Exoskeleton Mount

Midpoint Report

Team J – Lerner Exoskeleton II

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EXECUTIVE SUMMARY

The purpose of this project is to develop a prototype for the Lower rib exoskeleton. There are some models that are currently in use but we seek to make a better model. This project has been undertaken as a team work. The end result of this report is a presentation of the best of the models that the team was able to put together. There are several processes that are undertaken to get the final model. We began by carrying out a research on the benchmark designs that currently exists. We then went ahead and developed prototypes for the models that we thought would be good for the team to process. We then embarked on the process of choosing the best of the model prototypes that we had developed. Finally, we were able to come up with the best for the prototype that we had designed. This prototype was simulated and tested and finally, we approved it as the best model to be developed.

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1.0 BACKGROUND

1.1 Introduction

The human exoskeleton has been used for different purposes, including upper body and lower body assistive activities. This project is aimed at improving currently existing exoskeleton designs to come up with a better human-exoskeleton mounting interface for lower limb rehabilitation. The new design will help in improving the general functionality of the health care industry, especially the sector dealing with neuromuscular disorders. The existing design uses a robotic system that includes motors. They work well in providing the required assistance to individuals with neuromuscular disorder. This project seeks to come up with a new exoskeleton design that can perform better compared to the existing designs.

The team seeks to apply different skills and information in developing the new system. There are various requirements and targets the team seeks to attain, including a better functioning model, providing a design that mounts it in an effective manner to the users' foot, thighs and the shank (the part from the knee to the ankle). The team will also make the design adjustable and ease to don off and on. The design will be low profile, insert into normal shoes, have reduced irritations, and be strong while at the same time lightweight. In addition, the team will include electrical engineering work in order to make the design function better. Through attaining these targets, the team will have met all the needs that the client had indicated.

1.2 Project Description

In order for the project to be viable and be effective in its intended purpose, the selected design must meet a variety of the clients' standards. For instance, the client requires that the team comes up with a design that meets particular requirements such as a design that is light in weight, adjustable, has minimal irritation to skin, good grip, and easy to use. Based on these requirements, the team came up with the engineering requirements for purpose of providing design and development details. A variety of ideas were considered through consultations with team members so that the final design will be of great benefit to the client. A variety of aspects of the design will be considered by considering the customer needs and the engineering requirements.

Patients who are unable to use their lower and upper limb muscles usually require assistive devices so as to enable them to carry out tasks that require the use of these muscles. The human exoskeletons were designed for purposes of providing assistance during these activities. The exoskeletons are also very useful since they provide functions that the weak muscles are unable to perform. Also, the exoskeletons are very crucial since they assist in exercising these muscles and in that manner help them to recover over a certain period of time and hence help them to regain their strength. Figure 1 represents an image of human exoskeleton and how it is mounted to users.

Figure 1. Exoskeleton mounted to custom-molded orthotic [1]

1.3 Original System

Engineers have always been interested in coming up with various designs that are able to provide assistive services to individuals having neuromuscular disorders. As a result of such interest, engineers ventured into the medical fields, among other fields, to come up with machines that are able to assist the medical practitioners in performing their tasks in an effective way [1]. Due to such interests, engineers have developed different kinds of exoskeletons for lower limb, upper limb, or full body assistance. These designs have existed for quite a long time but are consistently changing over time due to significant changes in the worldly activities, including changes in technological knowhow.

1.3.1. Original System Structure

Exoskeletons have existed for several years now and have been used for providing assistance to individuals who have issues with their muscles. They help in supporting people with neuromuscular disorders and assisting them in exercising their muscles. The original designs were built in different sizes, which help in fitting individuals that range in age difference [2]. The systems use materials that are readily available, including strong metals to provide enough support to the users. In addition, there are soft materials used that help in improving the comfort of the system, which allows for effective use. Despite the designs' performance, they still need improvements to make them better.

1.3.2. Original System Operations

The exoskeletons have been operating in different ways, which have been changing over the years with development in technology. The earlier systems were manually used, where the users had to be supported and manually moved for purposes of providing motion. This did not work well, which led to the introduction of control by a third party, where an individual had to help the users to operate the skeleton [4]. To further advance the designs, the systems now include operations that allow the users to control the skeletons by themselves, which has proven to be more effective and user friendly.

1.3.3. Original System Performance

The system designs have been performing their expected tasks as they were meant to. They did this with minimal challenges. The designs were created for purposes of providing assistance in movements for persons with limited muscle strength. However, the systems need constant improvements for purposes of increasing user satisfaction as well as meeting the increasing needs of patients [1].

1.3.4. Original System Deficiencies

Despite the original systems service the purposes that they were built for, these systems have various deficiencies that require being looked into. For example, the materials that were used in constructing the exoskeletons were quite heavy. These materials made it a challenge for the users to comfortably operate the skeletons for long hours. In addition, these systems are not comfortable to put on as they do not have sufficient protectors to the users [5]. The systems are also limited to specific users since they are not adjustable, which is a major reason why many individuals have to look for designs that are custom made to fit their sizes. In addition, the systems are outdated in technology since technology has significantly developed without seeing a change in the systems.

2. REQUIREMENTS

By the end of the project the team seeks to meet both the customer and the engineering requirements. These requirements will be included in the final design system to enable for effectiveness in functioning in addition to meeting the customer requirements.

2.1. Customer Requirements (CRs)

These entails the various forms of requests in which the clients and the users have on how to improve a design. They are the first stakeholders since they are the ones who normally use the device and have an experience on how the device operates. They are the best suited in giving the requirements since they already know the ups and downs of the device. Since they have an experience, the end users may have views on how the device may be improved, which are translated into customer requirements. There requirements are as shown in the table 1 below.

Table 1: Customer requirements

Customer Requirements	Description of customer requirement
Improve the original system	To improve the original system to have mounting points that is rigid, both to the thigh and to the shank
Flexible design	Create a design that is adjustable to fit people of various sizes from five to seventy-five years of age.
Ease of donning on and off	Making a design that has ease of putting on and removing
Comfortable design	Areas which can cause irritation should be minimized.
Weight of the device	The design should be light in weigh for effective use.
Be powered by an electrical battery	Preferable Lithium cells storage units
Long lasting electrical battery	Be usable for up to seven hours

Discussion

The table above shows the customer requirements as indicated by the client. These requirements are very crucial in the design process since they provide guidelines in which the team follows when designing the device. The first thing that the customer wants is an improvement of the original model that currently exists. We will have to remove the rigidity that is on the thigh area and shank area. This can only be done by making these parts to be flexible to allow for bending. We also need to make a design that is not rigid in size. This means that if the customer has a small leg, they can be able to adjust the design to fit to their legs. The same case applies to when the customer has a large leg. It should be possible to adjust the design to fit the larger leg. The customer also wants a design that they can e able to remove and put on easily. The customer must also be comfortable when they are wearing the design. There should not be any discomfort to the client when they are wearing this design. The best cells in the market that currently exists are Lithium cells. We seek to have the customer use the Lithium cells to power the design. The batteries named above should also be able to last for at least 7 hours.

2.2. Engineering Requirements (ERs)

When customers come up with various requirements so as to improve original designs, they must be translated into a manner that they can be specific and also detail the changes which are to be made. These details are defined in aspects which are specific and measurable, which can later be interpreted using the engineering requirements. The engineering requirements are as shown in Table 2 below.

Table 2: Engineering requirements

Engineering requirements	**Targets**
Strength of the device	Yield strength of at least 6Mpa
Adjustability	Adjustable to a length ranging 6cm to 20cm
Soft material	Low pulling force of below 5 Pascal
Weight limit	Limited weight of 0.75kg/limb
Distance above knee	No dimensions beyond the knee of 5cm
Rechargeable electrical batteries	Should last for seven hours before a recharge
Light electrical battery	Less than 2 pounds of weight of the battery

Discussion

The design that are making needs to produce some minimum power so as to be able to move the leg. In our case, the power to lift the mass of the design is at 6 Mpa. The range that the human leg can vary in width is from 6cm to 20cm. We therefore need to be able to adjust this design so that it can be able to serve this range. The design that we make should also be soft. The measure for the softness of a material is the amount of the pulling force that is needed for one to break the material. A material will only be regarded as soft if its pulling force is less than 5 Pascal. It is also required that the device be powered by a rechargeable battery. The battery that should be used to power the design should be durable in the day lifespan. A minimum of seven hours is the least amount of time that the battery should last in one session. The other characteristic of this battery is that it should also be light. There ideal weight that a battery should have is that it should have less than 2 pounds in weight.

2.3. Testing Procedure

1. Yield strength of at least 50 Mpa:

To test the yield strength of a material, we need to subject it to a force and see if it yields to force exerted on it. We needed a clamp and several weights of about 50Mpa. The material was first clammed with the clamp in a vertical manner. The weight was then placed over the material and the material was observed if it gave in to the weight that is placed on it. The next step was to clamp the material in a horizontal manner. The weight was then placed on it and it is observed if the material gives in to the pressure. In both instances, it was observed that the material did not give in to the weight.

2. Adjustable to a length ranging 6’ to 20’:

The adjustment that needs to be done is in the leg width. We used a wrap cuff leather strap to make the design. To see if the cuff could be adjustable, we cuffed the chord on the least cuff width. We then measured the width with a tape measure. It had a width of 4cm on the least cuff. We then cuffed it on the largest cuff and measured it with a tape measure. It had a width of 21 inches. The cuffs in between them were evenly space and we were therefore able to obtain the range that was required.

3. Use soft fabric
The measure for the softness of a fabric is the force that is needed to break a fiber. To measure the breaking force of the fiber, we tied it on one end to a firm position. On the other end, we tied the fiber to a spring balance. We pulled the end of the spring balance as the fiber got more and more tight. We observed the readings on the balance as the pulled the balance. Before the spring balance could read 5 Newton, the fiber snapped. A soft fabric should not exceed 5 Newtown in toughness.

4. Limited weight of 0.75 kg/limb:
Design weight is inclusive of all the parts of the design. The weight of the design was tested when the design was fully assembled and every bit of it had been put together. The total weight needed to be less than 0.75 kg/limb, which is as per the requirements. We used a spring balance to hang the complete design. The strength of the spring was below 0.75kg/limb.
5. No dimensions beyond the knee of 5cm:
To ensure that this design did fit the card that was given; we had to ensure that it did not go 5cm beyond the knee mark. When the design was complete, we took a tape measure and measured the length from the knee upwards. We established that the design was less than 5 cm in length which was the required length.

2.4. Design Links (DLs)

1. Yield strength of at least 40kgs:
The human exoskeleton seeks to ensure that strong enough to support its users. The materials used will be allowed for supporting users of not more than 40kgs. This is because the size and the weight of the materials used, based on the weight that the team wanted the structure to be, can only support a maximum of 40kgs.

2. Adjustable length ranging from 6 cm to 20 cm
One of the customer requirements was that the design should be adjustable. For the design, we decided that the system should be able to be adjusted in its length, where it should be adjusted within distances of 6 cm to 20 cm. this design based on the adjustability will allow for effective adjustments in the system.

3. Low pulling force of below 5 Pascal
The softness of a material is defined by the pulling force of the material. The softest materials are the ones that have the lowest pulling force. Some of the materials that are known to have a low pulling force are wool and polyester. The fabric will be used only in areas where the system comes in contact with the users.

4. Limited weight of 0.75kg/limb:
The customer requirement was that the design is supposed to be light in weight. From selecting the materials used, we calculated the combined weight of the system will be between 0.5 to 0.75 kg/limb. Based on this, we settled on the weight of the system be limited to 0.75 kg/limb.

5. No dimensions beyond the knee of 5cm:
For the system to be comfortable when putting is on, we agreed that it should not go too high above the knee. The maximum height above the knee should not go beyond 5cm in length, which is a size that is comfortable to provide the required grip on the user.

6. Use advanced technology, the electric system:
The electric system will include the use of electrical components, such as the record box and the motors, to make the design work in a better way. The electric system will allow for transfer of information throughout the system as well as enable coordination of the system as a whole.

2.5. House of Quality (HoQ)

House of Quality will also be applied since it will help in analyzing gadgets given various parameters. Its purpose is to investigate the plan that will be selected by the team to assist in settling on the plan to use. Remembering every one of the prerequisites, which we have investigated above, does this [3]. The requirements include a device that is moveable, light in weight, adaptable, simple to deal with, minimal effort, less settling time and the simplicity of use. This procedure assisted the team in making functional enhancements.

The house of quality enabled the team to adjust the exoskeleton design to meet the engineering requirements. Through understanding the weight that each of the requirements hold to the outcome of the design, the team took time to ensure that all the measurement are as expected for purposes of getting the best outcome out of the design process.

Table 3: House of quality

Customer Requirement	**Weight**	**Engineering Requirement**	Yield strength of at least 6Mpa	Adjustable to a length ranging 6cm to 20cm	Use soft fabric (Wool fabric)	Limited weight of 0.75kg/limb	No dimensions beyond the knee of 5cm
Should be adjustable	4			5	4		4
Have good mounting grip	5		4				
Easy to wear and remove	4				5	3	4
Reduce the irritation caused by the fabric	4					3	
Compatibility with shoes and clothing	3			3			
Strong and lightweight	5		5			5	5
Absolute Technical Importance (ATI)			10	10	8	9	7
The Relative Technical Importance (RTI)			9	9	7	9	7
Target(s), with Tolerance(s)			6Mpa ± 1 Mpa	6cm ± 2cm	30 pas ± 5 pas	0.75kg/limb ±0.05kg/limb	5cm ± 0.5cm
The Testing Procedure (TP#)			1	2	3	4	5

3.0. EXISTING DESIGNS

There are various forms of technologies that have been created for purposes of assisting individuals with different forms of health related issues, including muscular disorders. We have inquired about various gadgets that serve the purpose of assisting individuals with neuromuscular disorders. The team focused on systems that can help the users to be assisted with minimal effort and increased success rate. The team looked into various existing designs in order to understand on the various aspects that it may look into for purpose of improving their performance.

3.1. Design Research

Different designs have been created ever since the first exoskeleton was invented. These designs have been improved over the years, which make them function in a better manner compared to the previous designs. In order to ensure that the team comes up with the best design, one that is better compared to the rest within the markets, the team took time to analyze the downsides of the existing designs [7].

From getting to know the different challenges and downsides facing these designs, the team formulated a formula to design a system that solves all these problems, which is the design that the team is working on.

3.2. System Level

The exoskeleton systems have undergone different forms of changes over the last couple of years. Existing exoskeleton restoration robots have for the most part centered on the position and drive control, and they encounter three phases of advancement in previous decades. The first stage is to play out the robot control by giving position order from the administrator, for instance, the control of Hardyman exoskeleton [7]. This project proposed a mixture and various leveled dynamic, responsive control design for the created exoskeleton restoration robot framework. The existing designs have pros and cons, which the team will learn from in order to make the design better.

3.2.1. Existing Design #1: The ReWalk exoskeleton

This exoskeleton, as shown in figure 2, provides powered knee and hip motion in order to enable people with SCI to be able to stand in an upright position as well as allow them to walk. This is among the few exoskeleton suits that have been cleared by the United States. The system is controlled using an on board computer that includes motion sensors that help in restoring self-initiated walking through sensing of the forward tilt of user's upper body [8]. It then mimics the gait pattern of able-bodied individuals.

Figure 2: The ReWalk exoskeleton, adapted from Weiss, (2016)

3.2.2. Existing Design #2: The Vanderbilt Exoskeleton

The Vanderbilt exoskeleton, as shown in figure 3, is a design that was made by Goldfarb. This exoskeleton is advanced in nature as it assist users in performing the basic motions, including walking, standing, sitting, as well as walking up and down stair cases [9]. The design provides a modular-based design in which users can assemble and then wear it and also disable after use. Each of the thigh segments has been designed to include two different brushless direct current motors used in actuating the knee and hip joints.

Figure 3: The Vanderbilt Exoskeleton, adapted from Weiss, (2016)

3.2.3. Existing Design #3: Sarcos Exoskeleton

Figure 4 shows a design that is used for full body assistance. The design is wearable and an energetically autonomous robot. The energetically autonomous aspect of the robot implies that is uses its own power supply that is carried within the system [9]. The system is advanced within the hydraulically actuated concept. It usually employs rotary hydraulic actuators rather than linear hydraulic actuators located on its power joints. This usually takes the design to be powerful as well as effective to its users.

Figure 4: Sarcos Exoskeleton, adapted from Michael, (2009)

3.3 Subsystem Level

Studies have demonstrated that dynamic association for administrators in the creation of an engine design brings about more noteworthy engine learning and maintenance than detached development. Guaranteeing the security of the subject is an essential issue. Both programming and equipment ensures the dependability in the proposed framework. For equipment outline, it incorporates selecting secure gadgets, setting crisis to stop catch, and sensible component plan.

3.3.1. Subsystem level #1: Motors

The use of motors in the designs allow for effectiveness in movements within the structure, especially at the joints. Based on the clinical studies results of this exoskeleton, the paralyzed patients have the abilities of standing upright and also walk in an independent manner. The use of motors in the structure helps in improving the quality use. Figure 5 shows a design that has incorporated the use of motors to allow for quality movement by the users [11]. It is among the few exoskeletons to be manufacture that include the use of advanced and up to date technologies that influence its reliability.

Figure 5: The ReWalk exoskeleton, adapted from Michael, (2009)

3.3.2. Subsystem level #2: Controls

Controls are an important aspect of the exoskeleton designs. Controls allow for the devices to be maneuvered as per the users' needs and requirements. The controls are based on various factors, including the technology uses as well as the preferences of the user. The Vanderbilt exoskeleton, as shown in figure 6, has been design in a way that it includes brushless direct current motors used to actuate the knee and hip joints. The controls help in ensuring the coordination within the devise is well organized. It provides repeatable gait with hip and knee joints aptitudes that are same to the ones observed while in non-SCI walking.

Figure 6: The Vanderbilt Exoskeleton, adapted from Ingo, (2012)

3.3.3. Subsystem level #3: Structure

The Sarcos exoskeleton, as shown in figure 7, is made for purpose of using force sensing located between the robot as well as wearers for purposes of implementing the systems referred as the "get out of my way" system. The wearer's foot tend to interface with the design through the use of stiff metal plates containing force sensing elements that are able to keep the feet of users to be stiff at all times [11]. The structure of the device is made is a manner that it is able to be worn and removed comfortable as well as fit the users in a comfortable manner.

Figure 7: Sarcos Exoskeleton, adapted from Ingo, (2012)

4.0. DESIGNS CONSIDERED

Based on the various customer and engineering requirements, the team generated a variety of designs during the brainstorming process.

The designs look into various aspects of the improvements as they were highlighted by the customers while at the same time putting into consideration the engineering requirements. Some of the designs selected are as discussed below.

4.1. Design #1: Use of a black box

After a careful analysis of the original design, the team realized that it had issues with the general operations since its functionality was limited. In order to improve on its performance, the team made a decision of including a black box into the design and its major purpose will be to store data and to coordinate the movements of the user to those of the exoskeleton. By making use of the black box the general performance of the exoskeleton will be improved since the user will be able to coordinate it with minimal efforts and considerable ease. One of the major challenges associated with the black box is that it is expensive to install and require regular maintenance.

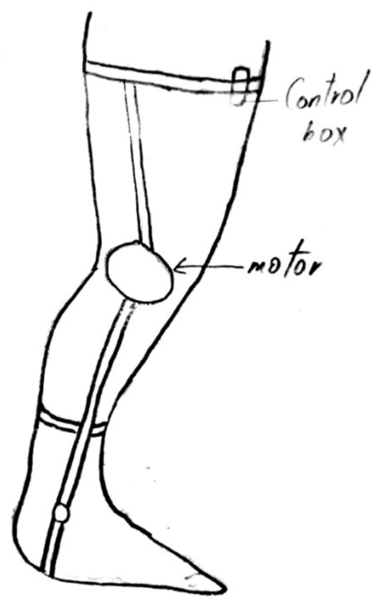


Figure 8: Use of a black box

4.2. Design #2: Use of a motor

After a careful and well sough analysis, the team made a decision of using the motors. This will be very crucial since motors will enable effective movements, especially at the areas which are jointed such as at the knee and the ankle joints. Use of motors will be very advantageous since it will enable the device to move in an effective manner at the joints. By joining the black box and the motors work will be made easier since it will allow for quality coordination and ease of use of the design. The major challenge which is evident is that the motors require constant maintenance due to wear and tear.

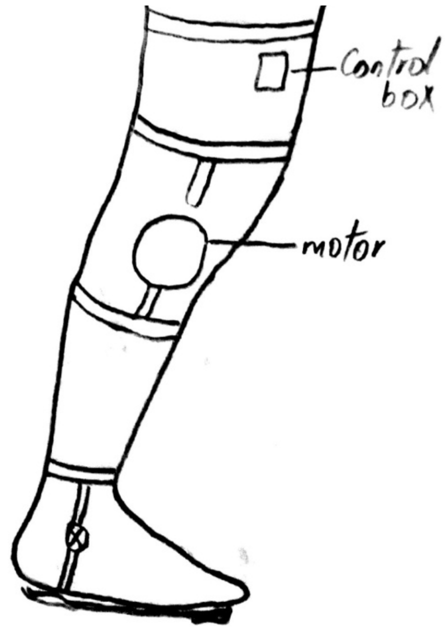


Figure 9: Use of a motor

4.3. Design #3: Adjustable structure

The team wishes to come up with a design which is adjustable since it will be used by people from 5 – 75 years. Purchasing a new device every now and then will be very challenging for the clients as it can be quite expensive. In this regard the team made a decision of coming up with a design which is adjustable so that it can be used by people of a wider age bracket. The design will be advantageous since it will be effectively used by individuals of different ages. For instance, users of a certain age group can be made to use a certain single design, which is just adjusted to suit their preferences or sizes. One of the main challenge of this design is that the team may require use of additional material so as to make the design operate in an effective manner.

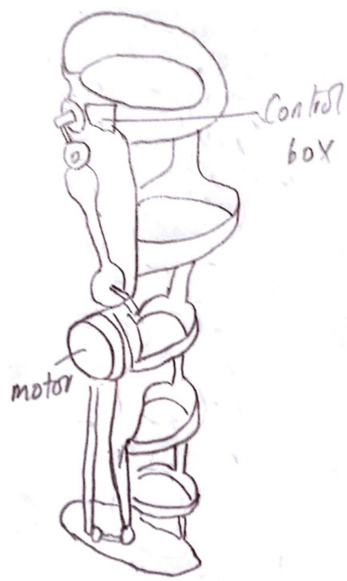


Figure 10: Adjustable structure

4.4. Design # 4: Adjustable straps

The current design is very much uncomfortable to be used by the clients since they are at times required to put on the exoskeleton several times. Therefore the comfort ability of the design while in use is very crucial and that is why the team considered including straps that can be adjusted so as to allow the users to fit properly. Also, the tightness and looseness of the design can easily be adjusted for effectiveness in using. This will be of great advantage since it will allow the users to be able to fit into the systems in an effective manner, hence ensuring that they will use the device in an effective manner. In addition, the design will allow for quality use since the user will be able to adjust the straps to the tightness of their choice.

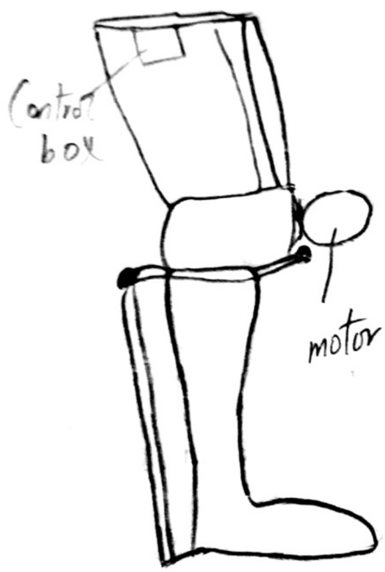


Figure 11: Adjustable straps

4.5. Design #5: Soft fabric

The exoskeleton may at times be quite itchy. The user may be unable to effectively use the existing design due to irritations at the points of contact of the system and the body. Based on this issue in the existing design, the team considered including soft fabric at points where the design comes into contact with the body in order to avoid irritation. The design allows for quality use of the exoskeleton. It is possible for the users to feel comfortable while using the design. Also, it allows for longer use without feeling irritated while using the design. The team considered using soft fabrics at these points.

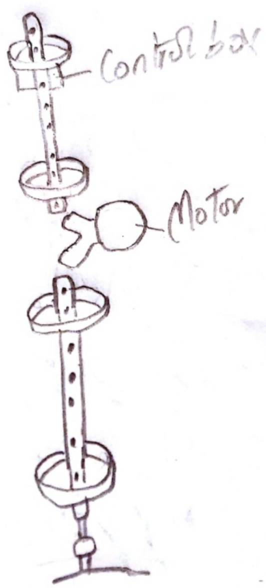


Figure 12: Soft fabric

4.6. Design #6: Iron Structure

The team considered using an iron structure. The rods supporting the structure need to be strong. The team considered using iron rods in order to make the structure strong. This design is advantageous since it makes the structure strong and easily used by users of different weights. However, using iron rod may make the design quite heavy for users, given the fact that they are physically challenged.

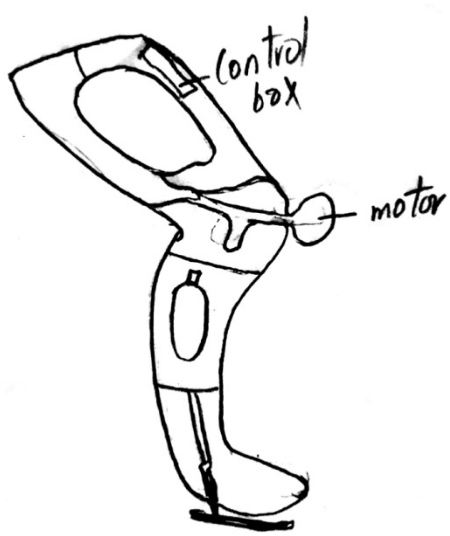


Figure 13: Iron Structure

4.7. Design #7: Aluminum Structure

Further, the team considered using aluminum for the structure. The team considered this since it allows for the use of a strong metal and light at the same time. This will make the design easy and effective to use since it will not be heavy. However, the metal may easily bend, which makes it unsuitable for use in the structure.

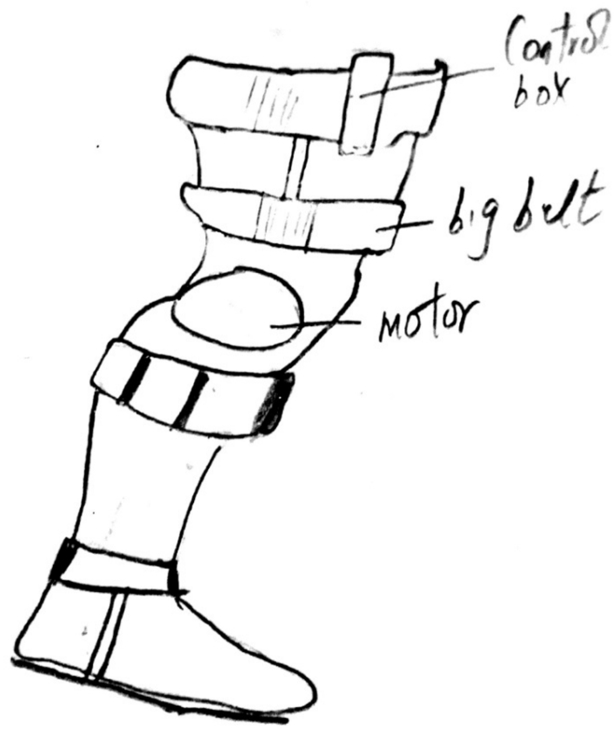


Figure 14: Aluminum Structure

4.8. Design #8: Complete Cover

The use of a complete cover is a design that may allow for quality griping of the user by the design. The complete cover allows for the design to go round the users' legs and cover all the parts. This allows for the design to fit properly and effectively. The design is advantageous since it allows for quality use of the system thus making it comfortable. However, the design may cause significant sweating, which may not be proper for use for long hours.

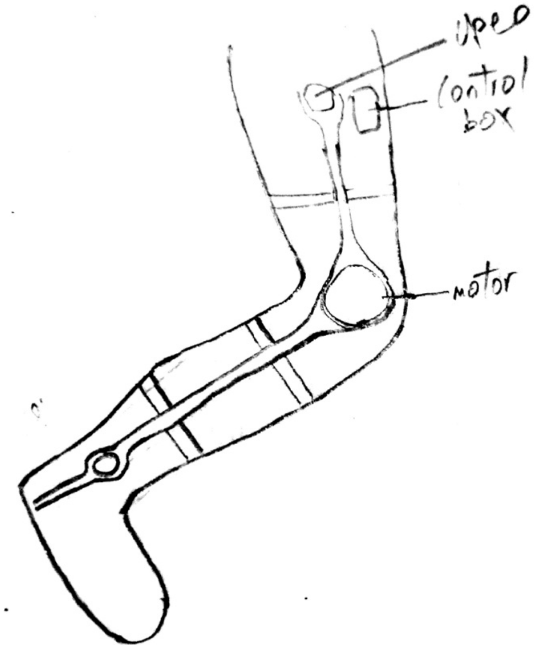


Figure 15: Complete Cover

4.9. Design #9: Partial Cover

On the other hand, the team considered a design that covers the users' legs partially. This design will use straps rather that complete covers. The straps will be located in different places on the leg to allow for effectiveness in griping. The design allows for quality use and reduces irritation as well as the increased warmth when completely covered.

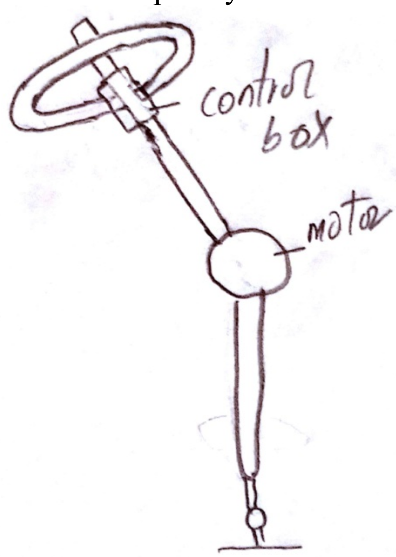


Figure 16: Partial Cover

4.10. Design #10: Advanced design

This design includes the use of advanced systems to make it effective. This includes using these designs into one high quality performance design. The design will include use of a black box, use of motors, use of an adjustable structure, using adjustable straps, and using soft fabric. This will make sure that the design is able to meet most of the users' needs.

The design is advantageous since it is able to ensure that users are comfortable when using the design. The users are able to use the design without being irritated. In addition, the use of the design will be easier due to the existence of motors and black box. Their size can be adjusted, and the tightness of the design can also be adjusted. The design is important since it meets most of the client needs.

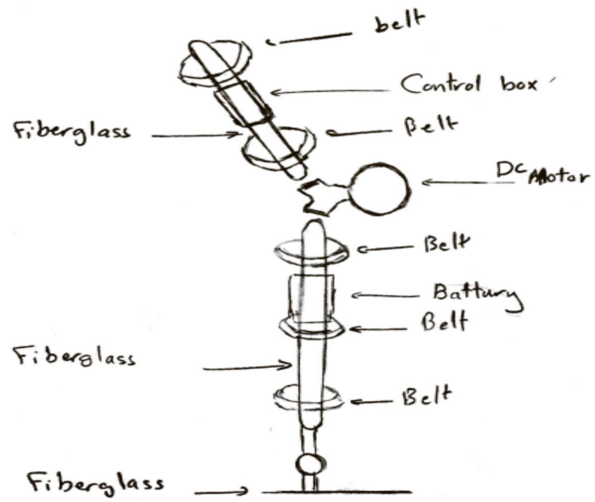


Figure 17: Incorporative design

5.0. DESIGN SELECTED

Before settling on the final design the team had to make sure that the design that was selected met all the requirements by looking into a variety of components. Among the major requirements that had to be fulfilled include meeting the customer needs and also come up with an efficient design as compared with the already existing ones. After a careful analysis and based on the agreed upon criteria the tenth design had the highest score. This is as shown in the decision matrix below.

Table 4: Decision Matrix
(The score of 1-10 is use, where 1 is the least effective and 10 is the most effective)

Designs:	Meets client's needs	Meets users' needs	Improves the existing designs	Total score
Design#1	4	3	2	9
Design#2	4	2	3	9
Design#3	4	4	5	13
Design#4	4	4	4	12
Design#5	4	3	6	13
Design#6	3	2	5	10
Design#7	3	5	2	10
Design#8	2	3	4	9
Design#9	3	4	5	12
Design#10	9	9	9	27
Design with highest score	**Design #10**			

The team selected design #10, which is a combination of several desings to meet the clients and users‘ requirements.

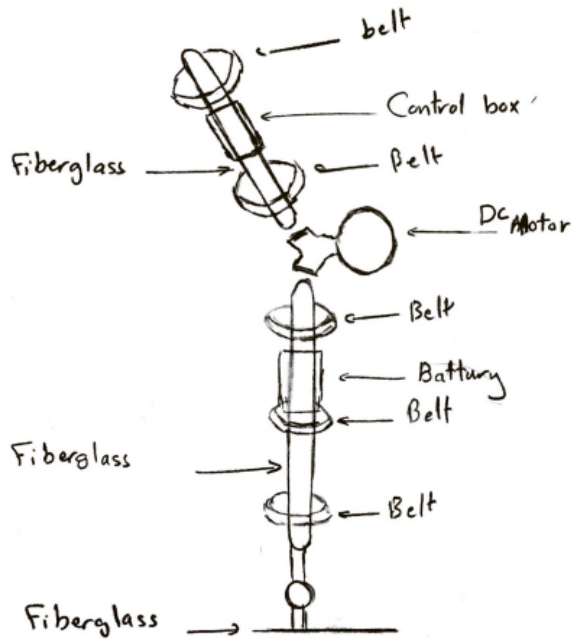


Figure 18: Selected Design

5.1. Rationale for Design Selection

The team selected design 10, which is a combination of a number of desings so as to meet the clients and users‘ requirements. The team was very comfortable with the design and made a decision of working with it since it met all of the client’s requirements. Also, by making use of the decision matrix the design is the most effective, since it was able to meet most of the users’ needs compared to the existing designs. The design selected had numerous advantages in a variety of ways. For instance, it is effective in use since it is comfortable for use by the clients as there was no irritation in the areas which were in direct contact with the body. Also, there will be use of motors and black box the design will be very effective as the client will be able to attend their activities with minimal energy. The design allows for adjusting of the size, and its tightness can also be adjusted to fit the user in an effective manner. The design is important since it meets most of the client needs.

5.2. Design Description

The design which was selected is an integration of several designs which were being analyzed by the tam during the brainstorming stages. For instance, there will be use of a variety of devices and components so as to ensure that the design is effective. Some of those components include a black box, motors, adjustable straps and structure and use of a soft fabric. The main purpose of a black box was to store data and coordinating the movements of the user to those of the exoskeleton. Some of the areas where the motors will be used include: the knee and the ankle joints so as to facilitate ease of movement in these areas.

The adjustable straps will also be beneficial since they will be adjusted depending on the requirements of the user. The design is also adjustable so as to ensure that it can be used by people of various ages. Also in order to avoid irritation in areas where the device comes into contact with the skin of the user, the team settled for a soft fabric and this ensured comfort ability. It is through a combination of all these factors that the team was able to come up with a final design that was effective and comfortable.

6.0 PROPOSED DESIGN

Figure 21 shows the proposed design for this project. The below figure has been modeled in 3D so as to give a clear view of what the final product will look like at the end. Using this modeling, the relative positions of the control box, DC motors, straps, fiber glass, and are simulated to mimic a real case of the engineering.

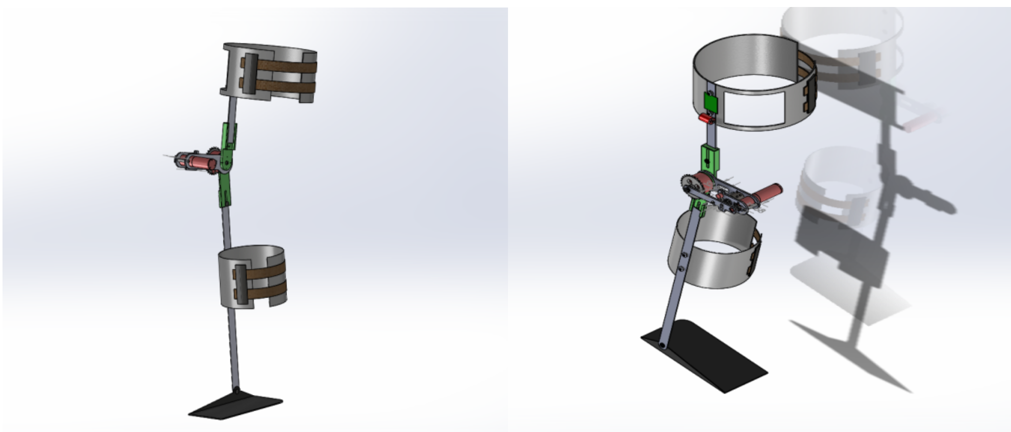


Figure 21 and 22: CAD Models

Bill of materials

Table 5: bill of materials and the source

No.	Material	Description	Source	Cost
1	Control circuit board	Raspberry Pi 3 Model B	https://www.circuitspecialists.com/controllers	$35
2	Carbon fiber glass reinforced with stockinet is adequate	3111-B 1 yd roll	http://www.fibreglast.com/product/Prepreg_3K_2x2_Twill_Weave_Carbon_03101/carbon_fiber_all	$450
3	Carbon fiber tape	2" – 10 yd roll	http://www.fibreglast.com/product/Carbon_Fiber_Tape_597/carbon-fiber-tapes-tow-and-sleeves	$70
4	DC motor	**DS-33RS528**	https://www.alibaba.com/product-detail/DS-33RS528-12v-Price-small-electric_60068268351.html?s=p	$20
5	Lithium battery	12V 4.5Ah Lithium-Ion Rechargeable Battery Set	http://www.jameco.com/webapp/wcs/stores/servlet/Product_10001_10001_2129351_-1	$50
6	Connecting wires	MC4 3T	https://www.aliexpress.com/price/connect-wire_price.html	$10
7	Adhesive	K-302 UV	http://www.dhgate.com/price/metal-adhesive-glue-price.html	$20
8	Screws and nuts	0.5 inches	https://www.alibaba.com/showroom/price-bolt-and-nut.html	$10
9	Leather belt	Wrap cuff (57cm by 13 cm) 3	https://www.leathercordusa.com/	$15
	Total Budget			**$680**

7. IMPLEMENTATION

Infrastructure preparation

The first step of project implementation is the preparation of infrastructure. This step involves the preparation of the factors that are used in making the design that we had chosen as the final design for our team. This includes the hardware that are needed, the software and the communications that are needed as well. The hardware that we need is the tools that are to be used in the implementation process. Below is a list of things the hardware that are to be used for the implementation process of this project.

Table 6: The components to be used for the manufacture process

Item needed	Function
Pliers	Holding of parts as they are getting operated on
Hack saw	Cutting of the fiber glass
Tweezers	Cutting of the wires
Sand paper	Smoothening of the cut sides of the fiber glass
Clamp	Holding down of parts while operation is in progress.
Tape measure	Measure the various sizes that are needed.

We needed software to be installed on one of the computers that we were to use. The software was to help us to do the CAD modeling. This was to help in the simulations that were to help in the making of the final model.

Coordination of the process

The process of implementation will need to be highly organized. We are working as a team each one of us needs to have a role to play in the process that we shall be undertaking. The coordinating process will therefore entail division of task to the members of the team that we have. Coordinating process will be informed by the various skills that each of the team members have so that they can be able to do the duty to the best of their level of skills.

Preparation

The resources that will be used needs to located and harnessed to produce results. The preparation stage entailed finding the palaces where we shall find the manufacture process. This stage also entailed finding a suitable working environment, a place where we would put the items that we were working with and storage for our work in progress. We also used this time to find the best way to execute the process at a minimum cost. There are several errands that needed to be run and we had to find a way to use the least amount of resource in the execution of our duties.

Process monitor

The implementation process also entailed finding a way to monitor the process. In the actual manufacturing process, there will be the actual use of tools and instruments to make our final design. We used this stage to know how to use the tools that we were to use to make the final design. We also consulted on the safety practices that we needed to employ while making our final design.

We had to consult on the methods that we were to follow in the connection of the circuit board, the power supply control and the inter-phase of the control systems.

Demo making
The implementation began with the making of a demo that was to act as our guide to making the full product. We began by making a CAD model of the design that we had chosen. The CAD model was not based on any actual data. It was just an outline of the component layout that was adopted from the drawings that we had made. The CAD was to provide the component location for the various parts of the device. With this model, everything could be conceptualized before the actual manufacturing takes place.

7.1 Manufacturing

The first thing to do in the implementation process was to gather the materials that were needed for the manufacturing process. Prior to this stage, we had also identified the places where the materials would be obtained by the team. We therefore went ahead and obtained the necessary implements that were needed for our design. The below table shows the materials that are needed to make the final design.

Table 7: The usage of the various materials

No.	Material	Description	Role of the component
1	Control circuit board	Raspberry Pi 3 Model B	This piece will relay the commands to the motor so that it can be able to execute the motion to carry the leg.
2	Carbon fiber glass reinforced with stockinet is adequate	3111-B 1 yd roll	The carbon fiber glass will be used to make the backbone of the stepping area and the vertical support of the design
3	Carbon fiber tape	2" – 10 yd roll	The carbon fiber tape will be used as an adhesive for the carbon fiber glass
4	DC motor	DS-33RS528	The motor is the part that will execute the commands that will be sent form the circuit board control command.
5	Lithium battery	12V 4.5Ah Lithium-Ion Rechargeable Battery Set	The lithium battery will be used to power the device so that it can be able to execute the commands that are given.
6	Connecting wires	MC4 3T	The connecting wires are the ones that will relay the commands that are sent from the motor and from the circuit board of the device.
7	Adhesive	K-302 UV	The adhesive will be used to connect the parts that need to be connected to each other.
8	Screws and nuts	0.5 inches	There are some parts of the fiber glass that will need to be screwed together to make a perfect device.
9	Leather belt	Wrap cuff (57cm by 13 cm) 3	The leather belt will be used to strap the design to the leg of the person that will be using the design.

Gather data

To make the design, we need to make the design according to the tailored specifications. We used this stage to make the specification measurements for our design. The first thing was to obtain the measures for the foot area of the design. The second thing was to obtain the measures for the vertical support of our design. The third thing that was done was to obtain the measures of the leather straps that were to be used for fastening the design to the leg. The circuit box that we made also needs to be contained in a hold. We obtained the measurements of the circuit so that we could design a box hold for it. Other measures to be determined were made including the measure positions for the control panel and the motor for the design.

Process

The process begins with the cutting of the fiber glass. The fiber glass is cut according to the various sizes that are needed. The hack saw is used in the cutting of the various sizes of the fiber glass. Since it may be difficult to smooth the fiber glass after the assembly, the fiber glass is smoothened after it has been cut. The bottom part that makes the stepping of the design is then riveted to the vertical fiber glass shaft. The motor is riveted in place, the battery and the control box is also riveted at the place where it is supposed to be fixed at. The cables that connect the control box to the motor and the control panel are then fixed at their appropriate points. Finally, the leather straps are fixed at the respective points where they are supposed to provide a grip on the leg.

7.2 Analytical Analysis

Choosing materials for use in prosthetic applications are depended on the user's demands. All the components are have proved to be durable with layers of reinforcing compounds. The compound used and how it is applied with resin determines the durability of the prosthetic. For the majority of geriatric users, fiber glass reinforced with stockinet is adequate. However, if the user's level of activity requires heavy duty device, carbon-fiber glass is recommended. Weight is very important in these components. The end product has to be light enough. The properties of fiber glass and carbon allow for applying several layers of each to achieve high strength at the still low weight.

The layer of materials used depends on the activity level of the patient. Vertical strips of carbon tape or a layer of bi-directional carbon cloth are used in heavy duty and super duty applications to achieve increased tension, stiffness and resistance to compression. A layer of fiber glass reinforced with stockinet is used to cover the inner layer and then reinforced with suitable acrylic resin (Cifuentes, et al., 2016).

Properties of Fiber glass and carbon in Orthotics

Fiber glass and carbon are in the category of compounds which are mainly used for orthopedic applications. Both of them have unique properties and features, and this gives them an advantage over each other. Among these compounds, fiberglass is the most economical and that is why it is widely used. One of its significant characteristics which make it to have a lead is that it is durable and flexible. It is also heavy but can saturate easily with resin. In addition, fiberglass can be found in a variety of forms and properties. The fibers provide strength under compression than under tension.

On the other hand, Carbon fiber is a significant compound and is also used in orthopedic functions. Even if it is extremely light, it is stiff and retains its shape when under stress since it has impressive strength when subjected to tensile and compressive forces. Carbon fiber is very stiff, a property that makes it brittle and as result reduced resistance to effect. In this regard, the strength characteristics must be taken into account so as to ensure that the final device is strong. However, it is prudent to ensure that the strength characteristics of the compound fiber are shown and developed in the course of the fiber (Pons, 2008). For the maximum resistance degree to fracture of the compound to be achieved, it is important to consider the fiber's position relative to the applied stress. Fiber materials including tape compounds and woven cloth have proved excellent for localized strength. However, they provide one compound property in a single direction. In addition, the fibers in the compound have to be placed at a 90^0 angle to the plane of stress for their effectiveness.

In fiber glass and carbon, the uniform strength is achieved with resistance of equal magnitude to fracture in multiple directions. This is achieved using a quasi-is-trophic compound is used. To achieve this, the compounds are applied in a knit type. This compound fiber is rendered in a 3-dimension plane manner. Because each compound has unique properties, effectiveness in the application for the fabrics is achieved by fusing the constituents to obtain a quasi-is-trophic hybrid compound. It produces a combination with the most desirable characteristics of each fiber in one medium. These characteristics include compressive, torque resistance, tensile, shear, and affect stress from all directions (Lusardi, et. al., 2013). When carbon is blended with fiber glass, it achieves superior high resistance to fracture. The resulting product also possesses a very commendable strength: weight ratio, and with low-cost implications. The product is a hybrid with lightweight characteristics associated with carbon, integrated with cost-effective, durable, as well as, flexible properties of fiberglass.

When reinforced with stockinet, fiber glass is widely used in geriatric amputees. Sometimes the activities may require high impact prosthesis. In such cases, a blend of carbon-fiberglass knit with stockinet is used. In the instances of the super-duty socket, carbon-Kevlar knit compounds provide the required strength. Carbon-fiber glass finds much application in the average disarticulation prosthesis. The disarticulation prosthesis offers many challenges relative to stress regions and fracture planes. The classical point of fracture forms the distal front and back edges of the socket attachment because of the extra torque moments, tension and compressive stress at this point of the component. Carbon fiber, therefore, meets the demands of this kind of heavy duty application.

The regions of localized stress at the distal points of socket attachment are reinforced using two to three layers of unit-directional carbon tape. This is done while ensuring that the fibers are perpendicular to the stress plane. Care is taken so that the carbon layers do not exceed four. With more than four layers of carbon tape, the prosthesis becomes stiff and unable absorb both torque and impact (Perry, et al., 2010). Because of the properties of fiber glass discussed earlier, it is applied up to two layers, placed between the layers of carbon to make an I-beam effect. This increases strength and resists forces and stresses that are applied by the user.

Maximum Cast Circumference (Centimetres)× Total Cast Length/3 = Total Resins required (grams)

Wight Analysis

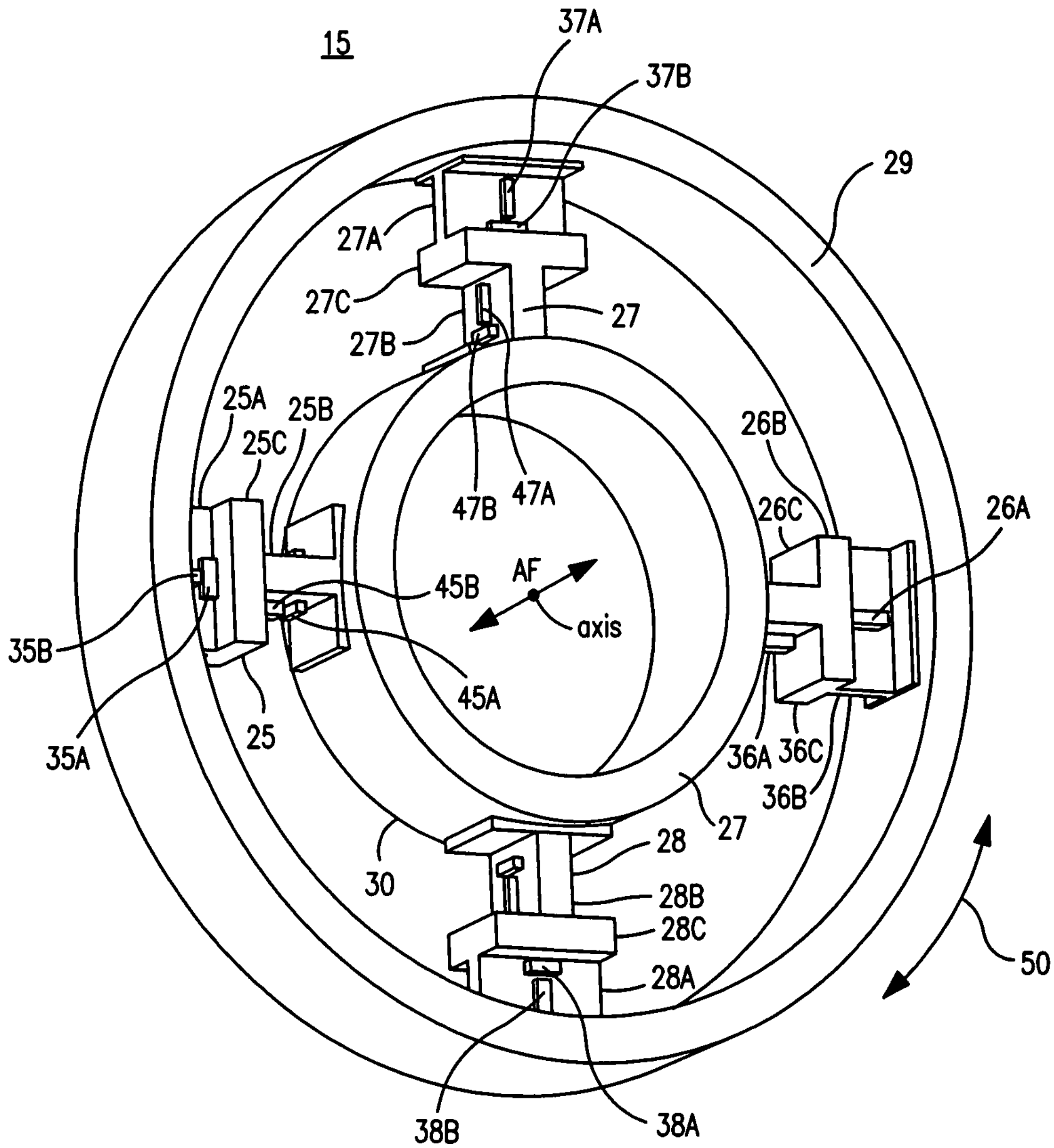
Using this method, the weight of a below-knee socket component is approximately 275g, while the finished prosthesis weighs about 960g. The knee socket described above has a weight of about 300g in average. The above-knee wood shin prosthesis weighs in average 3kgs. This weight depends on the size of foot and knee unit that is included without hydraulic systems.

Where very high levels of stresses are expected, it is advisable to adopt design of structures to develop an I-beam. With the socket layout, fiberglass mixed with carbon woven cloth adds no much weight but increases stiffness up to 40% and strength up to 20%. This achieves ultimate reinforcement at a reduced weight. Care is taken in this design to ensure that stress planes are identified, as well as carbon fibers are at 90^0 to it. (Knudson, 2007). Selection of compounds for the knee socket mentioned above depends on the activity level of the client and requires a total of five layers. Carbon tape is tied up to three inches circling the socket to maintain the shape of the socket and its rigidity. If the socket has to be flexible, layers of compound stockinet are maintained. Other two layers of fiber glass matting are included in the midst of the compound layers to make an I-Beam. This increases the strength, tension, stiffness, and resistance to compression.

Some areas require grinding to ensure the socket or other parts fits properly. Fiber glass layers are applied above the lining of half of an ounce Dacron sleeve. Because of its properties, fiber glass mating provides a light filter that is saturated by an acrylic resin which is easy to grind and buff to achieve a good appearance. The edges can be finished with a sand paper, and an acrylic paste incorporated as a thin coat.

Comparative analysis of orthotic mechanisms

Initially, the Solid Ankle Cushion Heel (SACH) was preferred as the foot of choice because of its light weight, affordability and durability. As long as the heel durometer is soft, the stability of the knee with this kind of knee is generally good. In cases where improved knee stability is required, a single axis foot with soft plantar flexion bumper is preferred. The major disadvantages of this option are the added weight and cost. Multi-axis designs present similar challenges to the single axis but comes with and extra degrees of freedom. This is because of the hind foot inversion/eversion along with traverse rotation. A multi-axis component accommodates uneven ground, absorbs some of the walking torque, protects the user's skin form shear stresses and reduces the wear and tear on the device's mechanisms (Cifuentes, et al., 2016).



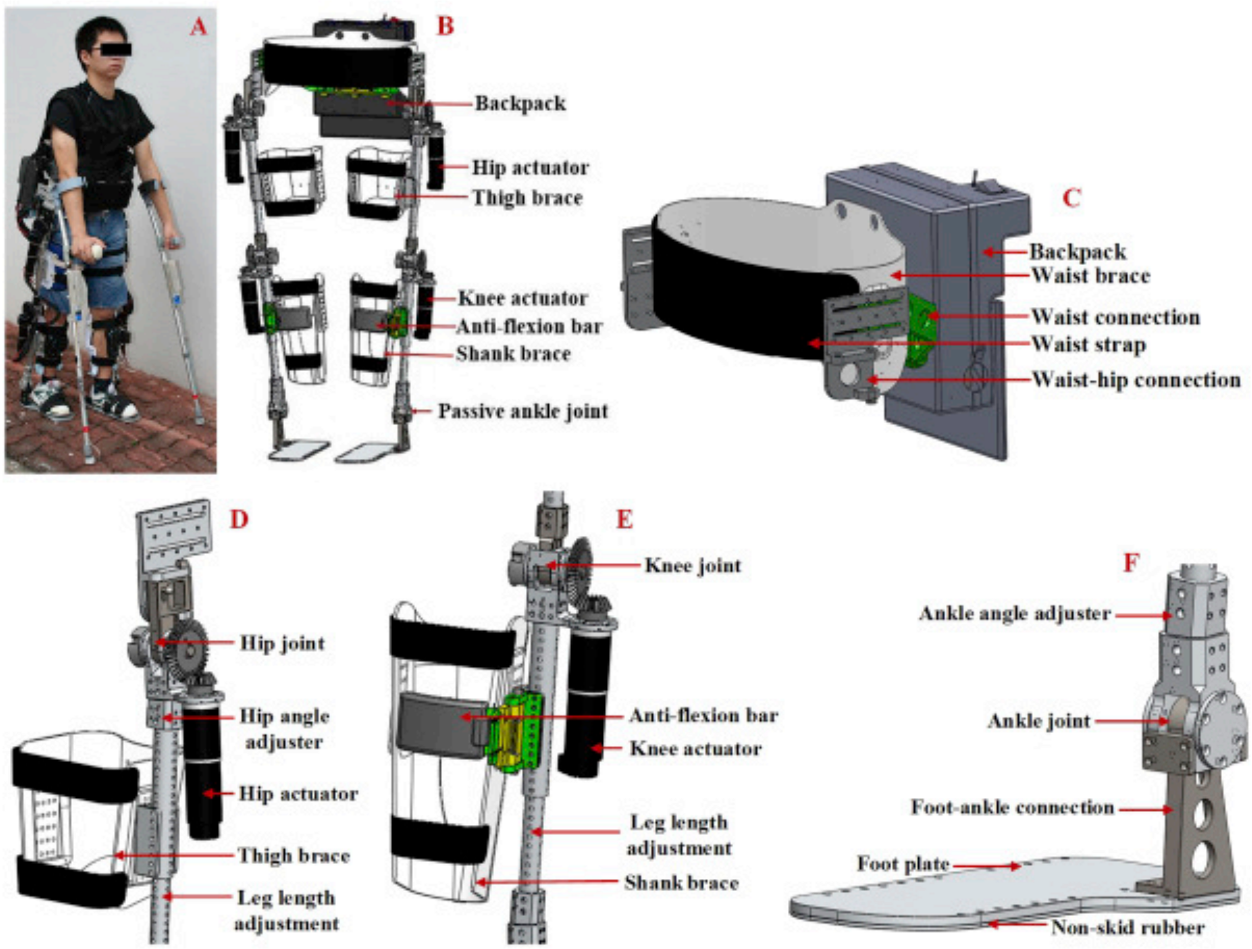
In recent years, more advanced foot prosthetic devices have emerged, and have proved to be successful to the users. There is Soft Ankle Flexible Endoskeleton that could be regarded as Flexible Keel design. Other similar designs include STEN foot and Otto Bock 1D10 which soft, flexible fore foot which providing a smooth rollover of the user. The SAFE design has traverse rotation. Special care is taken during alignment of the soft forefoot to prevent knee buckle from occurring. Nevertheless, if the soft foot is used together with polycentric knee, the opposite happens. The component becomes safer in the phase of late stance.

The polycentric knee mechanism is superior in that it can resist bending moments. This results in powerful stability at heel strike. During the swing phase, it only flexes when the forefoot is planted on the ground while the body rides the device above it. There is a resulting shearing force which interferes with the linkages and allows easy flexion on the knee. The soft, flexible keel delays the shearing moment. This makes the polycentric knee more stable in late stance. Dynamic response feet can also be used to help hip/hemi patient because it provides a subjective active push off.

In all components, it is important to monitor the interaction between the foot and the knee. If the foot mechanism is responsive, the knee unit resistances become more important (Knudson, 2007). Fluid controlled knee mechanisms or those with powerful friction cells are sometimes more preferred. This is because they reduce wastage of the forward momentum due to knee terminal impact. On top of the foot mechanisms, there are numerous ankle components designed for the amputees. They can, therefore, be used together with the feet devices discussed above. This increases the number of degrees of freedom. To reduce the shear forces that are transmitted to the users and the components, torque absorbing units are included in the prostheses. These torque devices are located beneath the knee mechanism. This allows increased durability because it places the mechanism far away from the sagittal stresses generated by the ankle.

Including torque absorbing devices is justified by the fact that the patient lacks three biological joints hence lacks regular rotation of ambulation. The absorbers are combined with almost any type of foot when it is desired. Recently, rotational units have been developed and are fixed above the knee mechanism (Cifuentes, et al., 2016). They allow the user to press a button, which rotates the shank by up to more than 90 degrees to attain sitting comfort. Users can sit cross-legged on the floor and easily enter automobiles and other places.

With the four potentiometers at each joint of an individual, we proceeded to connect the circuit to open the HyperTerminal window perform normal walking and for different readings of the analog signals. The design of these mechanisms is conceived with the help of different disciplines such as medicine, electronics, physics and mechanics. Within the field of electronics, electronic instrumentation and control are recognized as fundamental parts of the system. The instrumentation is responsible for collecting the information useful to be sent to a central processor, which contains the control strategies necessary to make a decision according to the information received. This information should be highly reliable and the principles used should be appropriate for each application. In the electronics of exoskeletons, there are a variety of ways of acquiring the information and different control strategies that are adopted depending on each development, taking into account that the agreed and implemented always have to be in accordance with the developments of the other areas applied to the construction of the exoskeleton. These tests can be performed on people suffering any kind of spinal cord injury in the lower limb, likewise be obtained many tools to design the operation of the exoskeleton according to the requirements of each individual.



(Engineering design, 2015)

The figure above shows the exoskeleton functioning mechanism

Component Design Equations

In this segment, the outline conditions comparing to the CRR-RRR component are exhibited. The motivation to do as such is that it ended up giving the most fitted instruments for the undertaking.

CRR-RRR linkages are considered as two serial chains, CRR and RRR, joined at their end-effectors. The tomahawks are marked as appeared in, beginning at the settled C joint and going around up to the last settled R joint. For each joint i, let si=si+∈soi be the joint hub, with revolution θi, and slide (for the C joint just) di. We express the forward kinematics conditions of the CRR and RRR chains utilizing double quaternions

$$\hat{Q}_{CRR}(\Delta\hat{\theta}_1,\Delta\theta_2,\Delta\theta_3)=\prod_{i=1}^{3}\left(\cos\frac{\Delta\hat{\theta}_i}{2}+\sin\frac{\Delta\hat{\theta}_i}{2}S_i\right)\hat{Q}_{RRR}(\Delta\theta_6,\Delta\theta_5,\Delta\theta_4)=\prod_{i\in\{6,5,4\}}\left(\cos\frac{\Delta\hat{\theta}_i}{2}+\sin\frac{\Delta\hat{\theta}_i}{2}S_i\right) \quad (1)$$

Where $\Delta\hat{\theta}_i=\delta\theta_i+\epsilon\delta d_i$ is the double edge, and all $d_i = 0$ with the exception of d_1 comparing to the round and hollow joint. The forward kinematics so communicated speak to the arrangement of relative relocations of the fasten as for a reference design.

So as to make the plan conditions, we limit the separation between the relocations caught in Section II.B. We perform dimensional blend, that is, the objective is to discover the area and measurements of the component that performs roughly the undertaking.

The outline conditions are made by likening the forward kinematics of the system to each of the discrete positions got from the movement catch. In the event that we indicate each limited uprooting of the thumb as $\hat{P}_i$, we can make the relative removals as for the principal position of the thumb, $\hat{P}_{1i}=\hat{P}_i(\hat{P}_1)^{-1}$, to yield plan conditions

$$\hat{Q}_{CRR}(\Delta\hat{\theta}_{i1},\Delta\theta_{i2},\Delta\theta_{i3})=\hat{P}_{1i},\hat{Q}_{RRR}(\Delta\theta_{i6},\Delta\theta_{i5},\Delta\theta_{i4})=\hat{P}_{1i},i=2,\dots,m \quad .(2)$$

In these conditions, the factors we are occupied with are what we call the basic factors, which are the Plucker directions of the joint tomahawks $s_i=s_i+\epsilon s_{oi}$ at the reference setup. Furthermore, the advancement procedure yields the edges of the chains with a specific end goal to achieve the thumb relocations.

To finish the arrangement of conditions in we force estimate imperatives on the system so it can be joined to the lower arm and with sensible measurements. Specifically, for the six-interface CRR-RRR system, we include the limitations of separation between both settled tomahawks and furthermore between the settled tomahawks and the thumb,

$$S_1\cdot S_6=\cos\alpha+\epsilon a\sin\alpha S_1\cdot P_1=\cos\beta+\epsilon b\sin\beta \quad (3)$$

where P1 is the screw hub of the primary thumb position, and we settle the separation between the tomahawks along the regular ordinary, a, to an incentive in the vicinity of 50mm and 150mm, and the separation between the thumb connection and the coupler tomahawks, b, to comparable qualities.

Calculations

For the trial subjects, both the firmness and helping power were kept consistent (n = 1, Kt = 50N, Kd = 30Ns/m, Dt = 1m). What changed was the width of the virtual dividers, i.e. the level of requirement on the trail. The requirement was maximal for the principal square of preparing trials as the passage dividers were tightest (Dn = 0.002m). The pathway was less compelled (more prominent suitable deviation of the trail from the recommended way) for squares 2 and 3 (Dn = 0.005m). The imperative of the controller was additionally decreased amid the fourth square of trials (Dn = 0.007m).

Our analysis takes a look at the work load that that is to be done by the motor of our prototype based on the load that it shall handle. The load will definitely use power and we seek to establish what is the duration of time that our battery will carry based on the load. Our analysis will be based on the bill of material that was made and the expected load that will be carried by our prototype. Our first analysis is the weight analysis that that device will be dealing with

Table 7: The total expected weigh to be carried

Part	**Projected weight**
Human leg	5kg
Control circuit board	0.125kg
Carbon fiber glass reinforced with stockinet is adequate	0.75kg
DC motor	0.35kg
Lithium battery	0.65 kg
Total weight	8kg

Our second analysis will be the power needed to carry the weight in terms of voltage.
The force that is needed to drag the above weight is
8X10 = 80 Newton's
The power storage has to be able to carry this weight at every instance.
It takes about two seconds of suspension of the leg to carry it to the next step.
This means that we shall need to use the power at the rate of 40 Newton per second. Energy is a product of force and distance. A single step has an average of 0.3 m. The energy needed to take a step will therefore be 80x 0.3= 2.5 Joules

Our third analysis will entail the power that is produced by the battery and the duration that the battery is likely to last the person as they walk.
The capacity of the battery is

$=\frac{1}{2}CV^2$

$=\frac{1}{2}\ X4500 \text{ X } 12X12$

= 32400 Joules

$=\frac{32400}{2.5}$

= 3.6 hrs

Given that the legs walk in an alternation rate, this time is doubled as time is given for the other leg to move. We therefore have 7.2 hours of walk that can be made at one time without recharging again. If a person it working during the day, they can work comfortably with two batteries as they will provide the optimum power that is needed.

Material analysis

The other thing that we need to establish is the life span that our model that we are making. First of all, the fiber glass is a tough material that is known to last for as long as ten years with a low pressure being applied to it. We have a moderate pressure that is getting applied to the glass fiber; they are therefore likely to last for a long time. However, we have riveting that is attached to the glass fibers. This make the glass fiber to wear out relatively fast at the areas where there are moving joints. The life cycle of the fiber glass is therefore reduced to about five years.
The motor of the device can last for three years if it working for full time. This is according to the manufacture information that is available about the motor that was chosen. The leather strap that was gotten by the team can last for three years before it starts wearing out because of the constant clipping an unclipping process. The control panel can last for a long time, since there are not many things that would lead to it wearing out. Shock is the only wear that may happen to wear out the control box. Taking all these factors into consideration, we realize we can take an average life span of the device to be reduced to three years. After this time, the device can be replaced or the parts that need replacement can be replaced.

Conclusion

Based on the analysis that was done the model that was made has an ability of serving the client for 7 hours without a recharge. This is a relatively good enough time that the client has to utilize the model. We have used as light material as possible on the design so that the client will not get too tired as they are walking with the device fixed on their legs. Based on the constraints of this project and the expectations that had been leveled on the team, we can say that we have made a model that is as good as the best for this project. Given more resources, we possibly could do a better job on this model. There are some expensive components that would give more efficiency in terms of the weight and the functionality. This will be left for a future study.

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Appendices

Appendix A: Decision matrix

Table A1: Decision Matrix
(The score of 1-10 is use, where 1 is the least effective and 10 is the most effective)

Designs:	Meets client's needs	Meets users' needs	Improves the existing designs	Total score
Design#1	4	3	2	9
Design#2	4	2	3	9
Design#3	4	4	5	13
Design#4	4	4	4	12
Design#5	4	3	6	13
Design#6	3	2	5	10
Design#7	3	5	2	10
Design#8	2	3	4	9
Design#9	3	4	5	12
Design#10	9	9	9	27
Design with highest score	**Design #10**			

Appendix B: Schedule