Exoskeleton Mount

Final Report

Team J – Lerner Exoskeleton II

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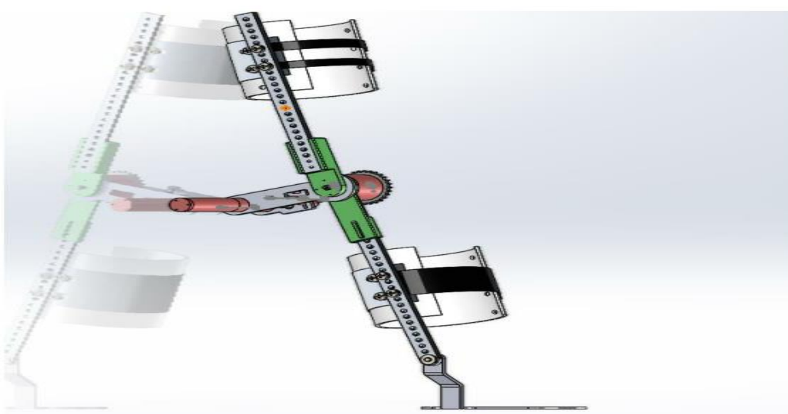
Disclaimer

Executive summary

Lower limb complications include amputation or paralysis that lenders the owner limb dysfunctional. There are solutions that currently exist for such complications. However, we realize that most of the solutions that exist are deficient in one way or another. This project seeks to improve on the existing models my making a whole new prototype that has a better performance. There are several stages that this project goes through. The process started with a research on the systems of exoskeleton that currently exists. This also included a background study of what has been done in the past. A criterion for choosing the best model was then chosen. The criterion included the customer needs and engineering requirements. The next aspect was concept generation. Concept selection looked at the major concepts and the subsystems that made the concepts. This was followed by concept selection. The selected concept was then implemented. The implementation process involved manufacturing of the design, testing and analysis of the design after which it was verified to be in prime shape. Therefore, the work presented in this report is a review of the interface and control framework for rehabilitation robot that coordinates the neuromuscuskeleton. The Bio Mechatronics Laboratory makes use of mechanical exoskeletons to enhance strolling biomechanics in individuals having a neuromuscular problem. As such, the objective of the project is to explore and outline a flexible framework, which mounts the exoskeletons' mechanical segments to the lower furthest point. Besides, exceptionally shaped orthotics is used though it needs a tedious and costly process.



A final CAD of an exoskeleton

Acknowledgements

First of all, we would like to appreciate the engineering community in the university. This includes our instructor, our lecturer, our client and the K&M machine shop in Flagstaff. These people have all the instrumental in making this project to be a success for our team. Our instructor has put up with s much from us in the many mistakes that we have made and also guiding us in the preliminary reports. Our client has provided us with all the material that we needed to make this project to be a success. The team members have all worked hard in this project and they all deserve part in the back.

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BACKGROUND

1.1 Introduction

The development of technology and technical know what has led to much advancement in the technical industry. The creation of the exoskeletons is one of the currently new developments that have come it not the industry. Exoskeletons provide solutions to people that have undergone amputation, or are paralyzed in the body. There are others that are used purely for the rehabilitation process. There are two types of exoskeletons. There are exoskeletons that are meant to support the upper body and there are ones that are used to support the lower body. In this project that we are undertaking we are going to deal with those that are used to support the lower body.

Currently, there some designs of exoskeletons that exist. However, there are challenges that come with some of these designs that exist in the market. Some of the challenges include the weight, the power system, and the comfort among others. In this project we have embarked on creating a model exoskeleton that is much better than the models that are currently in the market. Our aim is to provide an alternative that will replace the already existing models. After a succession of steps, we managed to come up with a final model that is presented at the final part of this report. This report offers a summation of all the major processes that we went through in the final prototype.

1.2 Project description

This project was informed by an existing need that was specific as stipulated by the client to be served. The specific details that the client has specified were all taken into account in the project so as to make sure that we gave the client have a better experience with the device. Some of the specifications that were outlined by the client includes making a model that is light in weight, the design has to be adjustable by the user in terms of the size, the design was also required to have a minimal irritation to skin of the user of this design, it was also supposed to provide a good grip to the user's lower (lib) so that they should have certainty with their motion and finally, it was needed that the design should be easy to use.

The other thing that we were keen to take note of is the engineering requirements. Engineering requirements state that the standard performance indicators are measurable and that they should be met. Some of the engineering requirements that we were keen on includes; the safety of the device, the threshold weight that should be met, the cost implications, the performance standard among others. One of the challenges was to find a point of congruence for the engineering requirement as the client needs. We used several analytical tools to be able to come up with the best of combination of the above factors for the project. In the finality of the project, the model that we developed had met all the necessary and critical needs for the customer and the critical engineering requirements that needed to be met.

1.3 Original system

There are various mutations of the original system that have existed. The model of him original systems have relied upon the concept of provision for a support of motion. This means that most of the past models just played the role of a prop and nothing more. This means that if there was a support that was offered, it was either rigid or it allowed a dangling effect for the lower limb. Mechanical (concisions) characterize most of the past models. These designs cannot operate or facilitate motion unless there is a prop that is offered. Larger part of their usefulness was for rehabilitation of the person that stood a chance of walking again. For the people that are amputated, they did not offer much of a solution except the role of a prop.

2.0 REQUIREMENTS

For this project to be a success, there are the requirements that we needed to figure out before we embarked on the project work. These factors are analysis factors that were to be used in the analysis process for the model that we were to make.

2.1 Customer requirements

These are the factors that the client outlined as the necessities that are needed to make the design. The client was very categorical in the necessities that he outlined as being some necessary components for the final product that we were making. First of all, the client has an experience with the precious model. The client therefore needed that we make a design that was better than the existing designs. The other thing that the client wanted was a design that was flexible. The client did not want a device that was to be still on them so that motion was inhibited for them. The other factor was the device should be easy to put on and put off. Comfort was the other thing that the client outlined as a necessity of the design that we were modeling. The client also said that the design should be light in weight. The client also wanted a design that will be powered by a power source so that it can aid in some of the motions and the task that could be executed through motor functions. The other postulate was that the battery should be long lasting to power the model.

Table 1: Customer needs summary

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	Design to be adjustable to fit people of various sizes
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

2. 2 Engineering requirements

There are several engineering requirements that were outlined as a necessity to be fulfilled. The engineering requirements include; safety of the device, weight that should be met, strength of device, softness of the material, distance above the knee,

Recharge ability of batteries. The above engineering requirements were all adapted from the customer needs and some were adapted from the general performance standards that are required for health devices.

Table 2: Engineering requirements summary

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 less than 2 kg
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

2.3 Testing procedure

We have defined a list of the customer needs and the engineering requirements that are supposed to be fulfilled by our design. To ensure that we fulfill the customer and the engineering requirements, there was a need to make a criterion to make sure that the requirements are all fulfilled. Below is the criterion that was made to ensure that the requirements needed were all fulfilled.

2.3.1 Yield strength of 50Mps

The material that was needed was placed between two points such that it could adjust when weight was placed on it. Several different weights were placed on it at its middle point. It was noted that 50 MPs, the material had not warmed. The material started to yield at over 100Mps.

2.3.2 Adjustable to a length ranging 6 inches to 20 inches

The vertical connection of the design was made of a sliding contact. A tape measure was used to test if this criterion satisfied. First of all, the contact was slid so that it was completely open. The distance between them was measured with a tape measure and the length was 22 inches. The contact wad then fully closed and the distance between then measured to 5 inches.

2.3.3 Soft fabric

A spring was used to test if the design that was made was soft enough. The softness was measured by tying one fiber of the material to a fixed point and the other end tied to the string. The string was then pulled and as the pulling was done, the readings of the string taken. At 4Newtons, the fiber snapped. This means that the fiber was soft as the stretch did not reach 5 Newton.

2.3.4 Limited weight of 0.75 kg

After the completion of the design, it was measured. A spring balance was used to hang the design and see what its total weight was. It was found to have a total weight of 1.5kg. This was below the weight that was expected of 2 kg.

2.3.5 5 cm extension above the knee

Once the design was completed, the length above the knee was measured. This was done with a tape measure. The tape measure revealed that the design was 4 cm in length above the knee.

2.4 Design links

After following the testing procedures that are outline above, an assessment was carried out to determine if the designs did meet the criterion that was given above in the customer requirements and the engineering requirements. This section discusses the results of the situational analysis that was carried out.

2.4.1 Soft material

The material that was laid on the design on the parts where there were the props that enabled that held the device in place. This was to provide a damping for shock that could injure the client. The material that make the prop is quite abrasive and hence the need of the soft material.

2.4.2 Yield strength of 50MPa

There was the size of the same material on all parts of the design. This means that every part of the design had strength of above 50Mpa. This made the design to be strong and attain the benchmark durability that had been stated as are requirement for the design.

2.4.3 Adjustable to a length ranging 6 inches to 20 inches

The need for adjustability was formed by the fact that some of the users are likely to be short while others will be tall. The range that was given for the height is within the range that most people fall under.

2.4.4 Limited weight of 2 kg

Individuals need to stand in upright position to be able to move freely without any strain. We measured our design and found that it was below the weight that was stipulated of being below 2kg in total.

5.4.5 5 cm extension above the knee

Human legs are almost in contact above the knee. If there was contact in this place for the led and the exoskeleton, there would be friction that may injure the other part of the body. However, with the safe distance, there is no friction expected to be there.

2.5 HOQ

The two major parameters for our design are the customer needs and the engineering requirements. These parameters all have different effects on the design that we are making. These parameters all have different weights that they impose on the design when they reweighed relative to each other. HOQ is used to weigh the parameters that are in the HOQ relative to each other. From this evaluation it can be said that the parameters are most important to consider when doing the design process.

Table 3: HOQ analysis

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)			24	10	8	45	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

This project is covering an area that is not entirely new. There is past research that has been done and advancements that have been made on this area of analysis. The designs that are in the east are marked with rigidity. There are equivalents of freely standing structures that can support themselves without falling. This is skeptical efforts that have to support the function of two legs. There are other models that are made to support just one leg. However, they also have a deficiency in that they are all rigid. One of the things that the client said is that they do not want a device that will be rigid.

3.1 Design research

Design research is one of the steps toward the generation of the final prototype to be used for the project. Design research looked at the various models that exist and the work that has been done in the past to act as a guiding light towards making the best model. The design research was carried out as an individual task by the members and then as a team activity by all the team members. The design research is part of the component of the designs that we were able to make as a team.

3.2 System level

There are many system levels that are currently in use as exoskeletons. In this report, we shall examine three of these system levels that are currently in use in the making of exoskeleton. The several exoskeletons are all inspired by the need to make reliable exoskeletons for the persons that need them to improve their ability to move from one place to another. The system levels that are analyzed are all applicable below the knee for a dysfunctional leg for motion.

3.2.1Design 1: The ReWalk exoskeleton

This design is used of persons that have dysfunctional legs. This exoskeleton is able to stand on its own. This is inherent of its rigid structure that enables it to make an upright position. This model is like a suit having some complex power and popping system. This prototype works through a computer chip that is in the model. This chip detects the body movements in reaction to the body balance, and then there is a response that will help in the motions that the body needs assistance.

Figure 1: The ReWalk exoskeleton

3.2.2 Existing Design 2: The Vanderbilt Exoskeleton

Goldfarb is the brain behind the making of this model. This model has its main strong points focused on the waist area and the ankles. The prototypes have motors on both parts that make it possible to facilitate motion. Some of the motion that are facilitated by this prototype includes the basic motions, walking functions, standing motion and sitting abilities. These actions are executed through motors that are on the knees and on the waist.

Figure 2: The Vanderbilt Exoskeleton

3.2.3 Existing Design 3: Sarcos Exoskeleton

This design is modeled like a robot. All the functions of the body motion are facilitated through the directive of the robotic motion. This prototype leaves no room for the personal input of motion. The person is therefore totally dependent on the robotic motion. This design covers the entire body as shown in the figure below. A power supply is carried on the back of a person. The power then drives the hydraulic motions that are directed.

Figure 3: Sarcos Exoskeleton

3.3 Subsystem level

The subsystem level is the smaller components of the design that plays a vital role in the performance of the systems considered. There are several systems that were considered and are discussed in this report

3.3.1 Subsystem level 1: Motors

Motors are used to provide power that moves the parts of the device that moves and acts as joints. From the analysis that was made, the three systems that were looked at all have two of the models using motors. The motor is therefore a critical part of our modeling process.

3.3.2 Subsystem level 2: Controls

The controls are the command centers where all the motions are directed from. There are several ways that commands are executed in the model above. The most one was the use of a microchip or a computerized system. All controls have to have a level of electronic engineering applications.

3.3.3 Subsystem level 3: Structure

Structure is the link between the end use and the concept that needs to be done. The structures of the system standing that were discussed include the free structures, there are the semi standing structures and there are robotic. The robotic is more of a body secular structural design.

4.0 DESIGNS CONSIDERED

The process of design systems informed some of the ideas that were formulated by the team. The concepts were first developed as individual tasks. The designs were then vetted by the team. There are several designs that were considered and are analyzed in this report

4.1 Design 1: Black box model

Most of the motions that are made by people are rather predictable. This means that they are repetitive. If a black box was installed in the functionality of the exoskeleton, it would store that would be remembered by the systems and used to execute motions. The black box installation has some shortcomings of the cost implications. However, it does ease the motion of the user.

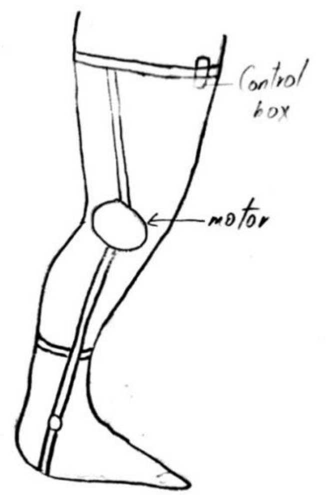


Figure 4: the use of a black box

4.2 Design 2: Use of a motor

In the design, systems that were considered in the research were established that most of the designs used motor action to execute the various functions where the body needs assistance in motion. This design provides power to the motion. Motor will also provide efficiency in the motion that needs to be executed. There are however, the motor calls for the use of power that may be insufficient.

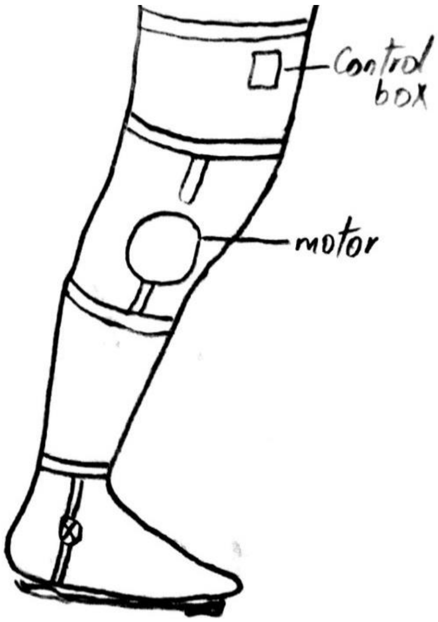


Figure 5: The use of a motor

4.3 Design 3: Adjustable structure

We are seeking to make a design that will accommodate both the young and the older kids as well. This design takes into account the expansion of the width of the device as well as the length of the device. The challenge with this device is the weight and the additional material that it may need to construct.

Figure 6: the adjustable model

4.4 **Adjustable straps**

The need for comfort is one of the top priorities for the client. This model seeks to employ adjustable straps that will be around the thighs and the legs. These can be tightened and loosened to fit to the needs of the client.

Figure 7: Adjustable structure

4.5 **Design 5: Soft fabric**

This design is allowing for the liming of the soft fabric. The cost fabric is used to dampen the effect on shock and therefore reduce the risk of injuries on the subjects that are using this design. The use of the soft fabric enables the user to be comfortable and can wear the design for a long time without getting injured or otherwise.

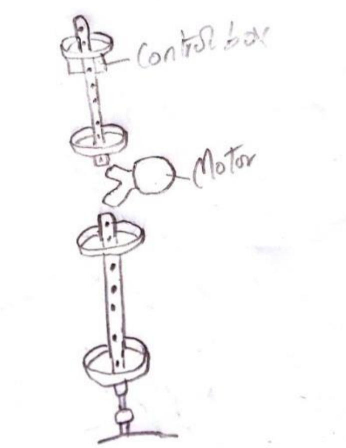


Figure 8: soft fabric

4.6 **Design 6: Iron Structure**

The iron structure design is one of the stronger designs that there is to any model. The iron structure can help to make the design to be stronger since iron is relatively strong metal. The disadvantage of this model is that it is very heavy to the users.

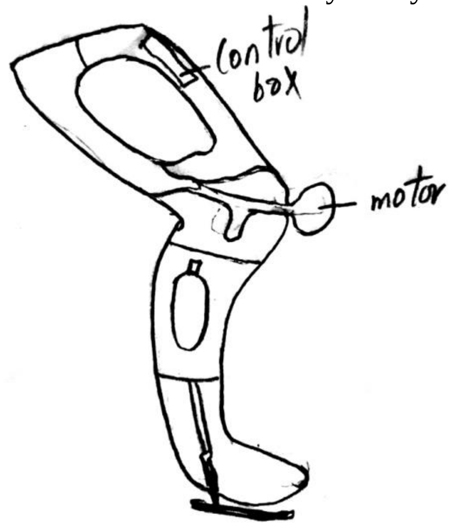


Figure 9: Iron structure

4.7 Design 7: Aluminum Structure

Aluminum was one of the materials that were considered as a possible alternative for use in the design process. Aluminum is light metal. Aluminum is also very strong metal and this makes it ideal for the prototype that we are seeking to make.

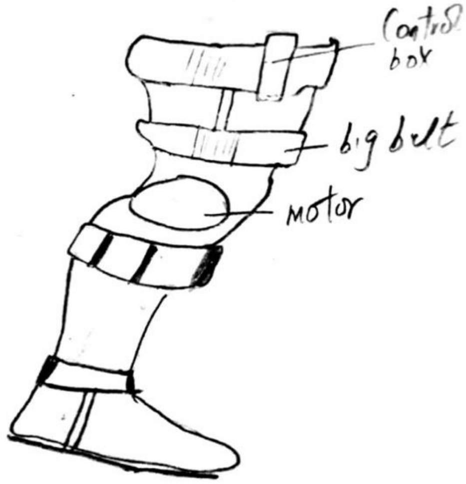


Figure 10: Aluminum structure

4.8 **Design 8: Complete Cover**

This design is made in a way that it covers on the space all around the leg. The purpose of this type of a design it to provide total comfort to the leg of the person that is using this design. The only disadvantage of this model is that it leads to a lot of seating the person that is wearing this design on the leg.

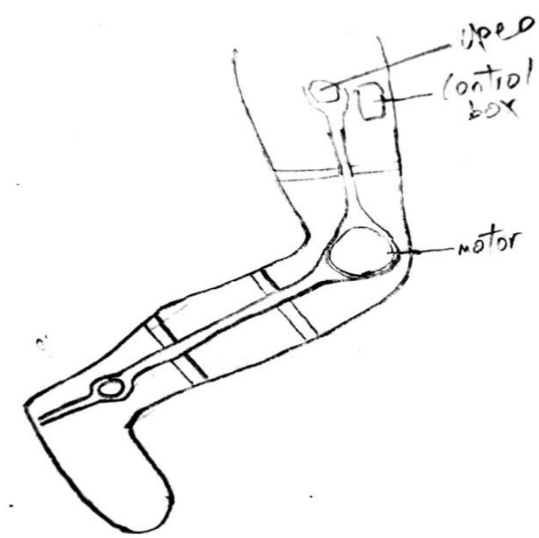


Figure 11 Complete Cover

4.9. **Design 9: Partial Cover**

In this design, the straps are located at different position on the leg so as to allow for free space within the leg. This is to allow for aeration of the leg in this model. This model gives less sweating on the user of this model.

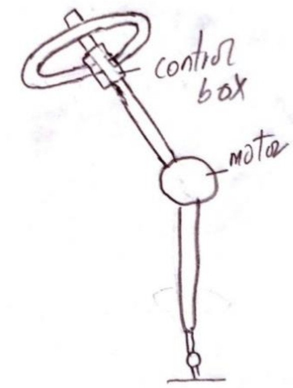


Figure 12: Partial cover

4.10 **Design 10: Advanced design**

This design is advanced based on the fact that contains a lot of components that were not in the other models. This models is a largely a hybrid of the other models. Some of the components of this model include the use of a motor, the use of a soft fabric, use of adjustable straps and the use of black box control system. This makes the design to have an epic efficacy that was not in the other models that were made.

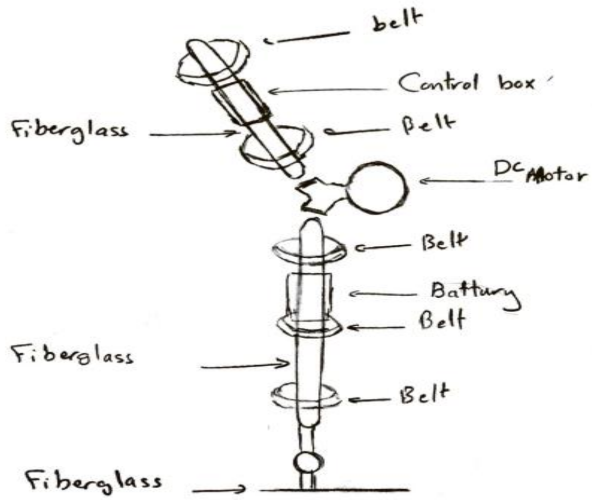


Figure 13: Advanced design

5.0 DESIGN SELECTED

The analysis on the HOQ gives prioritization to the criterion that was to be used in the design section. These criterions were the ones that were used in the decision matrix to decide on the best of the models that we had. The section was to be made from the ten models that we had chosen of the best model. Each of the models was evaluated against this criterion that was made by the team. The table below shows the choosing criterion that was used by the team. The analysis led to the choice of the tenth design as the best of the models that the team had to choose among.

5.1 Rationale for design selection

Our major aim was to find a design that meets you customer needs and satisfies the criterion for the engineering requirements as well. The design matrix made sure that this was satisfied. This Models more of a combination of the other models that were made. First this model satisfies the requirement of comfort. This is inherent of the soft parts that the model was adorned with. This model also satisfies the need for powered motor function. This model also meets the necessities for flexibility and comfort also. Given that most of these models were deficient in one or more of these factors; this model becomes the best of the models.

5.2 Design description

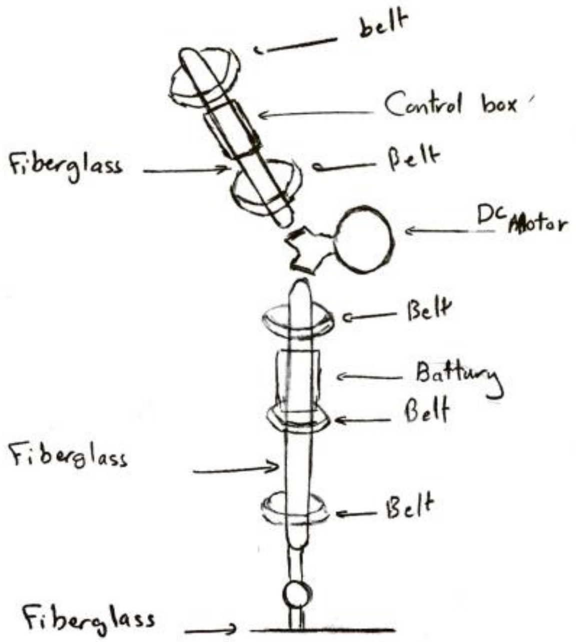


Figure 14: the selected design

The above figure shows the model that was chosen through the decision making criterion. One of the features of this design is that it is motor powered design with the motor being located at the knee area of the design. The second thing is that the model is made of a fiber grass as step vertical support for the design. The third thing is that the design has straps that used to strap the model to the leg of the owner of the person that uses this design. That battery of the design is embedded into the fiber glass of the design. The other thing to note is that ghost model allows for the knee joint to be free to move as well as the ankle joint. Finally, the design is lined with a soft fabric that will enhance conform of the user of the design.

5.3 First semester analysis

Choosing materials for use in prosthetic applications are depended on the user's demands. All the components 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)

5.4 Weight Analysis

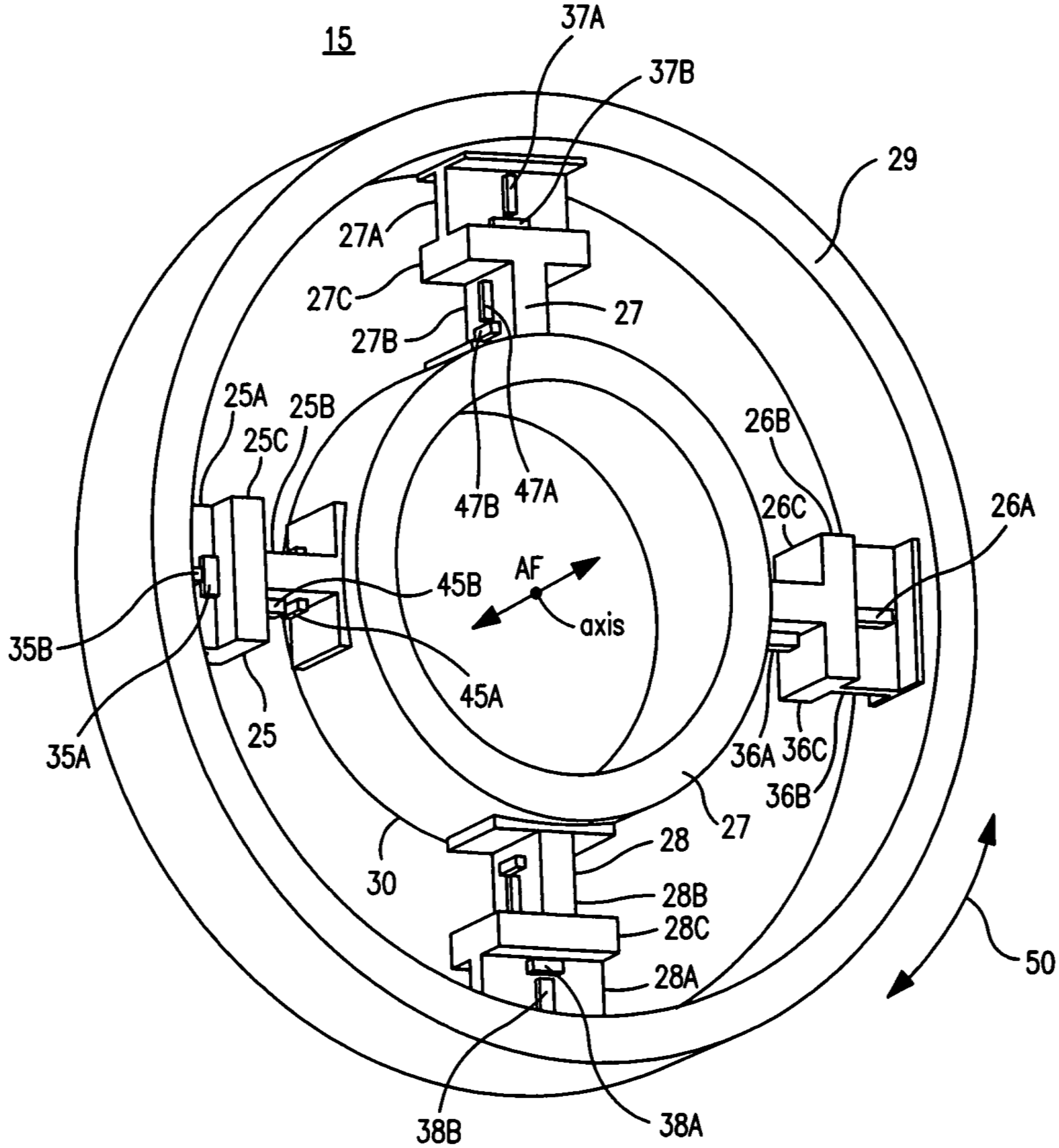
Using this method, the weight of a below-knee socket component is approximately 275g, while the finished prosthesis weighs about 960g. The knee socket described above has a weight of about 300g in average. The above-knee wood shin prosthesis weighs in average 3kgs. This weight depends on the size of 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.

5.5 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).



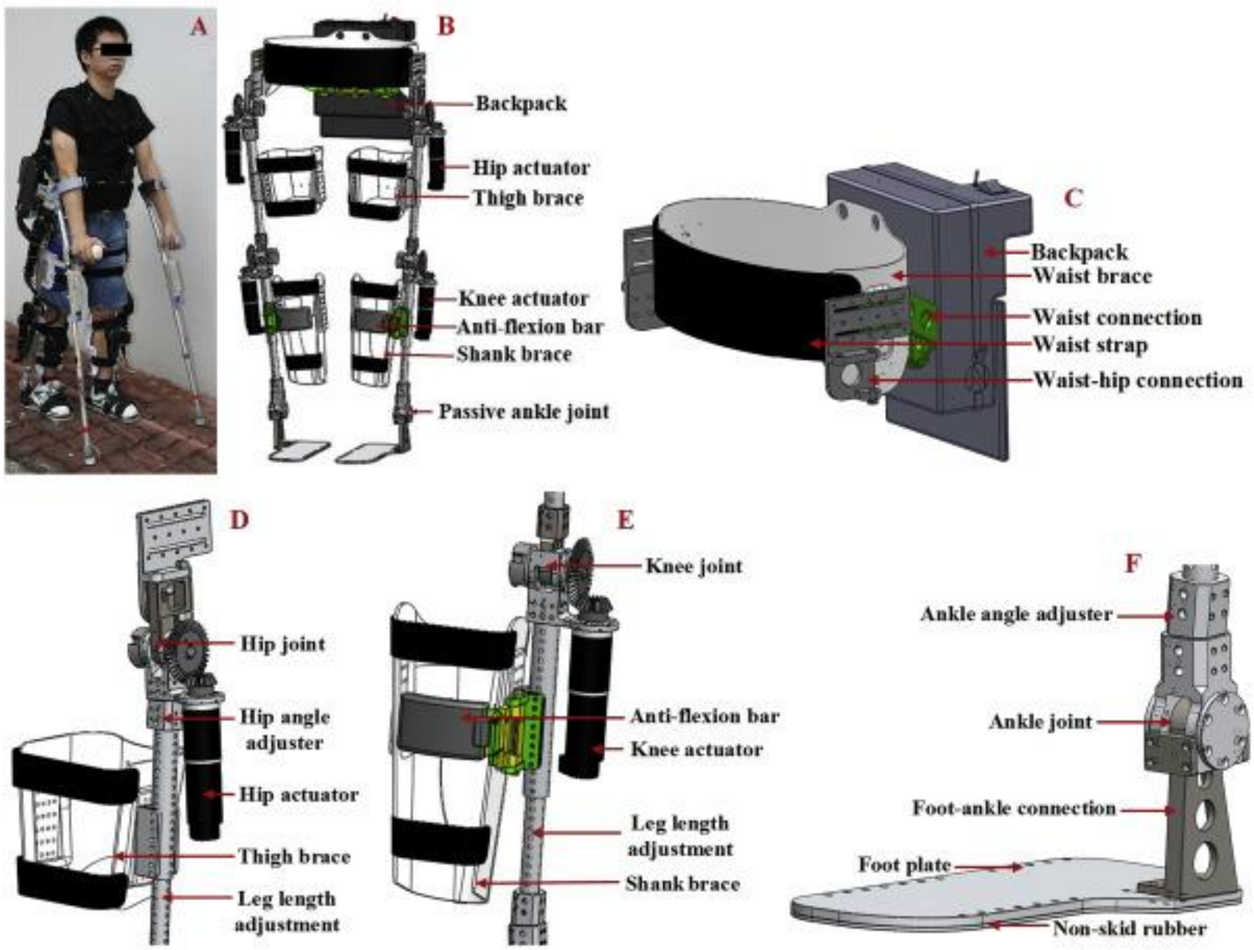
In recent years, more advanced foot prosthetic devices have emerged, and have proved to be successful to the users. There is Soft Ankle Flexible Endoskeleton that could be regarded as Flexible Keel design. Other similar designs include STEN foot and Otto Bock 1D10 which soft, flexible fore foot which 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

5.6 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 $s_i=s_i+\in s_{oi}$ be the joint hub, with revolution θ_i, and slide (for the C joint just) d_i. We express the forward kinematics conditions of the CRR and RRR chains utilizing double quaternions

Where $\Delta\hat{\theta}_i=\delta\theta_i+\in\delta d_i$ 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

In these conditions, the factors we are occupied with are what we call the basic factors, which are the Pluckier directions of the joint tomahawks $s_i=s_i+\in s_{oi}$ 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,

$$S_1 \cdot S_6=\cos\alpha+\in a\sin\alpha \quad S_1 \cdot P_1=\cos\beta+\in b\sin\beta$$

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.

5.7 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).

6.0 PROPOSED DESIGN

A simulation was made to assume the objective position for various components of the design. The figure below shows the relative organizational of the various parts of the design. The dead a clear view of the layout of the parts like the control box, DC motors, straps, fiber glass and the relation to each other. In the execution stage, the design will be made shown in the CAD model below;

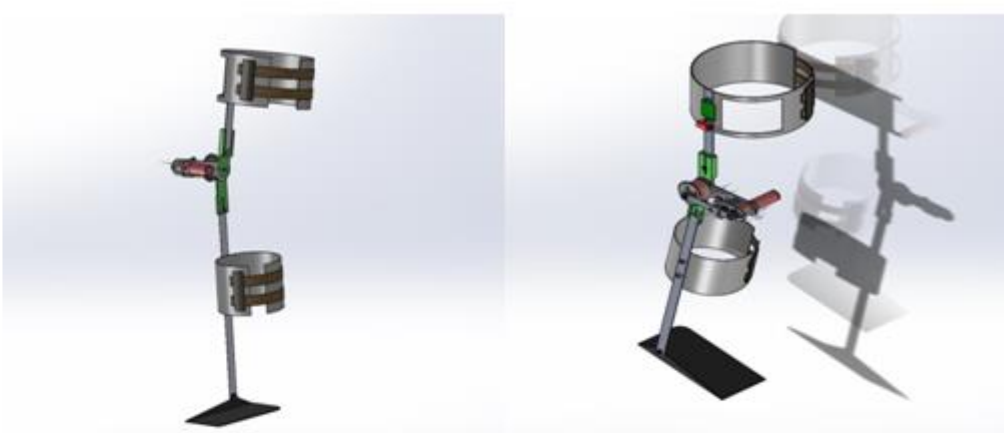


Figure 15: the CAD model

6.1 Bill of Materials

The material to be used for the design is a vital part of the fulfillment of the customer needs, the design links and the engineering requirements. This was to make the design to be durable and to meet the clients need. The details of the bill of materials are found in the appendix.

7. IMPLEMENTATION

The implementation process is one of the more vital processes as it is the one that leads to the making of the final model. The process begins with the analytical process for the materials that will be used in the implementation process. All the materials that are used are all analyzed. This will be followed by an analysis of the mechanics of the device. This includes the relation of the various parts of the device and the way the work together with each other. Finally, there is the manufacturing process that was used in manufacturing of the device. This is the implementation phase in making the device to its final model.

7.1.1 Analytical analysis

7.1.1.1 Setting up of workshop

The design work was done in the workshop. The first step was therefore, to look for the implements that will be used in the construction of the design. The implements are for the cutting purposes, holding purposes, riveting purposes and adhesive purposes. The table below gives a summary of the implements used in the implementation.

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.

7.1.2 Preparation

This field of actuation of work with the use of the materials gathered is a new field. The preparation was guided by the need to make sure that the materials are not destroyed in the process of making the design. Accuracy and decency in work was also part of the inspiration. The tasks were all divided based on the abilities that each of the members. There is however some of the tasks that were carried out as joint effort of all the team players in the process of manufacturing the device.

One of the points of analysis is the total weight that was carried by this design during the usage phase. The weight value is a criterion to establish if the design had gone overboard in its functionality as per the customer need. The total weight is evaluated as;

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

This design was found to have met a reasonable went that was not going to be problematic to the persons that will be using the design.
The second analysis is on the force that will carry the weight that was found in this report;
The force that will be needed;
8X10 = 80 Newton's
The energy needed for this function will be;
80x 0.3= 2.5 Joules
The third analysis is about the time that the battery will be able to last before it gives up.
The capacity of the battery is
$=\frac{1}{2}CV^2$
$= \frac{1}{2}X4500$ X 12X12
= 32400 Joules
$= \frac{32400}{2.5}$
= 3.6 hrs
If the person has two legs with one of them being healthy, then the two alterations of the legs will double this time period and it shall therefore be 3.6X2 = 72 hours.

7.2 Manufacturing process

There are the various implements that are gathered to be used to me the design. The table below gives the various uses that the various implements were used for in the process of manufacturing the product.

Data setup

In the CAD model that was made, we had made generalities regarding most of the parts of the design. The design needed to be tailored in regard to the specifications of the design that we were seeking to make. This was done before we went ahead to the actual execution of the tasks. The various parts were listed based on the measurement of cut and proportions that needed to be made.

Process

The process started with the slicing of the various parts that makes the design. This was done with the cutting implements like the hacksaw and the scissors. The cut parts include chords, the fiber glass and the joinery pieces. The next part was to connect the various parts that were to make the design. These parts were put together with the use of adhesives and the joinery rivets. The finishing included the smoothening in processes and the finishing.


Figure 16: Screws


Figure 17: Different sizes


Figure 18: Lower aluminum


Figure 19: Upper aluminum


Figure 20: Hardware

8.0 TESTING

Testing was done on the design requirements that were presented by the client. The testing was done in stages with each of them trying to verify a certain requirement. The reason each of the requirements were done independently was to measure the extent of the compliance to the requirement by the specific requirement.

Flexible design

Flexibility was defined by the ability of the design to allow for the normal motions that are usually adopted by a person when they are moving. The suit was worn by the person and they allowed the device to simulate its movement. It was noted that the person moved almost like a normal person would move.

Ease of donning on and off

The ease of donning on and off was assessed through wearing and taking it off. It was noted that it took less than a minute to put it on and to put it off took also less than a second.

Comfortable design

During the time when the model was worn, there was not any reported case of discomfort by the wearer of the design. Discomfort indicators could have been marked with being pressed by parts of the design. However, since this did not happen, it was assumed that the design did not produce any discomfort.

Weight of the device

The design was put on a weighing machine and weighed to find its weight. This was one of the things that were to be done after the completion of the design. It was found that the design had a weight of 6.8 kg.

Long lasting electrical battery

The battery of the design was put in the design when it was getting used. The person wearing the design stayed with it for all the time until the battery had run completely dry. It was found that the battery lasted for 7 hours.

Test results

From the test results, it can be said that the design is flexible enough since it allowed for a natural movement of the person that is wearing the design. There was also a noted ease of donning on and off of the design as noted in this report. The battery of the design was also noted to be long lasting as expected. Meeting the threshold of the 7hrs that were estimated is an indication that there was a long lasting electrical battery. The overall weight of the device of the device was 6.8 kg which is less than the previously predicted weight of 8kg. The wearer of the design did not also complain of any sort of discomfort when they were wearing this design. This confirmed on the comfort of the design. N the overall, this was an improved design if it was compared to the original system.

Figure 18: 3D Printers attached to the upper aluminum with different sides including the thermoplastics material.

9.0 CONCLUSION

The project that we have undertaken has been a success. We have managed to go through the process that is supposed to be followed from the start to the end. The most notable success of the project is that we have undertaken the project based on the customer needs and the engineering requirements that are inherent from the customer needs that we researched on. We undertook the project as a team meaning that we all made contributions to the project success. The project results are very credible as a result of the use of very credible analysis tools. They include the HOQ models, the Pugh chart and the decision matrix. There is also the design of experiment that was used in checking if the customer needs and the engineering requirements that were commissioned were all authentic. The process has led to the making of the best of the models that possibly can be. Our final model is better the models that currently exist in the market. The analysis that was done after the model has been finished is a testimony to this fact. This design will serve the client well and it will also be used for other commercial purposes to serve the people that need this exoskeleton.

9.1 Contributions to the project success

The greatest contribution to the success of the project was by teaming that we working with. Every member of the team did play a vital role to the success of the project. We all played different roles in the project with all the roles that were to be played being divided equally among all the members of the team. Among the major roles that have been instrumental to the project success includes the leadership of the team that has guided the project through to this success. The other instrumental role is the technical team of the project. The technical part of the team has helped us to get all the analysis tools that we needed and make CAD models. The other part of the team that has been instrumental is the documentation. This project has been quite a lengthy one that entailed a lot of details. We needed flow of information to be able to make this project to be a success. The documentation team did do a good job in organization of the work such that we always had a work flow in the team. Collectively every team embarked on the success that can be reported at the end of this project.

The other contribution to the project was through the lecturer. The lecturer gave us the analysis tools that we were to use in the project. Most of the knowledge that was used in this project was acquired in the classroom. Without the lessons that we undertook, this project would have been impossible to complete. This project is part of the course work that we had to complete. The contribution of the lecturer is therefore paramount and it led to the success that we did achieve in this project.

The other contribution was by the tutors. They gave us the directives on the points that we failed to meet in the process of executing the project. The tutors also helped us to correct most of the mistakes that we had made in the project. We did submit the project at several stages and they we all analyzed by the tutors. We did correct these mistakes and were able to move on with the project. They also helped us with issues of consultation. We did not have clarity on some of the lessons that we were taught and some of the processes that we had to use for this project.

9.2 Opportunity for improvement

One of the areas that may need improvement in this project is the issue of making a model that has a lesser weight. The total weight of the design that we made is still very high. This makes it to be quite cumbersome to the person that is wearing it and trying to move. The other area of improvement is power optimization. There is need to have the battery to last for a longer period of time. It would be great if we were to have the battery lasting for the entire day. Further, it is necessary to emphasize on a design, which have been improving on their abilities over the past years. As such, this will ensure that the functions of the device are improved in a better manner compared to the previous designs. Therefore, to ensure that the team comes up with a better design, it is necessary to consider the challenges faced by the current designs. Hence, by understanding the drawbacks that faces such designs, it will be possible to formulate a formula to design a system, which will be able to solve all the problems.

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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

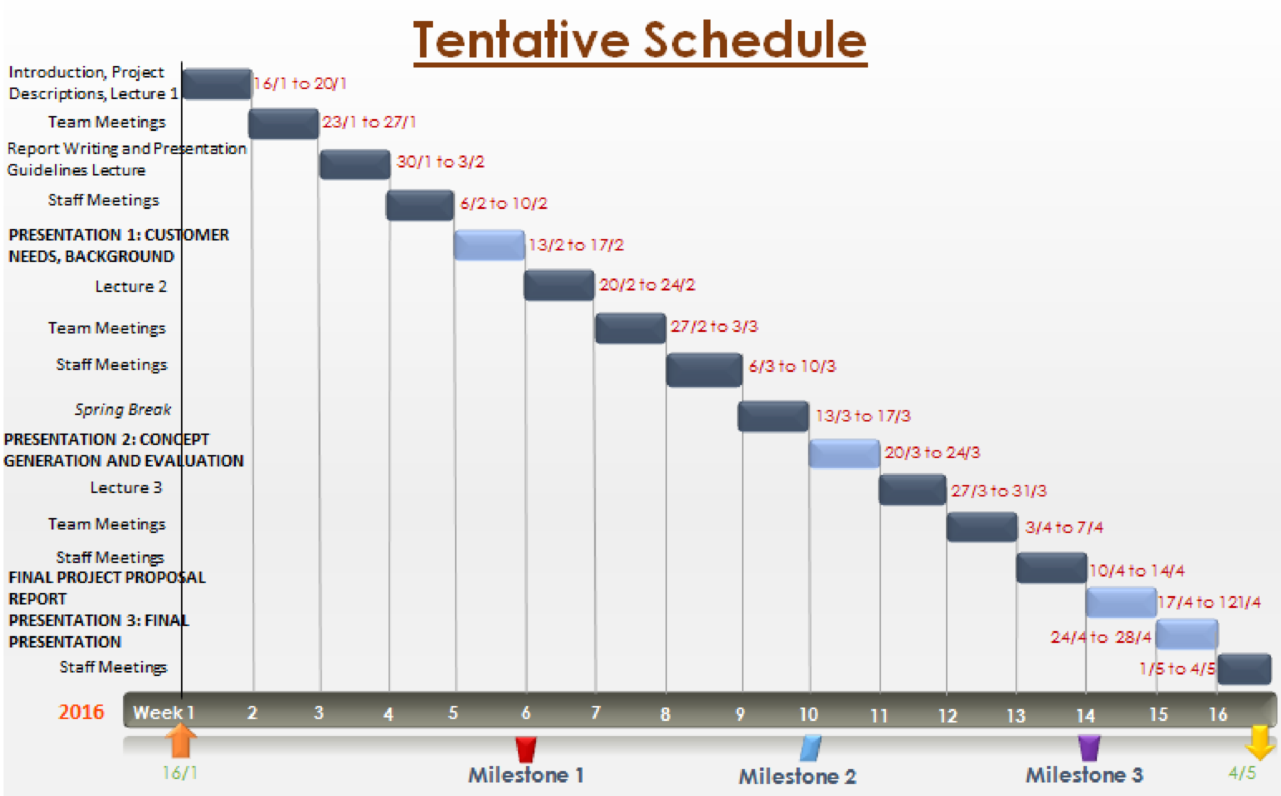


Table 5: Bill of Materials and the Sources

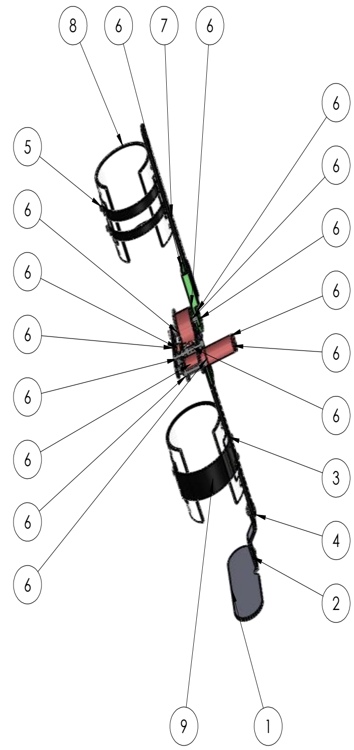
No.	Material	Description	Source	Cost
1	Control circuit board	https://www.circuitspecialists.com/raspberry-pi-3-model-B.html Raspberry Pi 3 Model B https://www.circuitspecialists.com/raspberry-pi-3-model-B.html	https://www.circuitspecialists.com/controllers	$ 35
2	Carbon fiber glass reinforced with stockinet 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

Table 7: The Usage of the Various Materials

No.	Material	Description	Role of the component
1	Control circuit board	https://www.circuitspecialists.com/raspberry-pi-3-model-B.html Raspberry Pi 3 Model B https://www.circuitspecialists.com/raspberry-pi-3-model-B.html	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.

Bill of Materials in CAD

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	foot		1
2	ankel		1
3	new lower leg		1
4	Selected Narrow FW 0.266		1
5	CR-PHMS 0.25-28x0.375x0.375-S		11
6	exo_rev_3_HR		1
7	upper leg new		1
8	thermoplastic		1
9	thermoplastic2		1



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
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