

# **Lerner Exoskeleton Actuators**

## **Final Proposal Report**

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## **EXECUTIVE SUMMARY**

Our project Lerner exoskeleton actuator is a type of a robotic exoskeleton that is used by people with neuromuscular disorders to improve their movement mainly by walking. This exoskeleton is mainly used on the lower part of the body. An example of a neuromuscular disorder is cerebral palsy which is a disorder found in children when the brain is damaged thus the child cannot be able to move.

### **Purpose**

1. To help improve the lifestyle of people with disabilities.
2. To observe and record data about disabled people and to find measures to enable their wellbeing.

### **Goal**

1. To improve the design of the existing exoskeleton in order to enable free movement of limb muscles using the engineering requirement.

The use of exoskeletons can be applied in several fields. These are:

- a. Medical field- in this case, people with neuromuscular disorders can be able to use exoskeletons in order to enable movement and for extra energy to those with little energy to move.
- b. Civilians- here, exoskeletons are used as a means of research for science and technological inventions for the purpose of improving the lifestyle of neuromuscular disordered people.
- c. Military- exoskeletons for military purposes are made in order to maintain peace and order while reducing the chances of injuries and death to normal citizens.

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# **1 BACKGROUND**

## ***1.1 Introduction***

The team looks into making improvements on the existing exoskeleton such that it could work better and more efficiently. The robotic exoskeletons are normally used by healthcare industries in order to assist people with neuromuscular disorders to be able to walk better than how they walk without the devices. The device has a system with motors that collaborate with the transmissions produced and give enough support to the ankle joints of the user [1]. Another aim of this project is to design a series elastic actuator that can assist the patient to have a more clinical gait and improve the walking movement. First, a new design of the exoskeleton is to be put in place. The previous form was not comfortable and came along with various difficulties. The new one is meant to set the record by enabling a stiff point of mounting on the user's organ, to be able to adjust to different sizes and ages of users, to be able to be easily put on and off, to be comfortable to the user as well as to be way lighter than the previous. Secondly, after making a design using springs in different ways that can help the patient not slip and walk more comfortable, then the project would have been successfully completed.

## ***1.2 Project Description***

The project entails the design, prototyping and manufacturing plan for an exoskeleton actuator system. The exoskeleton actuator can be classified as an electro-mechanical assistive technology that uses engineering and computing technologies to actualize the design of an artificial exoskeleton for use in assisting the disabled to walk again. Other uses of exoskeleton are to promote occupational safety and operability by enhancing the strength and safety of the wearer. In hospitals, the exoskeleton is used to assist people with neuromuscular disorders to walk and perform other functions that they cannot perform on their own. This is done by assisting their walking usually done when the device's system collaborates with its motors and the transmissions produced to support the movements of the ankle joints [1]. Most of the time, however, the exoskeleton is difficult to be mounted on the user's limb. This project, therefore, is meant to improve the existing exoskeleton to another design that can have the series elastic actuators implemented and successfully help the patient to achieve a no-slip walk and more comfortable movement and attach it to the exoskeleton in order to make the walking of the user easier than before.

## ***1.3 Original System***

There have been several iterations of an exoskeletal system for use as assistive technology to individuals with neuromuscular deficiencies. However, the original design was faced with various technical and operational challenges such as their excessive weights that ended up burdening users in other areas and hence exacerbating their conditions, others were not strong enough, there were also issues of low-quality built design and implementation, mismatched user and product requirements and functionalities, lack of adjustability and fluidity in response and operations, as well as a barrage of other operational, structural and mechanical deficiencies (Walsh 35). Such problems and deficiency are what promoted people to seek for more quality and custom fitted exoskeletons that are capable of meeting their individual needs with the only deterrent being the expensive nature of achieving such kind of modification and localization. There is, therefore, a need for investors and factory stakeholders to take into consideration the factors stated above in order for a higher level of customer satisfaction to be achieved

The original system comprised of a damping mechanism /system made up of springs, plates and a housing assembly. In the past, several designs were put in place so as to assist people living with neuromuscular disorders. The previous designs were greatly disadvantageous as they were; heavy for the user, weak, of poor quality, not able to be adjusted to the user's preference and not according to the user's demands [2]. These disadvantages propelled people to seek better ways to make and design the exoskeleton in order to eliminate the disadvantages. However, the new inventions were also more expensive and could not be afforded by everyone who required the devices. This project is meant to eliminate the disadvantages while also making the device more affordable to everyone. Therefore, the purpose of this project is to design a spring and choose the location to place it and have analytical data.

### **1.3.1 Original System Structure**

The original system structure is designed to suit everyone no matter the age difference can able to use it. The robotic exoskeletons exist in different sizes; there are the big ones that are meant for adults, while there are smaller ones that are meant for little children [2]. They are normally strong, flexible and can be used for a long period of time thanks to the high-quality materials used in manufacturing them. The high-quality materials are used in order to make sure that the user is comfortable with the functioning of the device. Meaning that the exoskeleton is light and the chances of being injured are very low if an accident occurs. The exoskeleton is also designed such that the areas that touch the body have been made with soft materials in order to reduce friction and increase its comfort during walking [2]. In this way, the design of the exoskeleton meets all the user's expectations. Below is an example of the robotic exoskeleton.

### **1.3.2 Original System Operation**

The original exoskeleton operated in two different ways, meaning that it was made in two different forms [3]. The first form was the one that was operated by the individual. This one is designed in a way that it contains an operating system fitted with sensors which enable the user to walk by guiding the movements of the limb. The second form is the one operated by someone else who is not the original user. This form of the exoskeleton is only allowed to be used when someone else is available in order to operate it while the user is moving. Despite their different forms, both of them function successfully when there are no disadvantages being experienced [3].

### **1.3.3 Original System Performance**

The original system had a successful performance with very little disadvantages. The system is made with a design that it assists the user's limbs to move and also provides the user with energy for those that lack enough energy to move their muscles [2]. The system worked successfully and had been used in the past few years in order to improve the lives of individuals with neuromuscular disabilities. The system, however, needs to be upgraded in order to function well. This upgrading can be done by use of inventive technologies that emerge each day so as to make the exoskeletons more effective.

### **1.3.4 Original System Deficiencies**

The original system had several disadvantages which this project tends to correct or improve on them. For instance, the materials used in the designing of the exoskeleton were responsible for its heavyweight thus causing the user to use most time trying to utilize the device without having to rest [3]. Furthermore, the way the limb was mounted on the exoskeleton was not always successful and therefore a better design should be invented in order to enable a tighter and a more effective grip. This means that the original system could not be adjusted, and the



users had to look for custom made exoskeletons which were far more expensive and time-consuming [2]. Some materials are also uncomfortable to the user as they tend to cause friction and irritation on the skin.

## 2 REQUIREMENTS

The team requires several customer requirements that are wanted by the client in order to look into the original system's disadvantages, search for ways to improve on them as well as work on improving the quality and function of the exoskeleton. These requirements can be compared to the requirements of engineers too.

### 2.1 *Customer Needs (CNs)*

The customer requirements are shown to be given by the client or stakeholders. Therefore, the team weighted the list of requirements and afterward set a target towards the improvement of the exoskeleton so as to be able to make a more efficient form of the exoskeleton

Table 1: Customer Needs

<b>Customer Needs</b>	<b>Description</b>
Measure torque	Measure the required torque in and out of the pulley and motor
Weight	The material of the exoskeleton
Spring location	The design of the best location of spring
Non-invasive	No contact of the ankle
simple	Make the spring design as easy as possible

### 2.2 *Engineering Requirements (ERs)*

The engineering requirements are created by the team based on customer needs. Engineering requirements are derived from the customer need and are more detailed according to engineering perspective.

Table 2: Engineering requirements

<b>Engineering requirements</b>	<b>Description</b>
Measure torque	0-7 Nm out of the motor  0-21Nm out of the lower pulley
Weight	Patient 50 lbs-150lbs
Spring location	design selection for the spring
Non-invasive	Make sure that metal bars and pulley system don't contact human ankle
simple	Simple modular design that relies on separate but easy to assemble sections

### **2.3 Testing Procedures (TPs)**

1. Design a device with a weight limit.

This device should be able to accommodate the limb of a patient weighing from 50 to 150 lbs. to accomplish this requirement; individuals ranging from 50 all the way to 150 lbs. were tested on the exoskeleton. The feedbacks were analyzed, and it was noted that each and every individual was comfortable with the way the design was made on the exoskeleton.

2. Designing a more adjustable exoskeleton.

This was accomplished when the same individuals used to test on the weight limit were also used to test if the exoskeleton could be adjusted. In this case, the exoskeleton would be increased or decreased in size depending in the size of the individual's limb. The individuals also reported that the limb was comfortable despite the varying sizes. The limb could also be rotated at 180°.

3. Using of a softer fabric.

During the design of the exoskeleton, a softer fabric such as polyester was used so as to create comfort in the exoskeleton and to reduce the friction thus reducing chances of skin irritation. The fabric also helped in the reduction of the weight of the device. Therefore, after testing the device on individuals with varying ages and weight, it was discovered that the new design was far much better in terms of weight and comfort.

### **2.4 House of Quality (QFD)**

QFD is House of Quality, which determines the relationship between the engineering requirements and customer requirements. Engineering requirements are the technical aspects of the project according to the client requirements and customer requirements are basically the project information provided by the client. As the Engineering requirements have developed from the customer requirements, therefore, it is necessary to make the relation between ER's and CR's and identify the effect of CR on ER. QFD is a matrix in which customer requirement and engineering requirement relate to each other and assign a value according to the importance in the corresponding matrix.

From the QFD, we obtained the targeted values of engineering requirements and determine the importance of each engineering requirement with the help of absolute technical importance and

relative technical importance. QFD table is showing below.

Table 3: QFD

Engineering Requirements	Importance	Provide Torque	Specify Material	Perfect location for spring	Must not contact with ankle	Not complicated design
		Customer Requirements				
Measured the required torque	9	9	3	1	1	1
Make the design lightweight	3		1	3	3	3
Make the people with disability walk normaly	3	1		1	3	1
It must be non-invasive	1	3	1	3	1	3
It must be simple as possible	1	1	3	3	3	1
<b>Technical Importance: Raw Score</b>		88	34	27	31	25
<b>Technical Importance: Relative Weight</b>		42.9%	16.6%	13.2%	15.1%	12.2%
<b>Technical Target Value</b>		7	-	-	-	-
<b>Units</b>		Nm	-	-	-	-

From the above table, it is clear that most important engineering requirement is “Provide torque from 0 – 7 Nm and 0-21Nm which will be the torque out of the pulley” and the least important engineering requirement is “Not complicated design”. It can see that provide torque has a raw value of 88 and RTI value of 42.9% whereas not complicated design has a raw value of 25 and RTI value of 12.2%.

### **3 EXISTING DESIGNS**

Before the 1960s, people suffering from neuromuscular disorders had no way of improving their state. Thereafter, research groups located in the USA, as well as the former Yugoslavia, began researching on the human exoskeleton devices that could be powered [4]. The USA main research was however mainly on developing technologies that could be able to increase the functioning of normal people especially those in the military. On the other hand, Yugoslavia was mainly focused on developing the technology that could be able to help the physically handicapped [5]. Ever since the first design was made, other designs have always followed, the new version always being better than the previous in terms of effectiveness. The new developments were either meant to improve the previous designs or were completely new designs [4].

#### **3.1 Design Research**

In the past several years, various designs have been invented with the main purpose being helping those that are physically disabled on the lower part of the body, which is the limbs, to effect movement and other activities. The earlier designs created a platform for the team to look at and design a better exoskeleton. The team researched on the previous designs, on the internet and from scientific journals, and after coming up with an analysis the team learned of the issues that are related to the previous designs. This enables the team to come up with new ideas of designs as better analysis have been made. Apart from that, the team also searched up for more information in books and articles so as to create a better design of the exoskeleton. Since the invention and design of the first exoskeleton, there have been several improvements over the years that aim at producing a better product in terms of built functionality, quality and flexibility (adjustability). The proposed system that's under construction for this project was based on the apparent vulnerabilities and weaknesses/challenges of the existing exoskeletal systems. This design aims at achieving three main objectives; increased mobility. Increased flexibility and durability of the final product.

#### **3.2 System Level**

The original exoskeletons have always been the center of attention for a long time. Over the past 10 years, the exoskeletons have gone through three stages. The first one was being operated by an administrator as the base of the system. A good example of this is the Hardiman exoskeleton [3]. With time, inventions came up and individuals could be able to operate their own exoskeletons. The team analyses the combination of the various examples and then comes up with a more efficient design that exceeds the limitations of all the other previous exoskeletons.

##### **3.2.1 Existing Design #1: Sarcos exoskeleton**

This is an exoskeleton that can be used on the whole body. This exoskeleton contains a section that stores its energy for the functioning of the body. It produces the energy by use of the liquid medium. This helps as the liquid is found right where the joints that require support are [4]. The availability of the fluid medium allows the limb to rotate at an angle of 180°.



Figure1: Sarcos exoskeleton

### 3.2.2 Existing Design #2: Berkeley exoskeleton

This exoskeleton is mainly made for patients with neuromuscular disorders on the lower part of the body [4]. The system also moves with its own source of power. This exoskeleton is marked to be load bearing and would be very effective on patients with heavy weights. It is, therefore, suitable for patients from 50- 150 lbs.



Figure 2: Berkeley exoskeleton

### 3.2.3 Existing Design #3: MIT exoskeleton

1. This device works by learning the human walking style and then creates a mechanism of supporting the limbs thus making the human more comfortable as the weight of the exoskeleton is reduced. This exoskeleton depends on the energy that is in the springs when one walks [4]. This kind of exoskeleton is greatly similar to the team's project of spring invention. It also satisfies the need of accommodating the weight of the user, be it a child or a grown up.



Figure3: MIT exoskeleton

### 3.3 Functional Decomposition

The main purpose of this project is to design a series elastic actuation for a robotic lower extremity exoskeleton. The system will be actuated by a high-performance DC motor. Series elasticity will be implemented in the form of linear or rotational springs. In addition to the design and manufacturing of the system, the capstone team will provide the analytical characterization of system performance validated through experimentation.

#### 3.3.1 Black Box Model

The original design was observed by the team and upon completion found to have difficulties with the functioning of the entire operating system. The team, therefore, looks into improving on the difficulties by use of a black box model. The black box model works by assisting the user's movement by creating coordination. This would be advantageous as the user would use less energy while moving faster. In this experiment, the team formed springs that can be attached to the exoskeleton. These springs are attached on the ankle. The main purpose of the springs is to be able to improve the design and functionality of the exoskeleton.

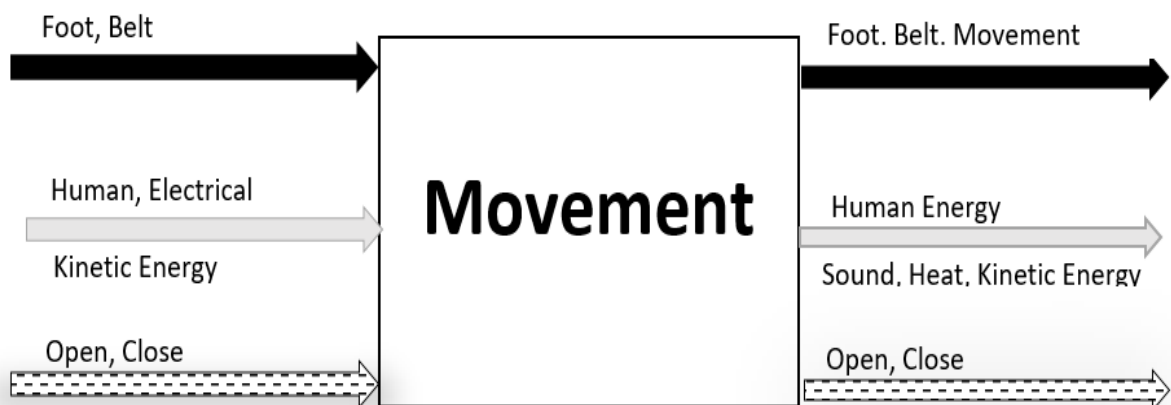


Figure4: Black Box

### 3.3.2 Functional Model/Work-Process Diagram/Hierarchical Task Analysis

In order to work well, the exoskeleton should be designed in such a way that the springs are located on the joints. In this case, it would be easier for the device to turn, retain its energy as well as support the user. In this case, springs are durable, unlike joints, they do not require greasing or much maintaining. Springs are also effective when it comes to reducing the weight of something. For instance, a heavy person would feel comfortable when using an exoskeleton with springs as the springs absorb shock in case of accidents. In this project, the team looks into designing a model that would generate its own energy and work effectively to satisfy the customers.

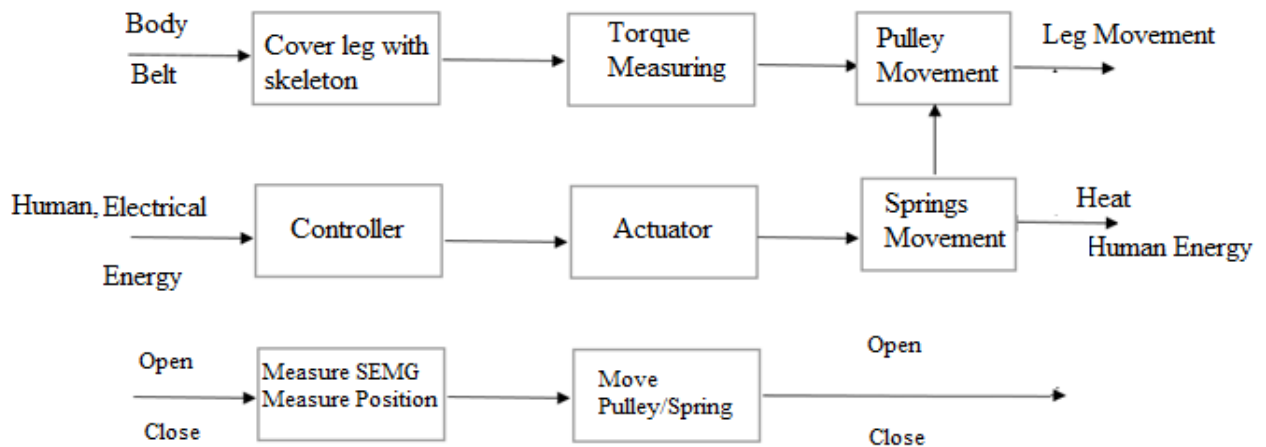


Figure5: Functional Model

### 3.4 Subsystem Level

In order to make the design effective, the components of the system should also be included [6]. The components are the ones that make up the entire system and when the team analyses the entire system's components then they get the perfect view of the efforts put in place to design the exoskeleton. In this case, the exoskeleton designed by the team will be perfect and satisfactory to the user [3]. This explains the reason as to while the subsystem is important too in the designing of the exoskeleton.

#### 3.4.1 Subsystem #1: Motors

Motors support the movement of the joints and have been known to enable patients that are paralyzed to stand upright and walk. This helps to increase the quality of the exoskeleton.





Figure 1: exoskeleton motors

#### **3.4.1.1 Existing Design #1: Sarcos exoskeleton**

This exoskeleton utilizes energy produced by sensors that are located between the user and the exoskeleton [4]. In this case, the motors make it easier for the user to move as it supports the whole body and the liquid medium aids in movement of all the joints of the body. This exoskeleton utilizes energy produced by sensors that are located between the user and the exoskeleton [4]. In this case, the motors make it easier for the user to move as it supports the whole body and the liquid medium aids in movement of all the joints of the body. The Sarcos exoskeleton was built by military contractor Raytheon for use by the US military and is described as a wearable robotic suit used for increasing human agility, strength and endurance. The human, in this case, is a soldier on active duty such as a battlefield or providing relief effort during a natural catastrophe. The exoskeleton allows the wearer to easily lift heavy payloads at a ratio of almost 17:1. The result is the ability to repeatedly lift a given load without any injury or exhaustion to the wearer. The motor is hydraulically actuated. The system, however, incorporates a robot which is energetically autonomous. The system employs rotary hydraulic actuators as opposed to linear ones that are located on the system's power unit. The main disadvantage of the Sarcos exoskeleton is its bulky and heavy nature that ordinary users may find uncomfortable. Making it with smaller and thinner components may, however, allow for better functionality and may increase its popularity and acceptance by the civilian population.

#### **3.4.1.2 Design #2: Berkeley exoskeleton**

This exoskeleton is used by being mounted at the hip, knee and/ or the ankle. The motors are very efficient as they assist the lower body to function and even those who cannot walk completely have a chance of being able to move their limbs. The Berkeley exoskeleton unlike the Sarcos one is not full bodied and is only worn on the lower body. Its full name is the Berkeley Lower Extremity Exoskeleton (BLEEX) and its functionality just like the Sarcos one is to help soldiers to complement their strength through the addition of extra force to the lower extremity of the users. The system has two motors that are electrically actuated and located on the hips [8].

### 3.4.1.3

#### *Existing Design #3: MIT exoskeleton*

This exoskeleton has springs on the joint that flexes and extends. Combined with motors, the springs provide more energy and are sufficient for a longer period of time. The MIT exoskeleton, unlike the rest, is quite unique since it employs no motors for its operation. Instead, it relies on the principle of conservation of energy by using the user's weight and payload that they wear on their back and are attached to two similar leg-like springy mechanical structures that run parallel to the legs of the wearer. The structures or appendages possess elastic energy storage devices located at the hip and ankle as well as a damping device located on the knee. The spring-like joints are employed to harvest energy from the payload and user's motion and to store them for the next cycle of motion/ stride.

### 3.4.2

#### **Subsystem #2: ontrols**

This subsystem is responsible for the operation of the exoskeleton according to the need of the user. They can either be made according to the technology or the requirement of the user.

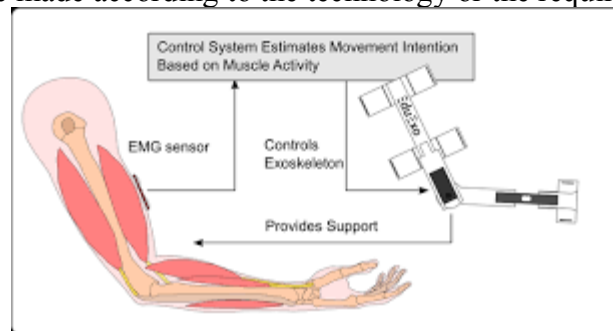


Figure 2: exoskeleton control

### 3.4.2.1

#### *Existing Design #1: Sarcos exoskeleton*

This exoskeleton is controlled by sensors that are located between the user and the exoskeleton. The team's project looks into coming up with a design that can be controlled by the user's movement to release energy.

### 3.4.2.2

#### *Existing Design #2: Berkeley exoskeleton*

The Berkeley exoskeleton is electronically actuated is controlled by impulses generated from the movements of the wearer. This project looks to assimilate the same control system whereby the exoskeleton can provide enough energy to maintain the user's movements. This exoskeleton is used by being mounted at the hip, knee and/ or the ankle. The motors are very efficient as they assist the lower body to function and even those who cannot walk completely have a chance of being able to move their limbs. The Berkeley exoskeleton unlike the Sarcos one is not full bodied and is only worn on the lower body. Its full name is the Berkeley Lower Extremity Exoskeleton (BLEEX) and its functionality just like the Sarcos one is to help soldiers to complement their strength through the addition of extra force to the lower extremity of the users. The system has two motors that are electrically actuated and located on the hips [8].

### **3.4.2.3** *Existing Design #3: MIT exoskeleton*

Here, the energy is released during flexing and is stored during extending. Therefore, the exoskeleton is controlled by the joint movements. The project design will allow the exoskeleton to be controlled by the movement of the limb. The system is controlled through the movement of an individual's limb impulses.

### **3.4.3** **Subsystem #3: structure**

The subsystem does not only aid in the effective functioning of the exoskeleton, but it also helps with creating comfort for the user. Which are the most important aspects?

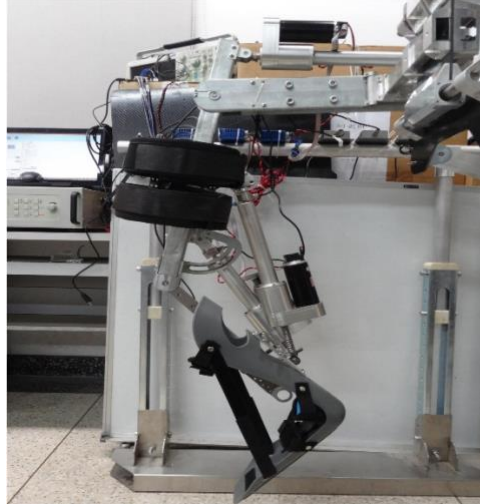


Figure 3: exoskeleton structure

### **3.4.3.1** *Existing Design #1: Sarcos exoskeleton*

The structure of the sources exoskeleton is made in a way that the user's limb is interfaced with the exoskeleton containing a stiff metal plate that ensures the user's limb remains stiff while using the device.

### **3.4.3.2** *Existing Design #2: Berkeley exoskeleton*

This exoskeleton is structured using springs loaded at the hip and at the ankles whereby the ankles are left to spin (). This project aims at loading springs at the hip and ankle joints too.

### **3.4.3.3** *Existing Design #3: MIT exoskeleton*

It is designed in a way that the limb of the user can be easily placed in and also can be easily removed. In this case, the user can be able to put it on and take it off with ease as the exoskeleton's structure allows it. The project aims at designing the exoskeleton with an easier way of wearing and removing it.

## 4

### DESIGNS CONSIDERED

The team considered a number of designs based on the customer and the engineering requirements. These are as shown below.

#### 4.1 Design #3: rotational spring

This design is a rotational spring that has a bearing in it such that it allows the heel to move with a normal human walk. Furthermore, the torsion spring has a very high deflection in case of spiral torsion springs. And has a bearing connected with the torsional spring

Advantage:

- Last for a longer time
- Can be adjusted easily

Disadvantage:

- We might add more parts than needed
- Hard to assemble

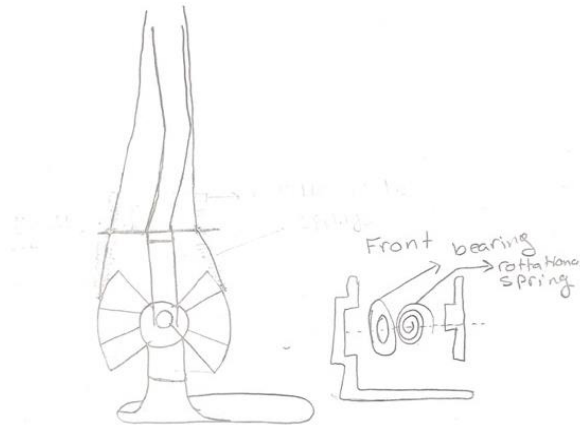


Figure 9: rotational spring

#### 4.3 Design #7: springs connected to the pulley.

For this design, we will not have to redesign the pulley all we have to do is figure out which spring to use. Also, this design will increase the torque.

Advantage:

- Will not change the pulley
- More power efficient

Disadvantage:

- It would do the opposite of what we are aiming for
- Springs are in parallel

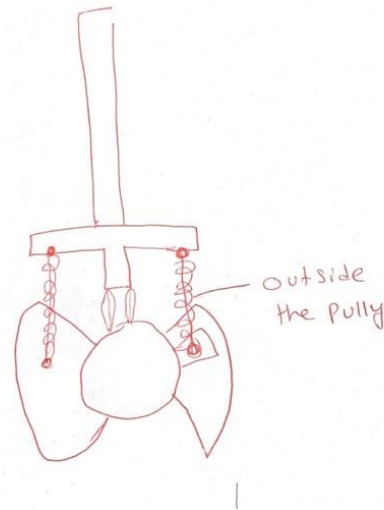


Figure 10: springs connected to the pulley

#### 4.4

#### *Designing of the exoskeleton using all the above designs.*

This design will be more flexible for the patient. When the patient moves the spring we also absorb the force while walking, and it has movable plates, so it can be adjusted and have a vertical movement.

Advantages:

- It helps the patient when he slips
- It has an adjustable length

Disadvantages:

- Increasing the design length
- Increasing the weight

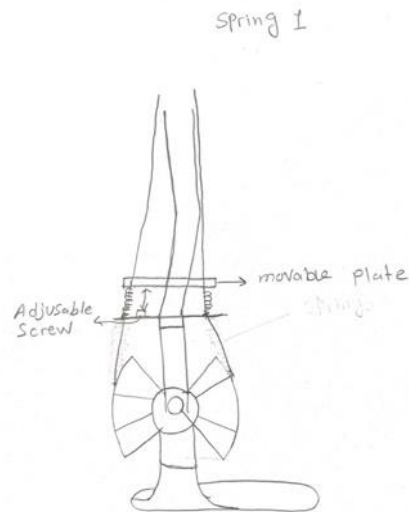


Figure 11: Designing of the exoskeleton using all the above designs

## 5 Design Selected

### 5.1 The rationale for Design Selection

The team was satisfied with this design as it met all the conditions of the engineering requirements as well as client specifications. Design 2 is the simplest design, so we chose it to be our datum. The selection was based on the outcome of Pugh matrix that indicated that 3 had the highest number of desirable characteristics such as simplicity and non-invasiveness.

### 5.2 Design Description

The team decided on using the above designs in order to come up with an exoskeleton that can be used individuals of any age group. This can be satisfied by the use of adjustable straps as well as the design being able to be elastic. The use of Decision matrix ensures that the design is functional and meet the requirement. The Decision matrix helped us to choose the best suitable design that will meet the requirement.

Table 4: Decision matrix

			Design		Design		Design	
<b>Criterion</b>		Wight	3		7		10	
Provide Torque		.429	90	38.61	70	30.03	83	35.607
Specify Material		.166	75	12.45	82	13.612	79	13.114
Spring Location		.132	80	10.56	90	11.88	85	11.22
Noninvasive		.151	90	13.59	85	12.835	80	12.08
Not complicated design		.122	70	8.54	80	9.76	85	10.37
<b>Totals</b>		1		83.75		78.117		82.391
<b>Relative Rank</b>				1		3		2

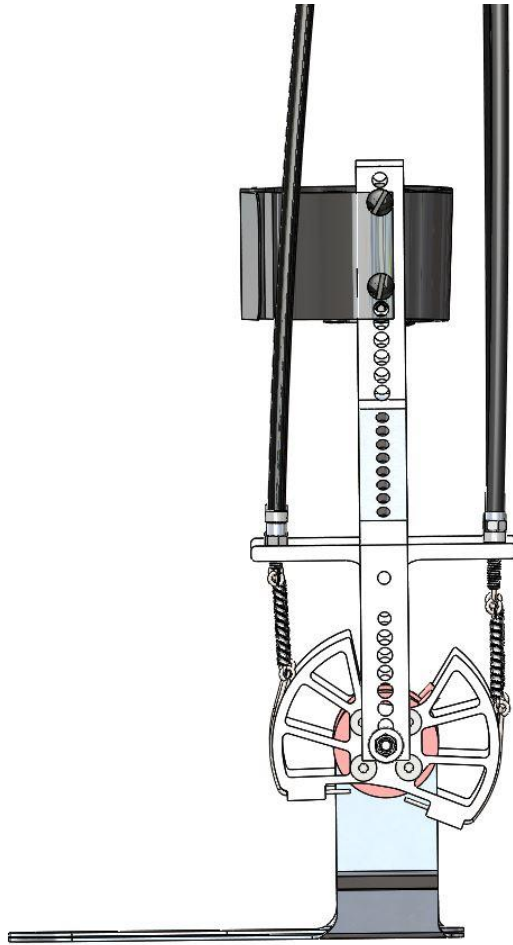


Figure 11: CAD image of the design

## 6.0 Costing and manufacture & prototyping

In this section the team will explain the process in order to build the design. First the team has done the drawing of the exoskeleton design in solid work, second the team will send the CAD package to the machine shop in order to know the cost and time it needs to build each part, expect three parts. The reason why the team does not know the machine shop name is because the team is waiting for the name of the machine shop from the Clint. The three parts which are the motor and the gear box will be order from the company called maximum motors and the back bag will be given from the Clint. Third the team will know the cost and will be filling the papers from NAU in order to pay the machine shop. Last is receiving the parts individually and attaching them together in the machine shop at NAU. The way in which the team will build the exoskeleton is by separating the work into two parts which are the two lower leg parts and the one back bag part. The two lower leg parts both has an individual plate on the bottom, which is connected to the torque sensor by a shaft and the shaft is connected to the pulley. They will be tied with four screws from each side. The pulley will be attached by two springs with a cable called a fishing cable. This is the two lower leg parts the second part of building process will be the one back bag part. This bag contains a gear box, motor and attached with the pulley from the lower leg parts. This is the way in order for the team to build the exoskeleton step by step process.

Table 5: BOM

Bill of Materials								
Team				Exhct-18F26				
Part #	Part Name	Qty	Description	Functions	Material	Dimensions	Cost	Link to Cost estimate
1	GP32C 123:1 (PN: 166945)	1	top performance per volume and weight unit		plastic	N/A	\$713.45	<a href="https://www.maxonmotor.com/maxon/view/product/311536">https://www.maxonmotor.com/maxon/view/product/311536</a>
2	PN: 438725 (ESCON 50/5)	1	highly efficient control of permanent magnet-activated brushed DC motors		plastic	N/A	\$157.15	<a href="https://www.maxonmotor.com/maxon/view/product/control/4-Q-Servokontroller/438725">https://www.maxonmotor.com/maxon/view/product/control/4-Q-Servokontroller/438725</a>
3	TRT-500	1	mm ESCON Module 50/8		plastic	1.63X1	\$221.15	<a href="https://www.transducertechniques.com/trt-torque-sensor.aspx">https://www.transducertechniques.com/trt-torque-sensor.aspx</a>
4	B0008MRCQ88	1	CLARKS Brake Cable Housing and Housing KICLARKS Brake Cable Housing and Housing Kit		Metal	5-mm x 30-m	\$33.99	<a href="https://www.amazon.com/gp/product/B0008MRCQ88/ref=oh_aui_search_detailpage?ie=UTF8&amp;qsc=1">https://www.amazon.com/gp/product/B0008MRCQ88/ref=oh_aui_search_detailpage?ie=UTF8&amp;qsc=1</a>
5	B0138E110G	1	zimo 50pcs Jagwire Bike 5mm Brake Cable Housing Ferrule End Caps		Metal	4.5 x 3.7 x 1.8 inches	\$6.99	<a href="https://www.amazon.com/gp/product/B0138E110G/ref=oh_aui_search_detailpage?ie=UTF8&amp;qsc=1">https://www.amazon.com/gp/product/B0138E110G/ref=oh_aui_search_detailpage?ie=UTF8&amp;qsc=1</a>
6	B077PXTM44	1	Dorisea Extreme Braid 100% Pe Grey Braided Fishing Line 109Yards-2187Yards 6-550Lb		Metal	100m/109Yards 400lb/1.4mm/16Strands	\$14.98	<a href="https://www.amazon.com/gp/product/B077PXTM44/ref=oh_aui_search_detailpage?ie=UTF8&amp;qsc=1">https://www.amazon.com/gp/product/B077PXTM44/ref=oh_aui_search_detailpage?ie=UTF8&amp;qsc=1</a>
7	N/A	N/A	Manufacturing parts (leg bar, pulley, etc)		aluminum	N/A	N/A	N/A
							1147.71	



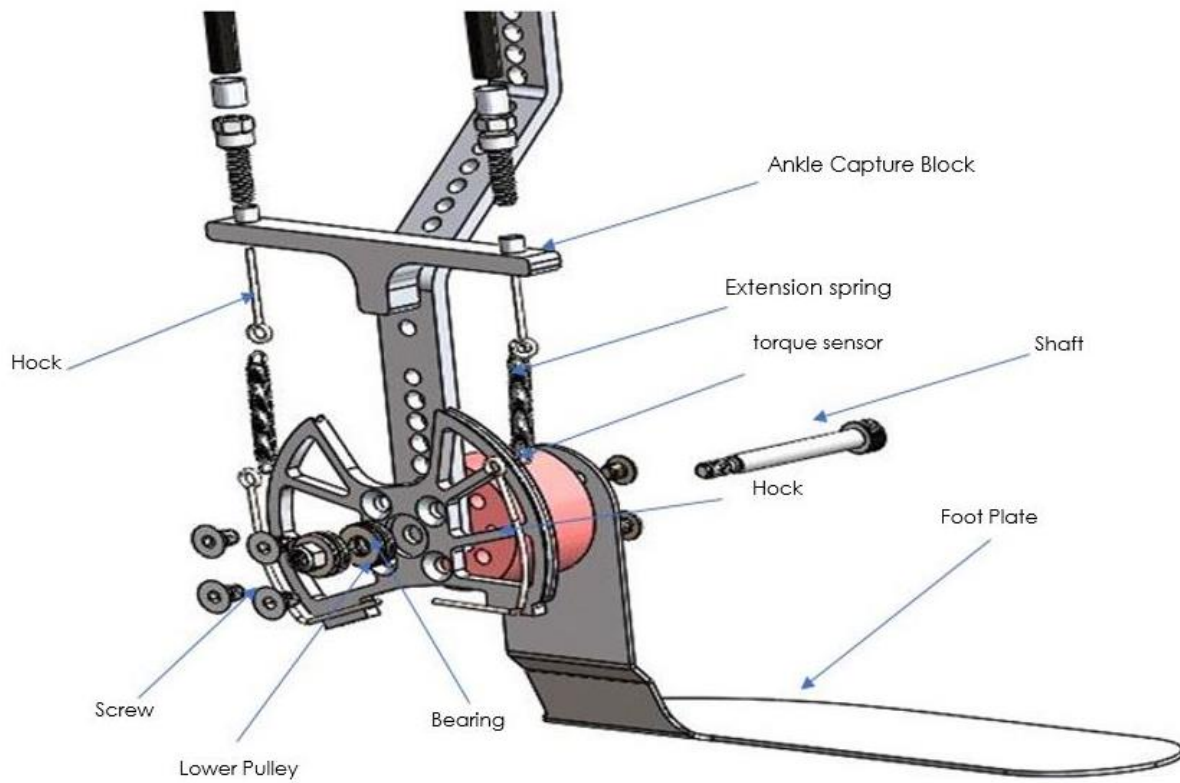


Figure 12: CAD Exploded View

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## 8 Appendix

### 8.1 Appendix A: Design Considered

#### i.Design #1: Spring connected to cables.

Here, the connection of the spring and the pulley in order to enable the user to walk with as little difficulty as possible. Furthermore, the springs will be connected to the pulley and will have a shock absorber and will have a rotational angle of 90 degrees. But this design was recently disapproved by our client because the springs are designed as a parallel elastic actuator. The advantages of this design will reduce the torque of the pulley. The disadvantage is that will do the opposite of what is required for us because they are in parallel.

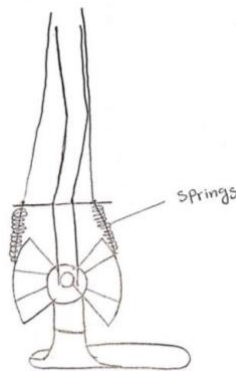


Figure 13: Spring connected to cables

#### ii.Design #2: spring connected to plated leg.

Here, the spring is connected to the exoskeleton's leg and is supported by another spring. Moreover, this spring will only help the patient to walk in a comfortable way. The disadvantage for this design it will not fit in the patient shoes.

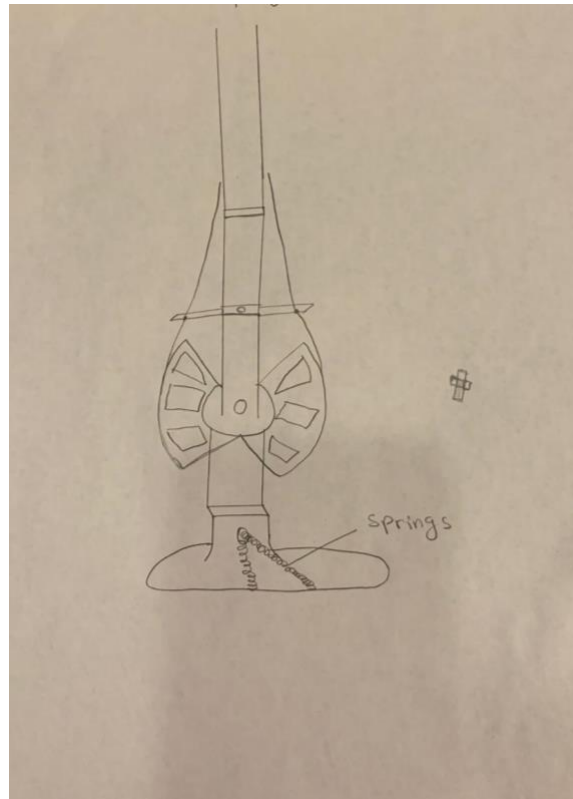


Figure 14: spring connected to plated leg

**iii.Design #4: pulley or hip joint design.**

This design is changed completely by moving the location of the pulley and adding an additional damping spring assembly this would actually work theoretically. The main issue was we had to change the exoskeleton model. Deservingness may not meet the engineering requirements. Finally, advantages for this is that it will handle more torque than required.

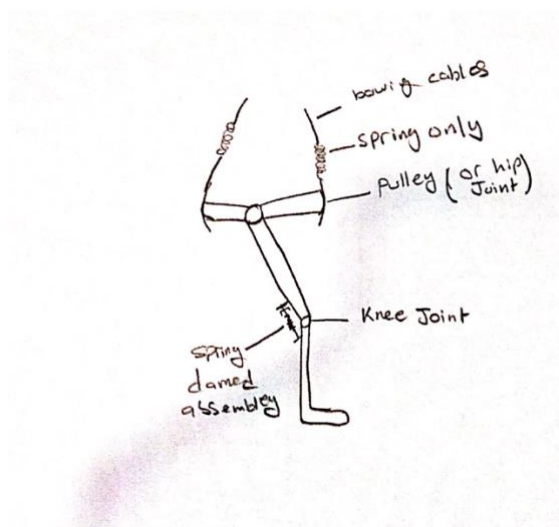


Figure 15:

**iv.Design #5: damping spring design**

This design was previously the same as the two springs connected to the cables but there would be a fixed plate up and have a moving plate connected to the pulley that would be moving vertically. Furthermore, having a spring damping connected between the fixed plate and the center of the pulley. The advantages of this design are that it has multiple cables that could make the walking of the patient more smoothly. The disadvantages are that we can only have at least two springs.

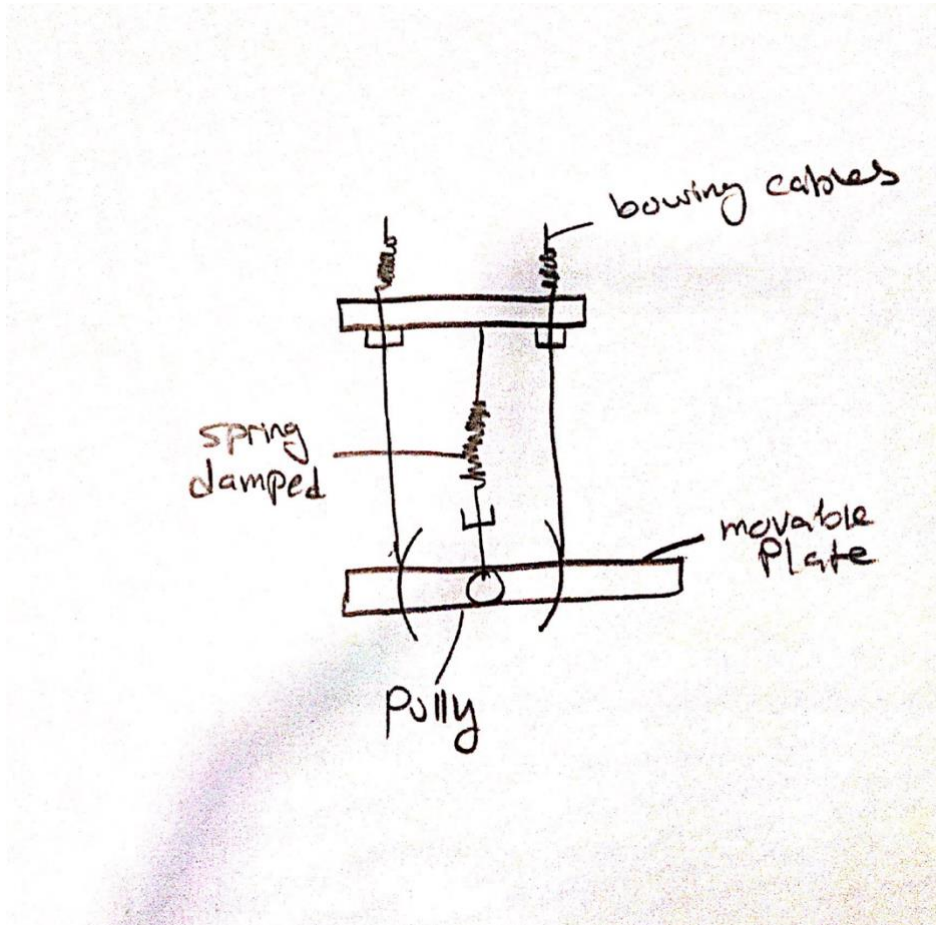


Figure 16: damping spring design

**v.Design #6: buckling cables**

For this design, we have created this design, so it could absorb the force that comes out of the surface pushed on (Newton first law). It will absorb it by the two fixed springs, and by the damping spring. The Advantages of this design as previously stated that it has the damping spring that will improve the walk of the patient. The disadvantage for this that it may have a parallel elastic actuator which will work opposite that what we are aiming for.

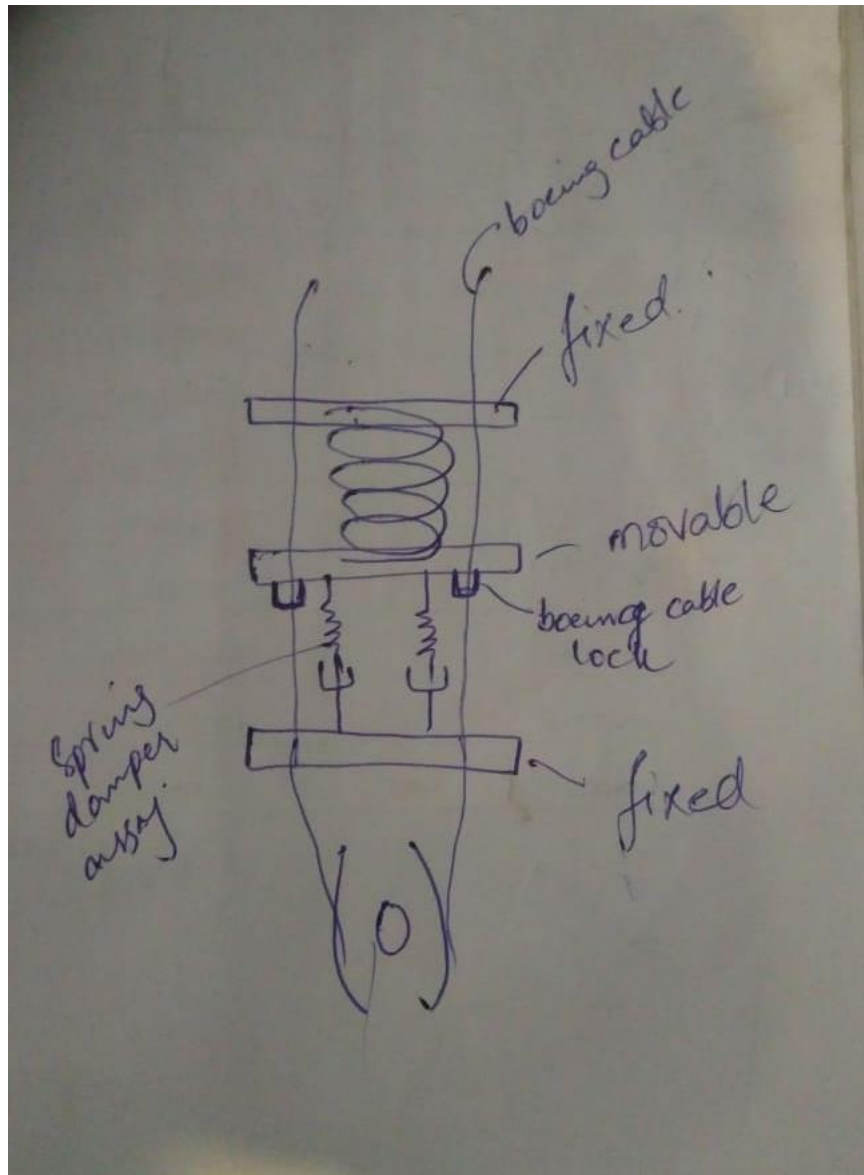


Figure 17: buckling cables

**vi.Design #8: Design with straps.**

This design had a more complicated way of understanding and implementing and did not match the engineering requirements. Furthermore, the tray that will have a vertical motion only and have a fix horizontal plate finally have an adjustable screw. The advantages for this that it will have adjustable screws that will make the springs move more freely rather than stick to one place. Disadvantages, it might contact the leg.

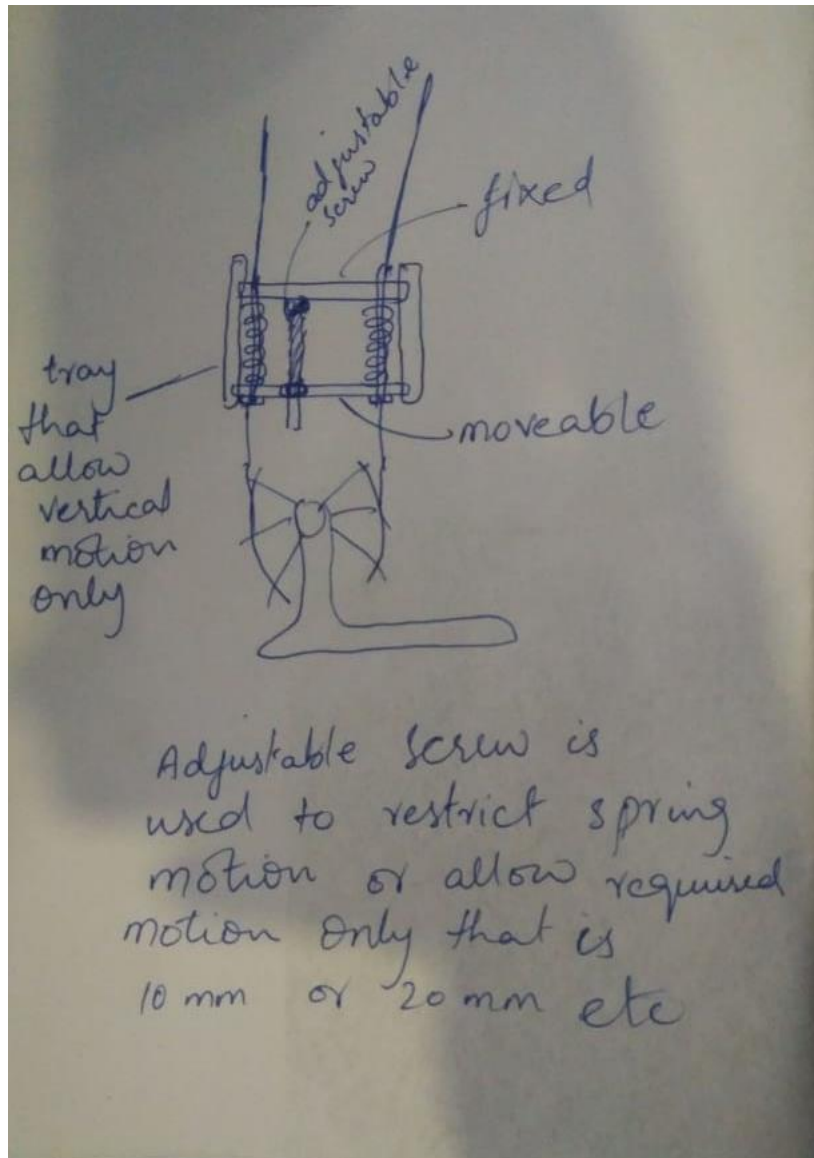


Figure 18: Design with straps

### vii.Design #9: Fabric

For this design, we thought about putting the spring above the cable screw, and that will only reduce the motor torque, not the pulley torque.

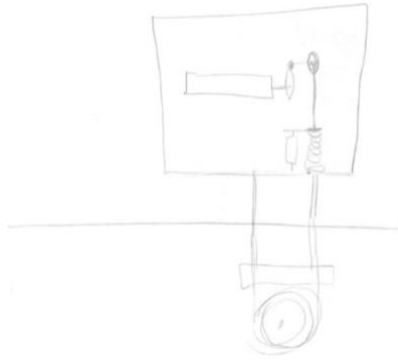


Figure 19: Fabric

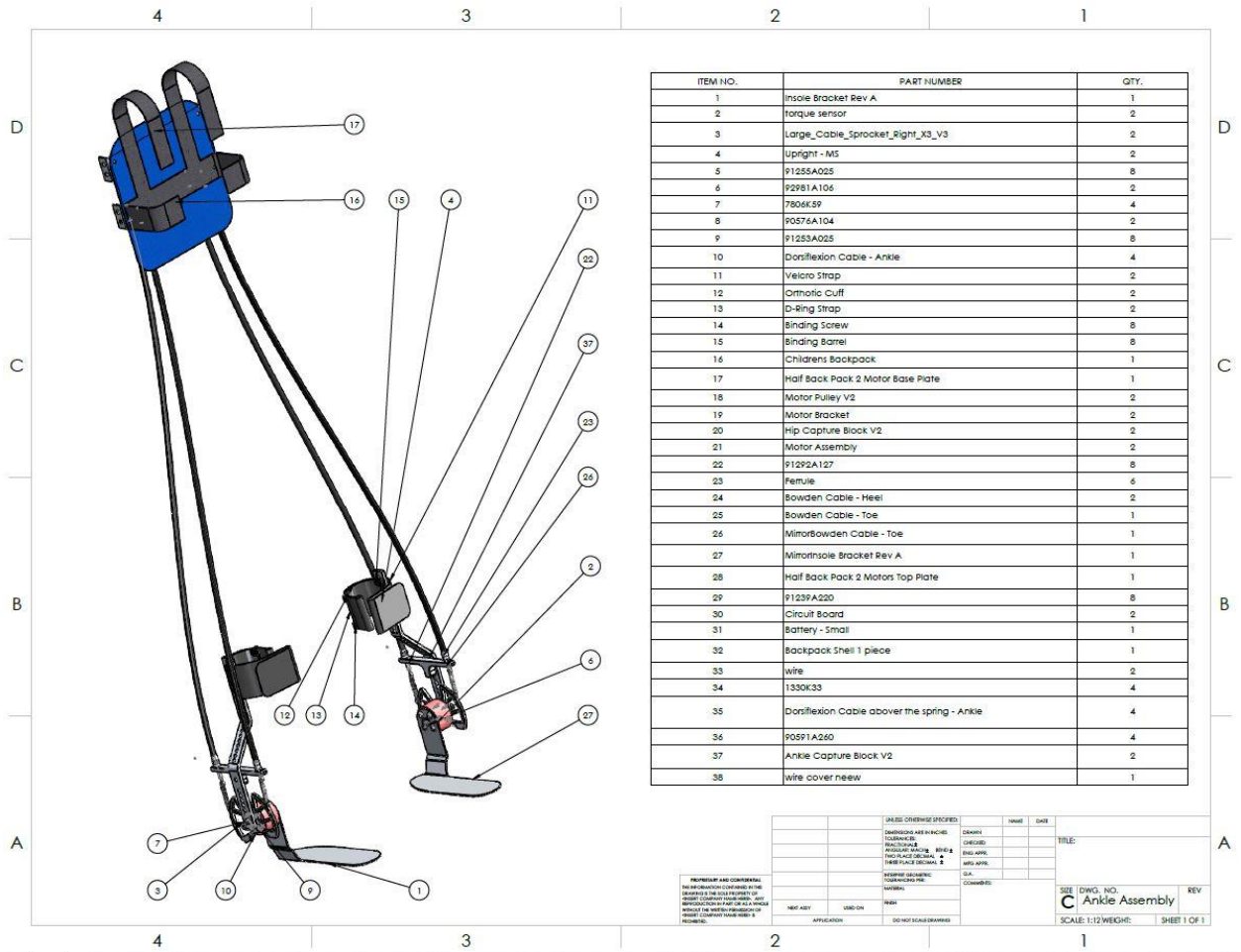


Figure 20: CAD Drawing Sheet



## 8.2 Appendix B:

Table 5: Pugh Chart

Concept										
Criteria	Design 1	Design 2	Design 3	Design 4	Design 5	Design 6	Design 7	Design 8	Design 9	Design 10
Measure torque	S	D	+	-	S	S	+	+	S	+
Lightweight	-	D	S	S	+	-	S	-	S	-
Clinical gait	-	D	+	+	S	S	+	S	+	+
Noninvasive	S	D	+	S	-	+	+	+	+	+
Simple	S	D	+	S	+	S	-	S	-	-
$\Sigma +$	0	D	4	1	2	1	3	2	2	3
$\Sigma -$	2	D	0	1	1	1	1	1	1	2
$\Sigma S$	3	D	1	3	2	3	1	2	2	0