Lerner Exoskeleton Actuators

preliminary Report

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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 more clinical gate and improve the walk 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 project would have been successfully completed.

1.2 Project Description

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

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 for 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 the 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 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 enables 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 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 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 heavy weight 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 if requirements and afterwards 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

Customer Needs	Description
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 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 is more detailed according to engineering perspective.

Table 2: Engineering requirements

Engineering requirements	Description
Measure torque	0-7 Nm out of the motor 0-21 Nm out of the 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	0-100%complicated design

2.3 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 box of 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.

$$\text{Technical importance Aboslute or Raw score} = \frac{\sum \text{importance}}{\sum \text{Engineering Requirement of each column}} \quad (1)$$

$$\text{Relative Technical Importance} = \frac{\text{Absolute}}{\sum \text{Absolute Raw Score}} \quad (2)$$

Table 3: QFD

Customer Requirements \ Engineering Requirements	Importance	Provide Torque	Specify Material	Perfect location for spring	Must not contact with ankle	Not complicated design
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
Technical Importance: Raw Score		88	34	27	31	25
Technical Importance: Relative Weight		**42.9%**	**16.6%**	**13.2%**	**15.1%**	**12.2%**
Techanical Target Value		7	-	-	-	-
Units		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 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 begun 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 are 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, in the internet and from scientific journals, and after coming up with an analysis the team learnt 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.

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 effective 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 functioning of the body. It produces the energy by use of 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^{o}.

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 operation 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 on 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.

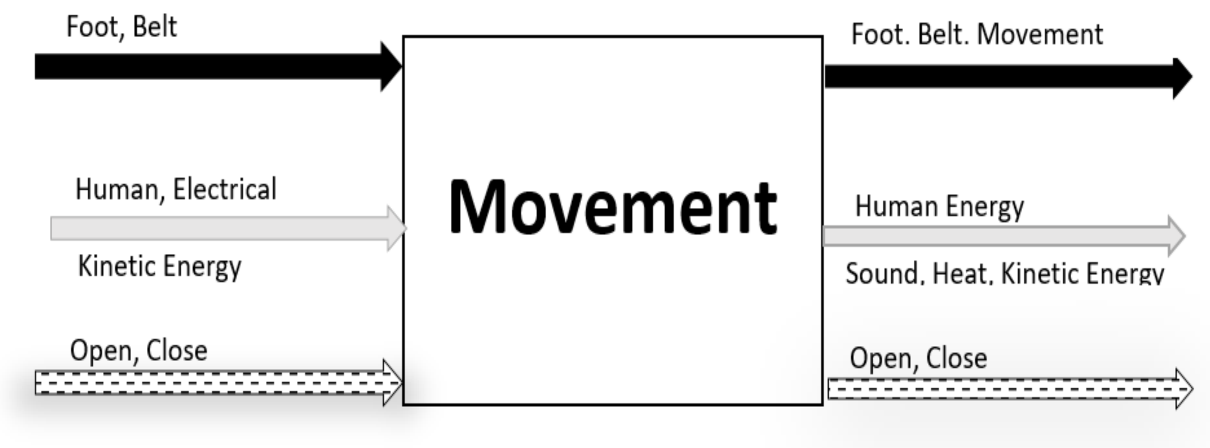

Figure4: Black Box

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.

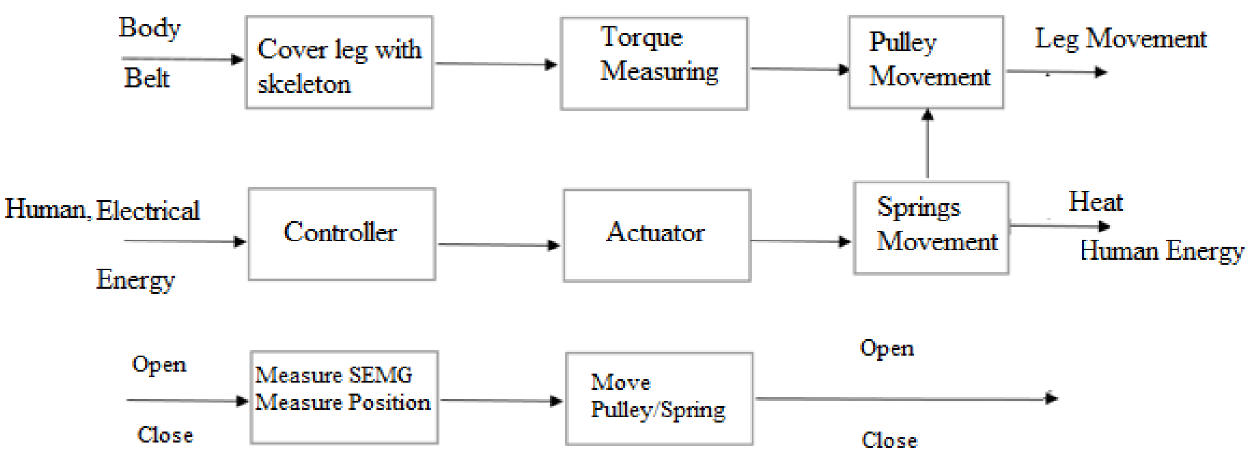

Figure5: Functional Model

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.

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.

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

3.4.2 Subsystem #2: controls

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.

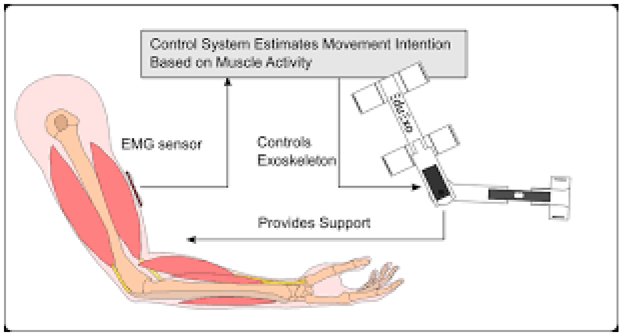

Figure 2: exoskeleton control

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

This model is designed such that the lower part of the body is controlled by use of motors that actuate the knee, hip and ankle joints. This project looks to assimilate the same control system whereby the exoskeleton can provide enough energy to maintain the user's movements.

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.

3.4.3 Subsystem #3: structure

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

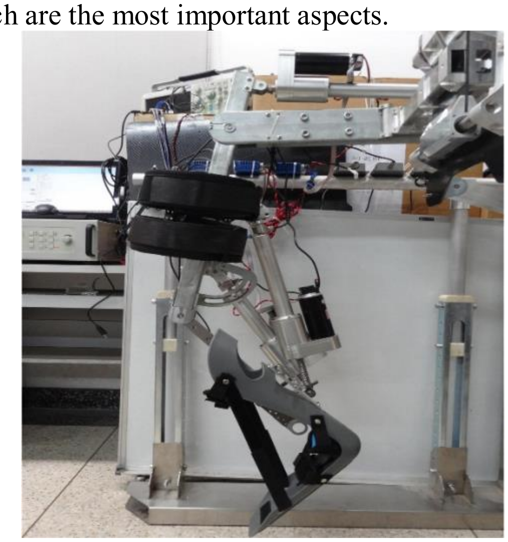

Figure 3: exoskeleton structure

3.4.3.1 Existing Design #1: Sarcos exoskeleton

The structure of the sarcos exoskeleton is made in a way that the user's limb is interfaced with the exoskeleton containing 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 been 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 heal to move with normal human walk. Furthermore, the torsion spring have 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

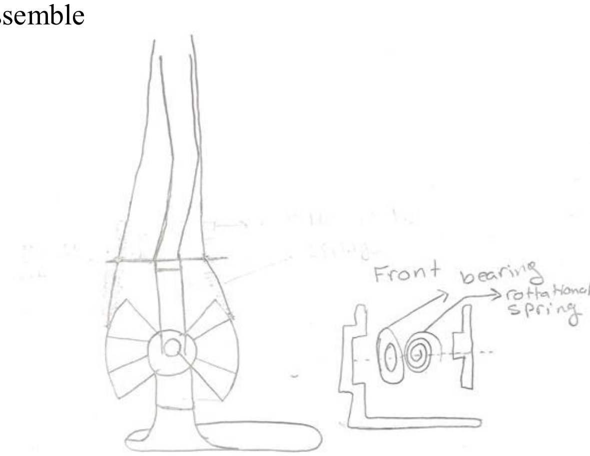

Figure 9: rotational spring

4.2 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

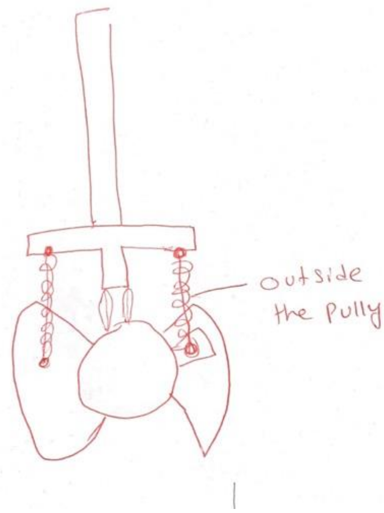

Figure 10: springs connected to the pulley

4.3 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

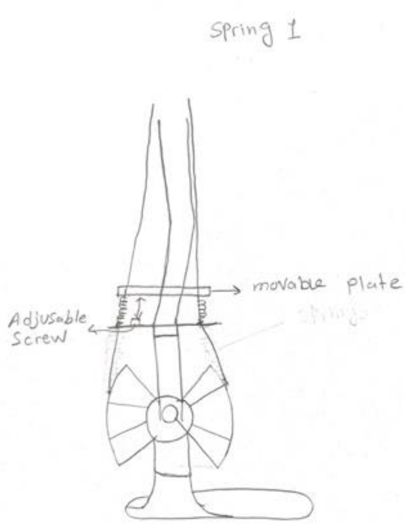

Figure 11: Designing of the exoskeleton using all the above designs

5 Design Selected

5.1 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.

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 motors and the black box ensures that the design is flexible and comfortable. Other than that, the use of soft materials to design it ensures that the device cannot harm the user at all.

Table 4: Decision matrix

Weight			Design			Design			Design		
Criterion			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
Totals		1			83.75			78.117			82.391
Relative Rank					1			3			2

6 References

[1]S. Hasegawa, M. Konyo, K. Kyung, T. Nojima and H. Kajimoto, *Haptic Interaction: Perception, devices and applications*. 2015.

[2]C. Walsh, *Biomimetic design for an under-actuated leg exoskeleton for load-carrying augmentation*. 2006.

[3]M. Ceccarelli and V. Glazunov, *Advances on Theory and Practice of Robots and Manipulators*. Cham: Springer International Publishing, 2014

[4]A. Azad, *Adaptive Mobile Robotics: Proceedings of the 15th International Conference on Climbing and Walking Robots and the Support Technologies for Mobile Machines, Baltimore, USA, 23-26 July, 2012*. World Scientific, 2012.

[5]H. Kawasak, S. Ueki, S. Ito and T. Mouri, "Design and Control of a Hand-Assist Robot with Multiple Degrees of Freedom for Rehabilitation Therapy", *Gifu-u.ac.jp*, 2016. [Online]. Available: https://www.gifu-u.ac.jp/news/news/upload/20140303_IEEEASMEPaper2012.pdf. [Accessed: 14- Oct-2018].

[6]H. Bleuler, M. Bouri, F. Mondada, D. Pisla, A. Rodic and P. Helmer, *New Trends in Medical and Service Robots*. Cham: Springer International Publishing, 2016.

[7]K. Mankala, S. Banala and S. Agrawal, "Novel swing-assist un-motorized exoskeletons for gait training", *Journal of NeuroEngineering and Rehabilitation*, vol. 6, no. 1, p. 24, 2009.

7 Appendix

7.1 Appendix A: Design Considered

7.1.1 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.

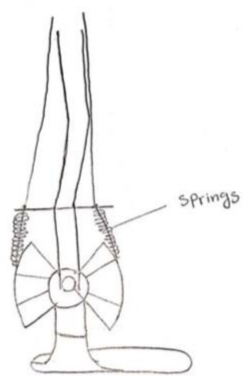

Figure 12: Spring connected to cables

7.1.2 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.

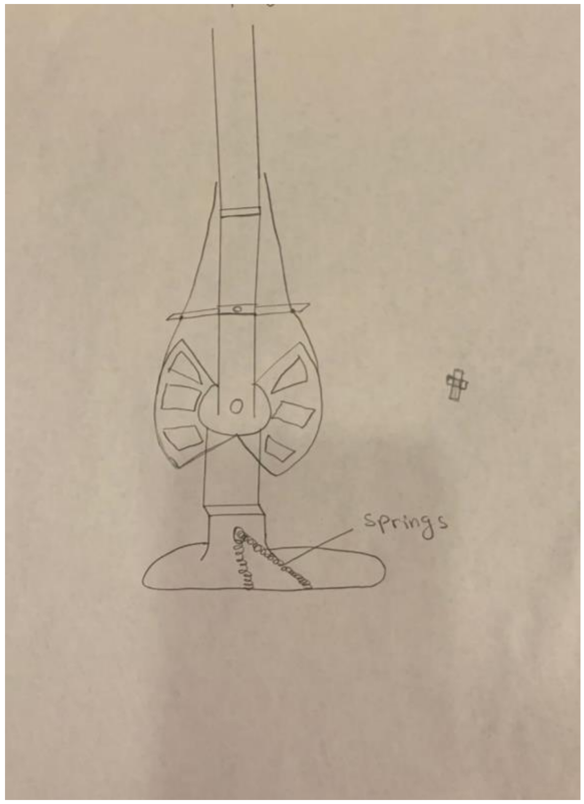

Figure 13: spring connected to plated leg

7.1.3 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.

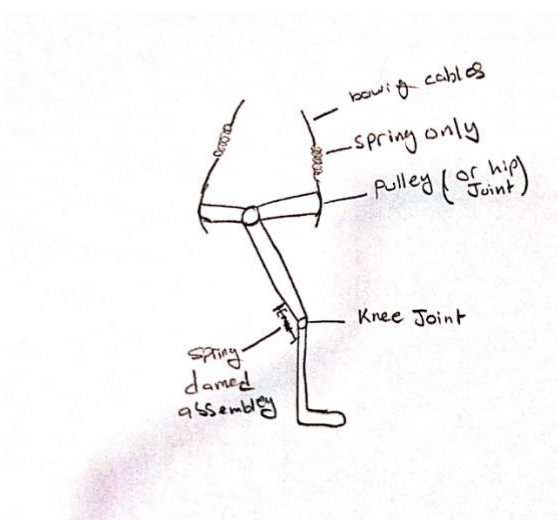

Figure 13:

7.1.4 Design #5: damping spring design

This design was previously the same as the two springs connected to the cables but there would be a fix 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.

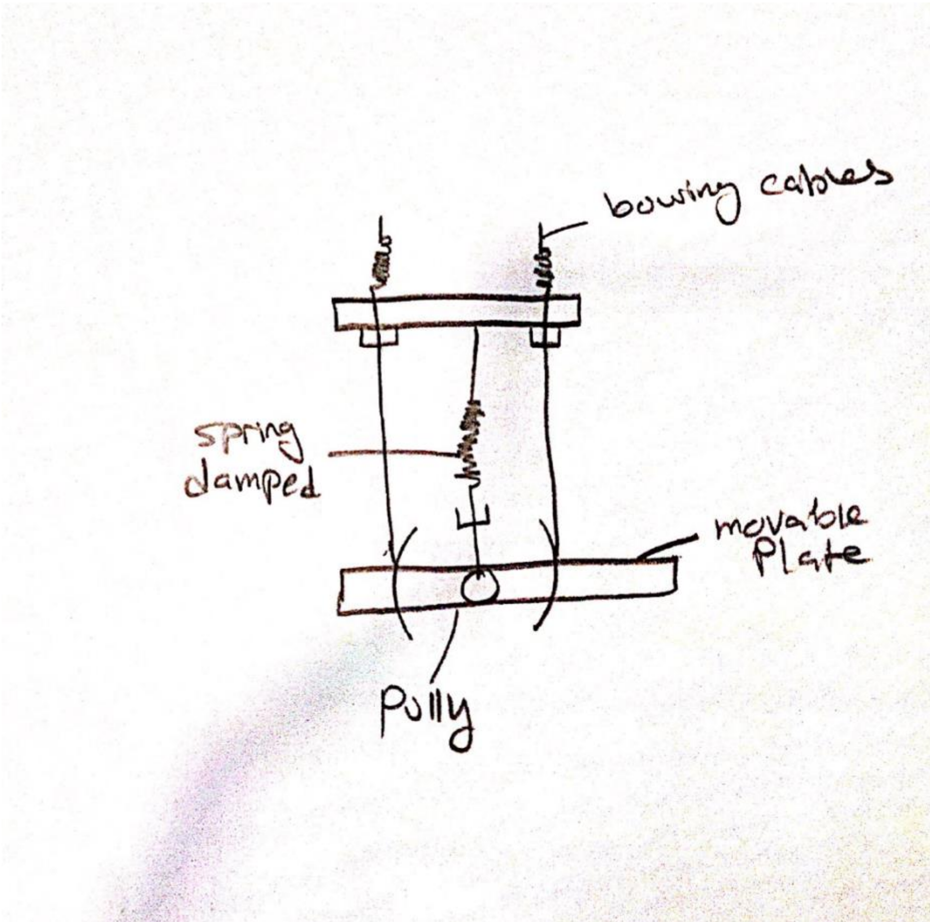

Figure 14: damping spring design

7.1.5 Design #6: buckling cables

For this design, we have created this design, so it could absorb the force that coming 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 for 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.

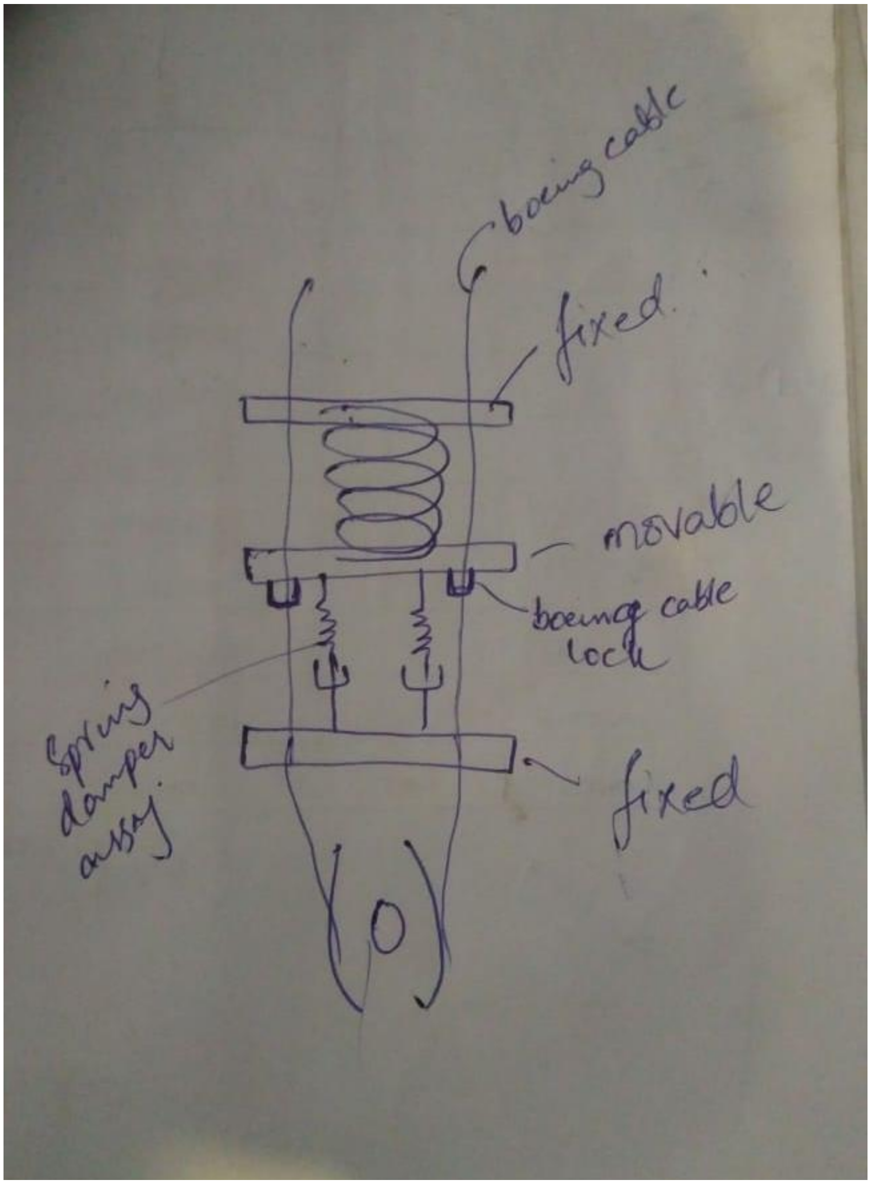

Figure 15: buckling cables

7.1.6 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.

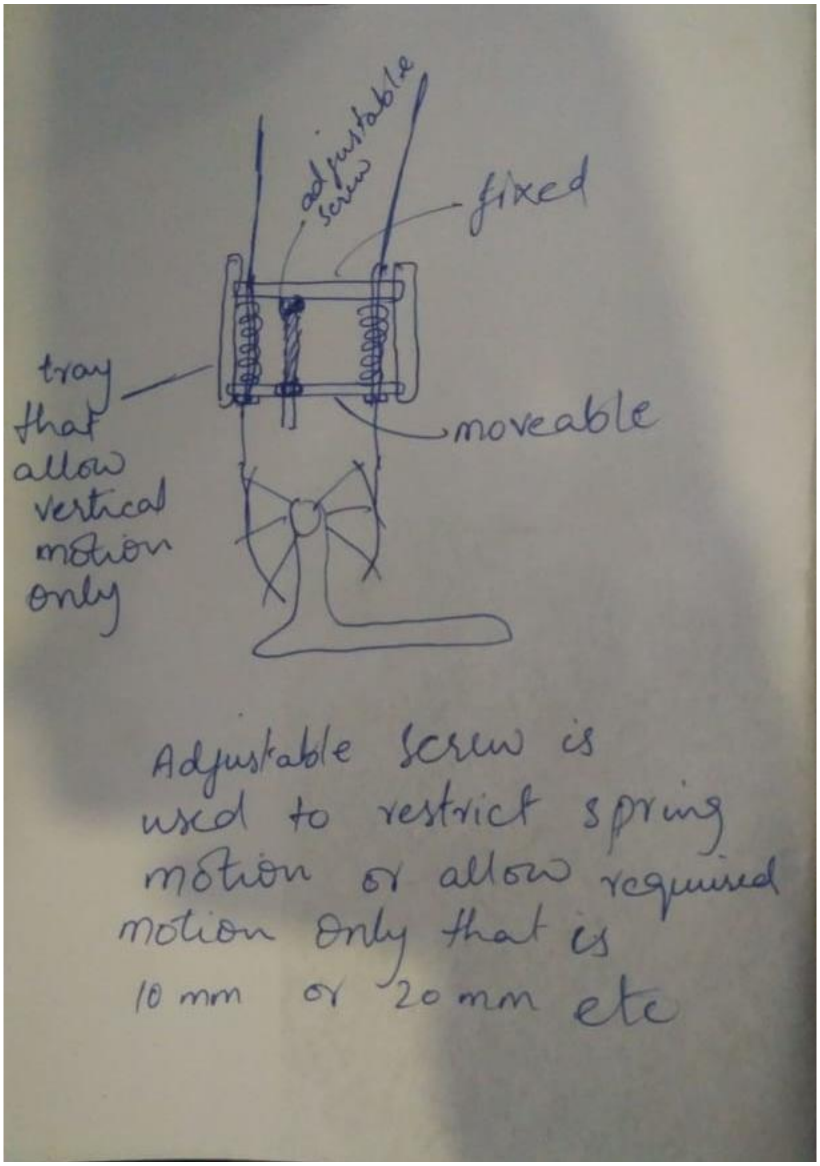

Figure 15: Design with straps

7.1.7 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.

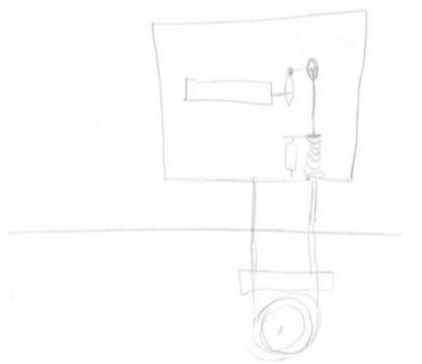

Figure 15: Fabric

7.2 *Appendix B: Pugh Chart*

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	-	-
∑ +	0	D	4	1	2	1	3	2	2	3
∑ -	2	D	0	1	1	1	1	1	1	2
∑ S	3	D	1	3	2	3	1	2	2	0