takes commands from RaspberryPi and translates into on/off of relay switches.

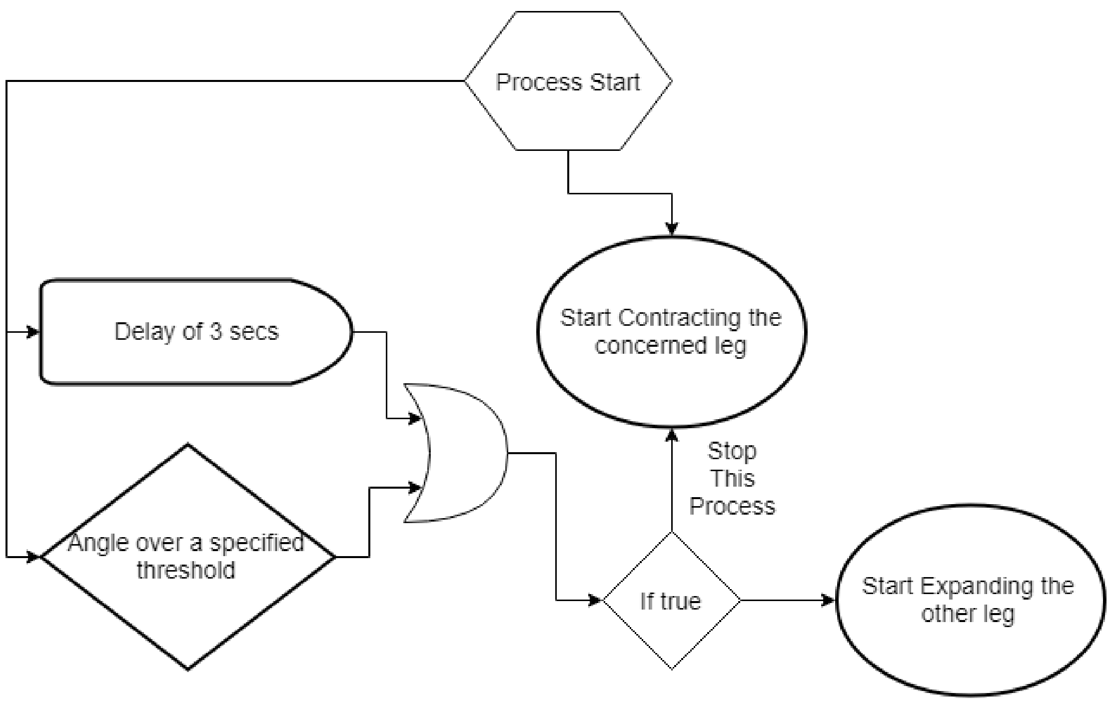
❖ Overall Circuit



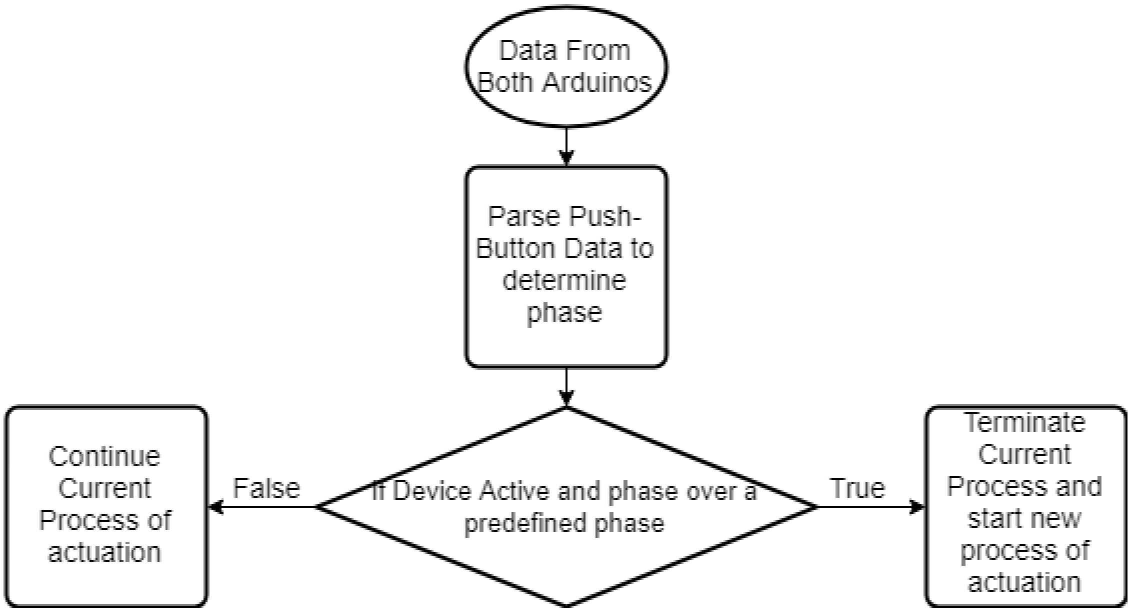
- ➢ In the above diagram, the input and output circuits are the circuits illustrated in the previous sub-sections. The single wire from RaspberryPi to the circuits represents USB Serial connection from RaspberryPi to Arduinos.7

❖ Algorithm

- ➢ The Expanding/Contracting of a specific leg is governed by the process given below



- ➢ The overall algorithm works as follows. The process of actuation in this diagram is described in the previous diagram.



Cost Report

Serial No	Name of Item	Cost Per Item	Quantity	Cost
1	EMG Sensor 1	4926	1	4926
2	EMG Sensor 2`	2277	1	2277
3	Gyro Sensor	229	4	916
4	Push Button	5	16	80
5	Arduino Mega	879	3	2637
6	Raspberry Pi	3390	1	3390
7	Solenoid Valves	800	4	3200
8	Steel Pipes	500	-	500
9	Hyme Joints	290	6	1740
10	Shoes	330	1	330
11	Ribbon Wires	100	3	300

12	Pneumatic Pipes	300	-	300
13	Pipe Fitting(Connectors)	300	-	300
14	Relays	60	5	300
15	Nuts/Bolts/Washer	500	-	500
16	Nylon Sleeve	300	-	300
17	Latex	25	4	100
18	Paint	200	2	400
19	Springs	200	4	800
20	Compressor	2500	1	2500
21	AC-DC converter	400	2	800
22	Others(tapes,windings etc.)	1000	-	1000

Total Cost of the overall final product : **₹27,596**

Manufacturing / Assembly Process :

The following processes were utilised :

- Drilling
- Welding
- Grinding
- Cutting
- Turning
- Other Joining Techniques

Limitations and future scope:

Though we tried our best to make the prototype as efficient as possible, but there are still some limitations in it. We are going to work on it to eliminate those. The plan is as follows:

1. Make a lighter structure.
2. Use better joints.
3. Introduce more flexibility.
4. Improve wearability.
5. Much more fast response times

6. Incorporate Machine Learning for better Gait Cycle Prediction
7. Extend actuation to arms
8. Extend its capabilities beyond load carrying

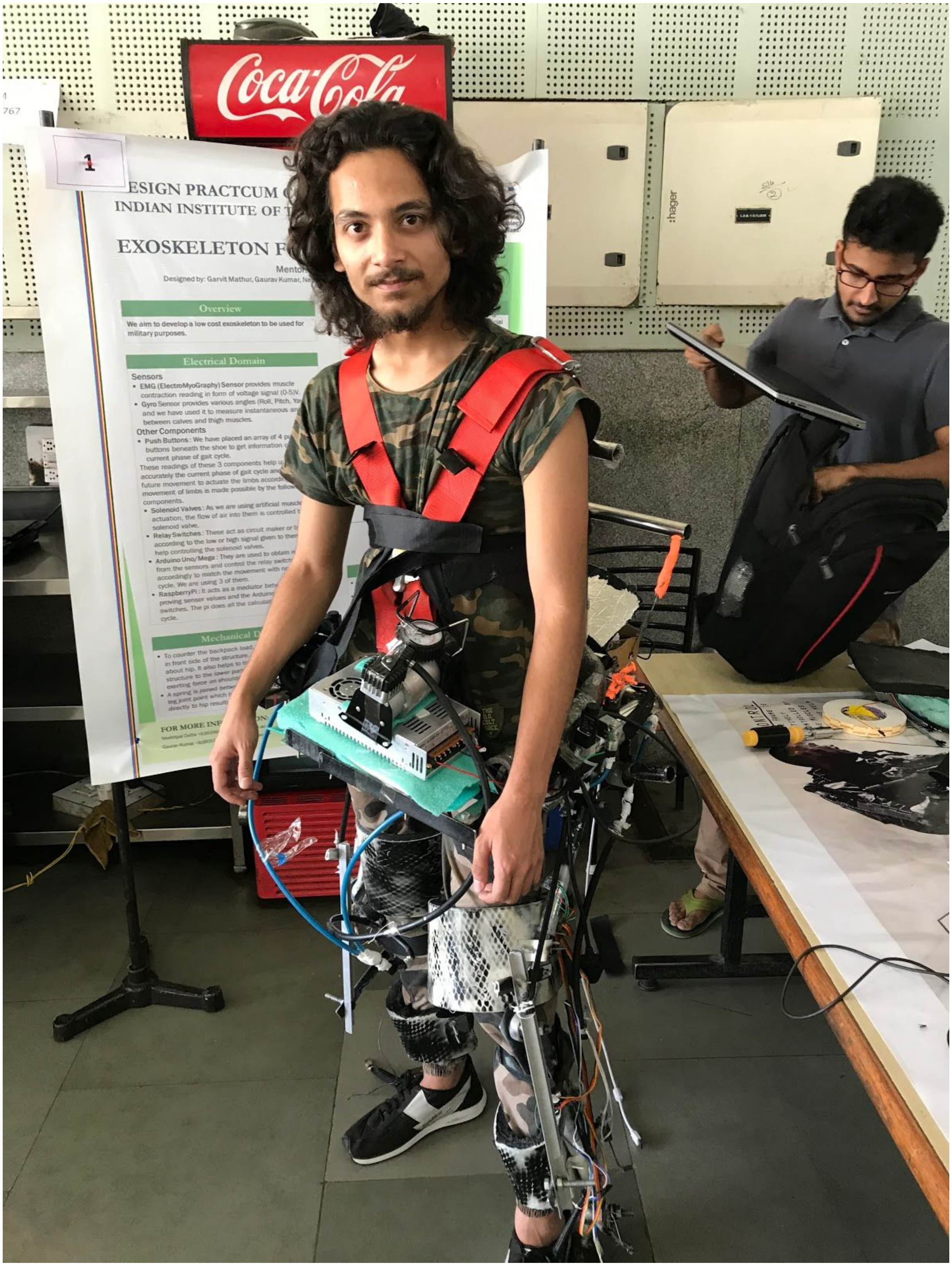
Conclusion:

Hence we are able to build an exoskeleton which can enhance the load carrying capability of the user. While standing, the pneumatic muscles were able to prevent the bending of the kees thereby letting maximum transfer of load to the ground. During the course of project, many changes were made to the design- either due to the failure in working or non- availability of the raw materials. We also introduced a number of innovative mechanisms like the pneumatic muscles. Though we were not able to introduce all the features that we had imagined, but we are definitely going to work on it.

The course has been an wonderful learning experience for all of us and we are thankful for getting this opportunity.

Team Members: Team 1

(From Left):Neelotpal Dutta, Gaurav Kumar, Garvit Mathur, Parimal Kumar, Ritwik Saha, Nikhil Gupta



Final Working Prototype on display in Open House