BiOM Prosthesis Adapter – 18F01

Preliminary Report

Abdulla Ghayeb

Ebrahim Hubail

Dominic Kristich

Leah Liebelt

2018-2019

Faculty Advisor: Dr. Zachary Lerner and Kiisa Nishikawa

Mentor: Thomas Huck

Instructor: Dr. Sarah Oman

DISCLAIMER

This report was prepared by students as part of a university course requirement. While considerable effort has been put into the project, it is not the work of licensed engineers and has not undergone the extensive verification that is common in the profession. The information, data, conclusions, and content of this report should not be relied on or utilized without thorough, independent testing and verification. University faculty members may have been associated with this project as advisors, sponsors, or course instructors, but as such they are not responsible for the accuracy of results or conclusions.

TABLE OF CONTENTS

DISCLAIMER i
TABLE OF CONTENTS ii
1 BACKGROUND 1
1.1 Introduction 1
1.2 Project Description 1
1.3 Original System 1
2 REQUIREMENTS 2
2.1 Customer Requirements (CRs) 2
2.2 Engineering Requirements (ERs) 2
2.3 House of Quality (HoQ) 4
3 EXISTING DESIGNS 5
3.1 Design Research 5
3.2 System Level 5
3.2.1 Existing Design #1: Basic Below Knee Prosthesis 5
3.2.2 Existing Design #2: Bone-Anchored Transfemoral Prosthesis 6
3.2.3 Existing Design #3: iWALK 2.0 Hands Free Knee Crutch 7
3.3 Functional Decomposition 7
3.3.1 Black Box Model 7
3.3.2 Functional Model/Work-Process Diagram/Hierarchical Task Analysis 8
3.4 Subsystem Level 9
3.4.1 Subsystem #1: Adjustable Pylon 9
3.4.1.1 Existing Design #1: Bike Seat Adjustment 9
3.4.1.2 Existing Design #2: Hiking Pole Clamp 10
3.4.1.3 Existing Design #3: Height Adjustable Crutch 10
3.4.2 Subsystem #2: Attachment 11
3.4.2.1 Existing Design #1: Crutch Attachment 11
3.4.2.2 Existing Design #2: Descriptive Title 11
3.4.2.3 Existing Design #3: Descriptive Title 12
3.4.3 Subsystem #3: Leg Support 12
3.4.3.1 Existing Design #1: Post-Operation Knee Brace 12
3.4.3.2 Existing Design #2: Descriptive Title 12
3.4.3.3 Existing Design #3: Descriptive Title 12
4 DESIGNS CONSIDERED 13
4.1 Design #1: Three Cuffs Single Crutch 13
4.2 Design #2: Two Straps Hiking Pylon 13
4.3 Design #3: Premium Two Straps Bike Pylon 14
4.4 Design #4: Premium Two Straps Hiking Pylon 15
4.5 Design #5: Basic Tow Cuffs Hiking Pylon 15
4.6 Design #6: Bio Inspired-1 Thread Pylon 16
4.7 Design #7: Two Velcro Straps Slots Pylon 16
4.8 Design #8: Bio Inspired-2 Side Screw Pylon 17
4.9 Design #9: Bio Inspired-3 Telescoping Pylon 17

4.10 Design #10: Three Velcro Straps Double Crutches Pylon 18
5 DESIGN SELECTED – First Semester 19
5.1 Rationale for Design Selection 19
6 REFERENCES 20
7 APPENDICES 21
7.1 Appendix A: Subsystem Pugh Charts 21
7.2 Appendix B: Subsystem Decision Matrices 24
7.3 Appendix C: Final Designs 26

Table of Figures

Figure 1: Orthomedics below Knee Prosthetic [1] 6
Figure 2: U.S. Department of Veteran Affairs Prosthesis [2] 6
Figure 3: iWALK 2.0 Hands Free Knee Crutch [3] 7
Figure 4: Black Box Model 8
Figure 5: Functional Model 9
Figure 6: Hope Quick Release Seat Clamp [5] 10
Figure 7: Trekking Pole Clamp [6] 10
Figure 8: Height Adjustable Crutch [7] 11
Figure 9: Crutch Attachment to Underarm Rest [7] 11
Figure 10: T Scope Premier Post-Op Knee Brace [11] 12
Figure 11: Final Sketch 1 13
Figure 12: Final Sketch 2 14
Figure 13: Final Sketch 3 14
Figure 14: Final Sketch 4 15
Figure 15: Final Sketch 5 15
Figure 16: Final Sketch 6 16
Figure 17: Final Sketch 7 16
Figure 18: Final Sketch 8 17
Figure 19: Final Sketch 9 17
Figure 20: Final Sketch 10 18
Figure 13: Final Sketch 3 19
Figure 11: Final Sketch 1 26
Figure 12: Final Sketch 2 26
Figure 13: Final Sketch 3 27
Figure 14: Final Sketch 4 27
Figure 15: Final Sketch 5 28
Figure 16: Final Sketch 6 28
Figure 17: Final Sketch 7 29
Figure 18: Final Sketch 8 29
Figure 19: Final Sketch 9 30
Figure 20: Final Sketch 10 30

Table of Tables

Table 1: Customer Requirements 2
Table 2: Engineering Requirements 3
Table 3: House of Quality 4
Table 4: Leg Support Pugh Chart 21
Table 5: Pylon Pugh Chart 22
Table 6: Attachment Pugh Chart 23
Table 7: Attachment Decision Matrix 24
Table 8: Pylon Decision Matrix 24
Table 9: Leg Support Decision Matrix 25
Table 10: Final Designs Decision Matrix 25

1 BACKGROUND

1.1 Introduction

This project of BiOM Prosthesis Adapter is objectively designed to make an adapter to be attached to a patient's bent knee. This adapter allows amputee's below-the-knee to connect the limp with the ankle prosthetic, allowing a comfortable and easy usage. The real intention of the project is to be part of the team aiding improvements within the medical field. The other benefits of the project design are; lightweight of less than 1 kg, reduced friction, flexibility in height adjustment up to 15 cm, 30 second attachment, capability of supporting least 180 pounds, socket diameter adjustable in the range of 7-20 cm, reduced cost, high safety factor, and high modulus of elasticity. Upon completion of the project, the stakeholders to benefit will be the below-the-knee amputees, the doctors within the medical field, and the hospitals. The clients for this project are Thomas Huck, Dr. Zachary Lerner, and Kiisa Nishikawa.

1.2 Project Description

The following is the original project description that was provided by Dr. Zachary Lerner. The description involves how benchmarking was done.

> "The previous designs involved an attachment on the outside of the leg. The original design was also a below-the-knee design with major components being the liner, socket, pylon and the foot, and in comparison, to our design of BiOM Prosthesis you will find that it has much more parts. The process of benchmarking involved testing the prosthesis on an individual without amputation.

1.3 Original System

This project involved the design of a completely new BiOM Prosthesis Adapter. There was no original system when this project began.

2 REQUIREMENTS

This chapter will provide the key requirement that must be met from the project. The requirements are categorized into customer requirements and engineering requirements. Under the customer requirements, the project's goals are enumerated. The engineering requirements will help to justify the reliability and durability of the project.

2.1 Customer Requirements (CRs)

What is required from this project is to create a design that is comfortable to the user. The prosthesis should also be quicker than the initial design but in addition to that it should be rigid enough to be attached to the outside of the leg. The project also intends to create a prosthesis which is height adjustable for convenience to the user. The team realized that the original design had limitation of high tare weight and our design intended to cure this limitation by creating a design which is lightweight. The BiOM prosthesis should also be easy to attach on the outside of the leg. The other key considerations are portability, affordability, type of material used, and the safety of the device. The list of customer requirements, as well as their weight of importance can be found in Table 1.

Table 1: Customer Requirements

Customer Requirements	Importance Weight
Lightweight	5
Comfortable	4
Quick Attachment	3
Adjustable	5
Durable	5
Portable	5
Affordable	4
Not Dangerous	5

2.2 Engineering Requirements (ERs)

Under this scope, the engineering requirements, found in Table 2, are those that are verifiable, measurable and objective. These requirements should also contain a specific target and a justification or rationale of the target selected together with the tolerance. The first parameter that should be considered is that the weight of the design should be less than 1 kg. The friction generated from the device needs to be very minimal so as to enhance comfort. The duration of attaching the device to the outside of the leg has also been designed to be around half a minute. The limit of adjusting the height of the prosthesis has also been set at 15 cm while the diameter is adjustable for up to 7-20 cm. Weight is a very key engineering component and the allowable weight supported by the device is set at 180 lbs. The minimization of cost is achieved through consideration of all engineering design requirements. The safety factor should be high, and this is achieved through proper engineering design. The modulus of elasticity of the device should be high because this requirement indicates the level of resistance it has against deformation whenever any stress is applied to it. The higher the modulus the stiffer the device but this should also not compromise on the safety and weight.

Table 2: Engineering Requirements

	kg	≤ 0.3	sec	cm	cm	N	$	unitless	GPa
	<1	N/A	<30sec	<15	7<>20	>800	N/A	3	>70
Engineering Requirements	Weight	Friction from Socket	Attach/Detach Time	Adjustment Height Range	Diameter of Socket	Applied Force	Cost	Factor of Safety	Modulus of Elasticity

2.3 House of Quality (HoQ)

The House of Quality, found in Table 3, defines the relationship between the customer requirements and the capability of the engineering requirements meeting the client's requirements. This chart will help to set out a limit on the extent to which the customer requirements can be met. Weights are given to each and every customer require according to its importance. From this the team can see that the large score given 5 which means that weight, safety, durability, adjustability and portability are key requirements while the least considered requirement is the speed of attachment. A target value for each engineering requirement is provided. For example, it is required that the net weight of the device should be less than 1 kg and the cost is not given a target value. The resistance of the device to any kind of deformation, as indicated by modulus of elasticity, is set as less than 70 gigapascals (GPa). Rank of importance is also given for each engineering requirement; the most important requirements are cost and safety factor while friction from socket and speed of attachment are least considered. This importance is categorized into those that are absolute and relative. Tolerance of each target is provided because some customer requirements also depend on the tolerance of engineering requirements.

Table 3: House of Quality

Customer Requirements / **Engineering Requirements**	**Weight**	Weight	Friction from Socket	Attach/Detach Time	Adjustment Height Range	Diameter of Socket	Applied Force	Cost	Factor of Safety	Modulus of Elasticity
Lightweight	5	9					3	3	3	
Comfortable	4		9					1	3	
Quick Attachment	3			9						
Adjustable	5			3	9	9		3	3	
Durable	5	3					9	3	9	9
Portable	5	3			3	3				
Affordable	4	1	3		1	1		9		3
Not Dangerous	5						1		9	1
Units		kg	unitless	sec	cm	cm	N	$	unitless	GPa
Target Value		<1	N/A	<30sec	<15	7<>20	>800	N/A	3	>70
Absolute Technical Importance		79	48	42	64	64	60	85	87	57
Relative Technical Importance		15%	9%	8%	12%	12%	11%	16%	16%	11%
Rank Order of Importance		2	5	6	3	3	4	1	1	4

3 EXISTING DESIGNS

This chapter begins with the research of existing designs related to the prosthesis adapter that the team will be designing. The research aided in furthering the knowledge of the team in the prosthetic field. Following the research of existing designs, the team managed the functional decomposition which includes a black box model and functional model. Once the function of the system was understood, research on the subsystem level began. This allowed the team to evaluate the system in several components to assist with brainstorming potential designs which can be found in chapter 4 of this report.

3.1 Design Research

Section 3.1 includes the research that was conducted using the benchmarking method. Using Google as the search engine, as well as Google Scholar, below knee amputee prosthesis' and leg supports were researched in order to compare the design requirements of the project to existing designs. The main focus when executing this research was finding quantifiable specifications, designs that create a fundamental understanding of the prosthesis the team will be designing, and/or designs that have different elements that could be implemented in the team's original design. The research of these existing designs also aided in creating the functional decomposition found in section 3.3, as well as team brainstorming which is discussed in section 4. Although benchmarking does not give the team extensive knowledge of the prosthetic field, it allows the team to see what designs have worked in the past and have been implemented successfully. Extensive research and technical analysis will be required in the future to gain a better understanding of what designs would be successful, but this benchmarking helped inspire creativity in the brainstorming and design process.

3.2 System Level

This section of the report includes existing designs related to the prosthesis adapter that the team will be designing. The benchmarking method used in this section helped the team further their knowledge on past and current prosthesis designs for below-the-knee amputees. The research of existing designs will be compared to the customer and engineering requirements to allow for a better understanding of prosthetics when brainstorming for the design process begins.

3.2.1 Existing Design #1: Basic Below Knee Prosthesis

The below knee prosthetic leg shown in Figure 1 is a basic design that includes a liner, socket, pylon, and the prosthetic foot. Orthomedics gives customers a prosthetist who determines a socket design, suspension system, and a type of prosthetic foot depending on body type, personal preference, and activity. This resource is relevant in terms of understanding the basic design of a below knee prosthesis. The liner and socket type are what assist with comfort for the user, and the pylon, depending on the material used, allows for a rigid support that is durable.

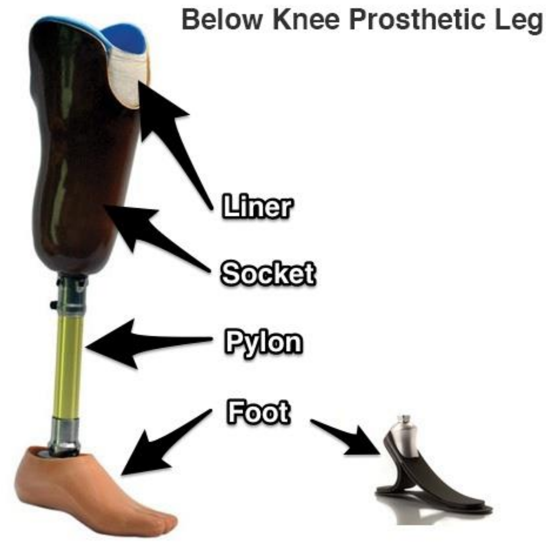


Figure 1: Orthomedics below Knee Prosthetic [1]

3.2.2 Existing Design #2: Bone-Anchored Transfemoral Prosthesis

The two prostheses shown in Figure 2Figure 2: U.S. Department of Veteran Affairs Prosthesis [2] were designed by the U.S. Department of Veteran Affairs. The designs are complex and are, in fact, anchored into an amputee's stump. These designs are useful because the documentation includes analysis for measuring the load applied to the knee, foot, and more. This analysis shows that the designs are not only durable and reliable but provides an idea of the analysis that will be conducted in the prototyping stage of the project. Attachment is surgical, therefore not a quick attachment, and the weight of each prosthesis exceeds the weight limit for the design requirements, but the designs show how different aspects of a prosthesis design can affect maximum loading that can be applied to the prosthesis.

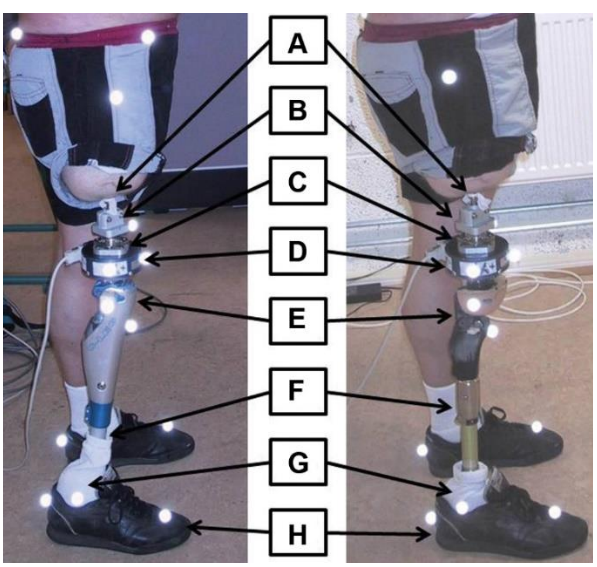


Figure 2: U.S. Department of Veteran Affairs Prosthesis [2]

3.2.3 Existing Design #3: iWALK 2.0 Hands Free Knee Crutch

The design shown in Figure 3 is not a prosthetic, but it relates to several design requirements discussed in chapter 2. The iWALK allows the user with a leg injury to walk without the pain and inconvenience of crutches or scooters. The main difference between this design and a prosthesis is that this knee crutch design is for injured persons, not amputees, but that difference is negligible. This knee crutch design is height adjustable, portable, durable, easy to put on and take off, somewhat comfortable, and is affordable.

Figure 3: iWALK 2.0 Hands Free Knee Crutch [3]

3.3 Functional Decomposition

The BiOM Prosthesis Adapter's main function is to help stabilize a person, so they are able to stand and walk with the assistance of adapter and prosthesis device. This device is to be designed for a fully-abled person so the device can be tested during the testing phase. The BiOM Prosthesis Adapter is to have three main subsystems -- pylon, attachment, and leg support -- and will be attached to the ankle prosthesis device when completed. When the device is in use, it will require the fully-abled person who is testing the ankle prosthesis device to attach their leg to the adapter to support themselves.

3.3.1 Black Box Model

Before brainstorming concepts for a possible BiOM Prosthesis Adapter, the team needed to have a rough idea of what the device needed to accomplish. This included knowing what would go into the system, what the system will ultimately be able to accomplish, and what is expelled from the system while the device is working. The team had decided to show this in a black box model shown in Figure 4. The black box model was used to simplify the adapter into material subsystems, energy, and signals. The material subsystems that go into the adapter design include the pylon, leg support, and attachment for the leg support and pylon, a human leg to power the system, and an ankle prosthesis to stabilize the system. The energy required to make the system work was human energy since this device is to be simple and include no other energies. The signal to show that the system was ready to work was a visual signal of the all the subsystem materials attached to one another and the person's leg attached to the subsystems. All of these inputs were combined to ultimately stabilize the person. The outputs of the device had to include the BiOM Prosthesis Adapter and Ankle Prosthetic attached together while using human and kinetic energy to help transport the person into forward moving motion, with a visual signal of movement.

The Black Box Model helped the team simplify the design, so concepts would be able to be discussed. The simpler the inputs and outputs of the design, the more creative concepts could be created. These ideas were just a baseline for the team to start brainstorming.

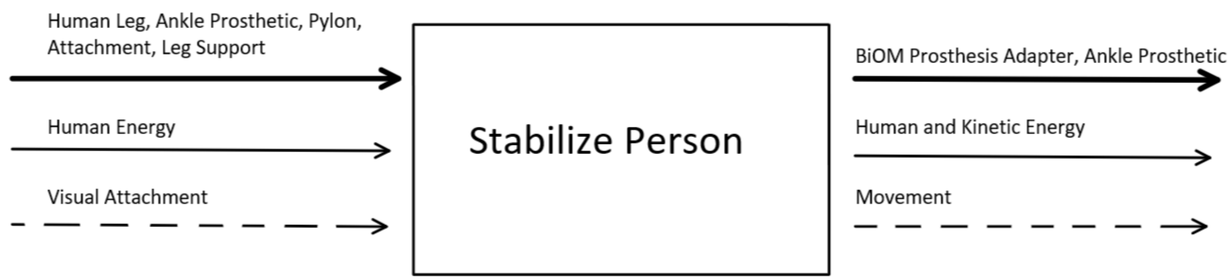


Figure 4: Black Box Model

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

After the Black Box Model was made and the device was stripped down into the simplest of tasks, a Functional Model, shown in Figure 5, was drafted to split up the different subsection materials, energy, and signals to see how the parts intact with one another before, during, and after operation. As shown previously in the Black Box Model, the Functional Model has the same inputs such as human energy, and all the subsystem materials such as the pylon, leg support, the attachment for the leg support and pylon, the ankle prosthetic, and a human leg. These subsystem materials were combined together using human energy to secure the adapter together, which included the pylon, leg support, and attachment, secure the ankle prosthesis onto the adapter, and secure the leg onto the leg support located on the adapter. Once the materials were secure, human energy was used to actuate the BiOM Prosthesis Adapter and the ankle prosthetic, which then supported movement through the use of human and kinetic energy. This created a visual signal that indicated movement and had an output of the BiOM Prosthesis Adapter and ankle prosthesis.

The Functional Model helped the team understand the system more in depth, and how different subsystems reacted with the different energies to produce a functioning prosthesis device. This was integral to the team's concept design due to understanding the system in depth before deciding what concepts would be ideal for this specific device. Concepts had to be brainstormed through the use of the functional model to help guide concepts. If the concepts brainstormed matched with what was to be put into the system and what was to come out of the system along with simply being able to secure all the subsystem material, transfer energy, and actuate the device so it could support movement, then that concept would ideally work for the device.

After the functional model was built and discussed, the team came up with concepts for the BiOM Prosthesis Adapter which is discussed in the next section.

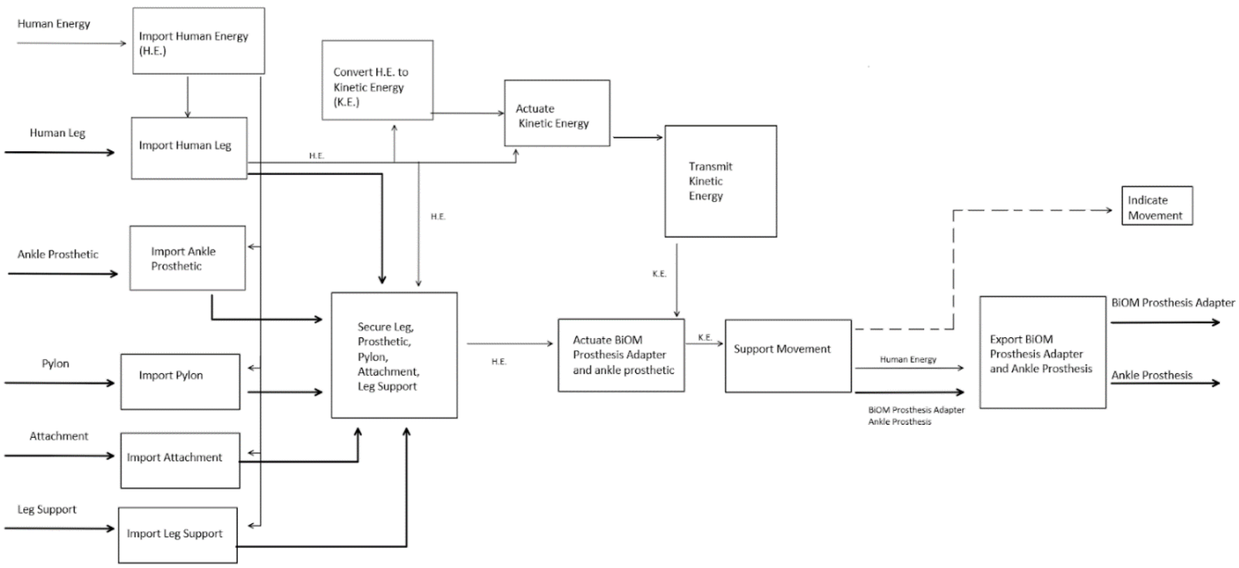


Figure 5: Functional Model

3.4 *Subsystem Level*

This section includes the research of existing designs that relate to the subsystem level. This research allowed the team to better understand the subsystems influence on the overall system and learn about existing designs related to each subsystem.

3.4.1 Subsystem #1: Adjustable Pylon

The pylon will be most relevant for the stability of the system. Although the material of the pylon is important, research on material options will be performed during the technical analysis portion of the project. The research completed for the pylon subsystem in this section will focus on different methods that can be used for adjusting the pylon while maintaining the integrity of the subsystem.

3.4.1.1 Existing Design #1: Bike Seat Adjustment

Reference [4] used in this section for describing this part.

http://hub.chainreactioncycles.com/buying-guides/components/seat-clamps-buying-guide/

[Describe this subsystem-level existing design and explain how it relates to your requirements.]

Figure 6: Hope Quick Release Seat Clamp [5]

3.4.1.2 Existing Design #2: Hiking Pole Clamp

[6] https://patents.google.com/patent/US8006711B2/en

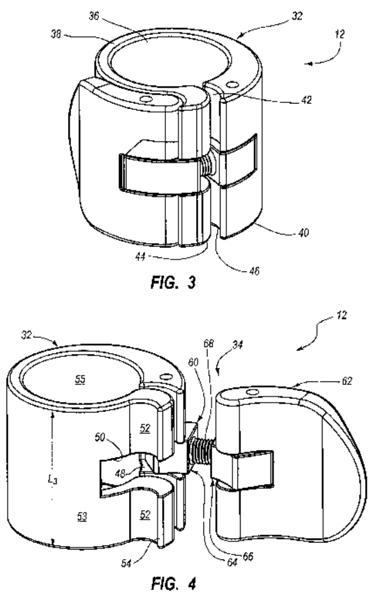


Figure 7: Trekking Pole Clamp [6]

[Describe this subsystem-level existing design and explain how it relates to your requirements.]

3.4.1.3 Existing Design #3: Height Adjustable Crutch

[7] https://patents.google.com/patent/US4509741A/en

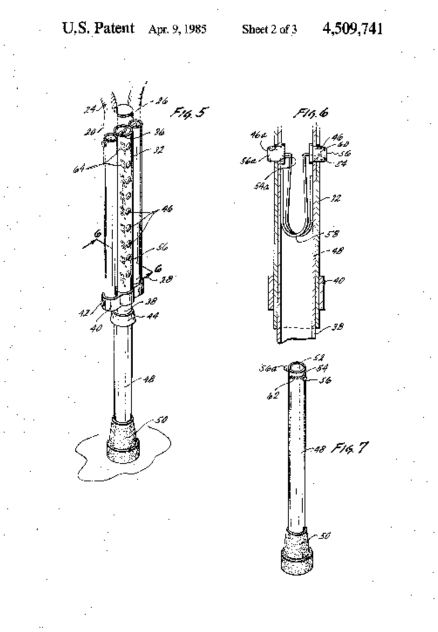


Figure 8: Height Adjustable Crutch [7]

[Describe this subsystem-level existing design and explain how it relates to your requirements.]

3.4.2 Subsystem #2: Attachment

The primary role of the attachment is to connect the pylon to the leg support. The attachment will need to be rigid, have equal distribution throughout the knee, and not compromise comfortability. The attachment is essentially the connector for the other two subsystems that the team is analyzing.

3.4.2.1 Existing Design #1: Crutch Attachment

[7]

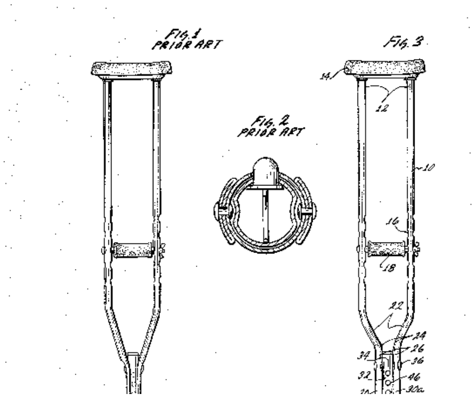


Figure 9: Crutch Attachment to Underarm Rest [7]

[Describe this subsystem-level existing design and explain how it relates to your requirements.]

3.4.2.2 Existing Design #2: Descriptive Title

[8]

[Describe this subsystem-level existing design and explain how it relates to your requirements.]

3.4.2.3 *Existing Design #3: Descriptive Title*

[9]

[Describe this subsystem-level existing design and explain how it relates to your requirements.]

3.4.3 Subsystem #3: Leg Support

The leg support subsystem is responsible for supporting the leg of the person who is testing the BiOM ankle prosthesis. The support must be able to help to leg maintain fixed once the device is put on, and at the same time, be comfortable.

[Describe this subsystem from your functional decomposition. Discuss why this subsystem is important to your overall project.]

[Include in Preliminary Report and all subsequent reports.]

3.4.3.1 *Existing Design #1: Post-Operation Knee Brace*

[10]

Figure 10: T Scope Premier Post-Op Knee Brace [11]

[Describe this subsystem-level existing design and explain how it relates to your requirements.]

3.4.3.2 *Existing Design #2: Descriptive Title*

[11]

[Describe this subsystem-level existing design and explain how it relates to your requirements.]

3.4.3.3 *Existing Design #3: Descriptive Title*

[12]

[Describe this subsystem-level existing design and explain how it relates to your requirements.]

4 DESIGNS CONSIDERED

To determine possible concepts to fit the scope of the project, the team used a modified 4-3-5 method to generate ideas based on the updated customer and engineering requirements. Each group member had to come up with three subsystems sketched individually. Everyone could then pass it to the next person to come up with their own three new subsystems or edit the sketches they had received. From beginning to end of the concept generation, the team had managed to come up with a total of twenty-four sketches, three of which are bio-inspired.

After completing the cycle, the team had set up a Pugh chart and decision matrix utilizing the customer requirements as the criterion to grade the sketches. The team kept in mind the customer requirements to make sure the designs were customer oriented and would satisfy the client. However, not all the customer requirements were applied to all the subsystems. Using the decision matrix, the team evaluated the design that would yield the maximum utilization to the customer, which meant to choose designs that had positive marks. As an example, one of the customer requirements was to construct a design for the customer to use comfortably. This criterion was applied on the subsystem that has contact with the body of the user.

4.1 Design #1: Three Cuffs Single Crutch

Figure 11 shown was the first design considered. It had high durability because the pylon was designed like crutches, so it could support the human body. Moreover, it is stable because the attachment was constructed to distribute the force applied. On the other hand, it required time to adjust the attachment, the angle of the leg support, and finally tie the three straps to secure the leg. Because the design had precise adjustment, it added to the weight and it made the design heavier than the other possible designs.

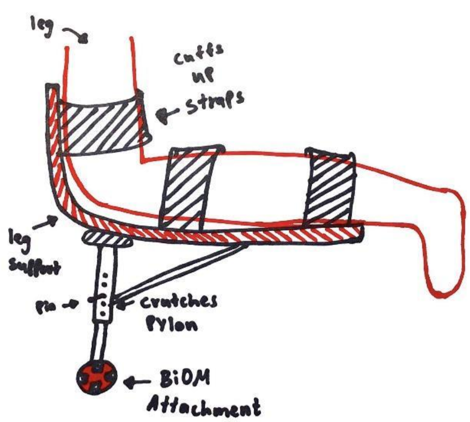


Figure 11: Final Sketch 1

4.2 Design #2: Two Straps Hiking Pylon

Figure 12 showed the second design looked at which was a lightweight design because it has less adjustable parts while also being durable and precise. On the other hand, it would take more time to adjust since it must be adjusted manually. Moreover, the design is not comfortable enough because the leg support had only one state, which was not adjustable.

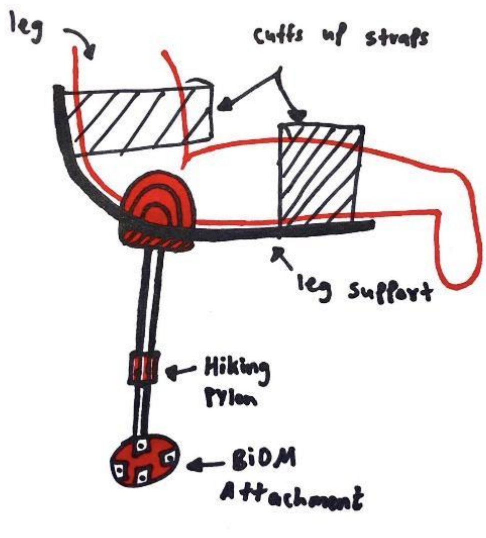


Figure 12: Final Sketch 2

4.3 Design #3: Premium Two Straps Bike Pylon

Figure 13 showed design 3, which had an adjustable lever similar to bike seats, this decreased the time to adjust the pylon into the right height and could hold a person as it has been in previous bicycle designs. The leg support has an extended bar to distribute the force applied and improve stability at the same time, this part controlled the angle. The leg support was designed to have memory foam that provided comfort for the user. The only disadvantage of this design was the added weight from the rigid bar and memory foam.

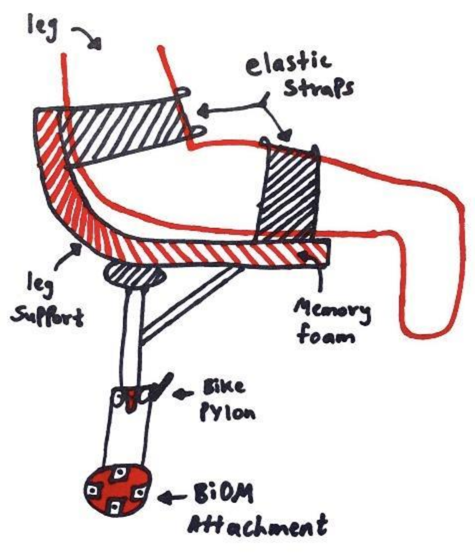


Figure 13: Final Sketch 3

4.4 Design #4: Premium Two Straps Hiking Pylon

Figure 14 showed the fourth design considered which was constructed to be lightly weighted as it didn't have many functions. The pylon was designed to be precise but would take time to adjust. The memory foam in the leg support helped improve the comfort in the design yet, the leg support is fixed in one setup, so the user would not be able to control the angle. Finally, the two straps were designed to have quick attachment.

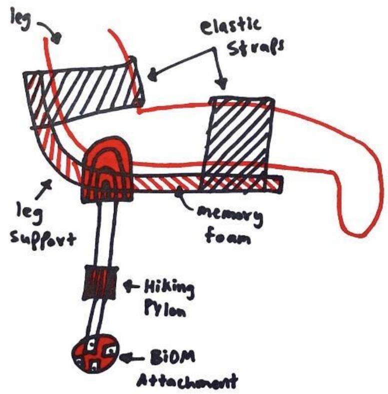


Figure 14: Final Sketch 4

4.5 Design #5: Basic Tow Cuffs Hiking Pylon

Figure 15 showed the fifth design which was lightweight and had quick attachment, although the leg support was not as comfortable as other designs. The leg support was adjustable in angle, and the attachment bar could improve the stability.

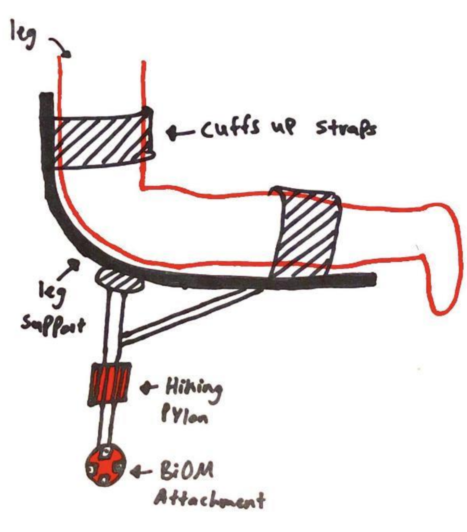


Figure 15: Final Sketch 5

4.6 Design #6: Bio Inspired-1 Thread Pylon

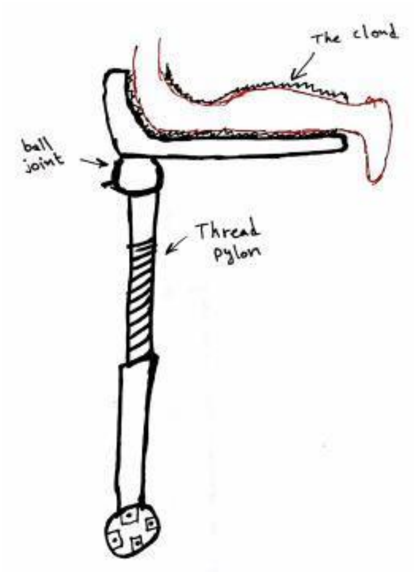


Figure 16: Final Sketch 6

The design is constructed as a light weight and the cloud improves the comfortability of the design. The ball joint makes it easy and movable easily and it enhances the mobility of this design. The thread pylon is relatively long to improve stability. However, this design does not have a memory lane.

4.7 Design #7: Two Velcro Straps Slots Pylon

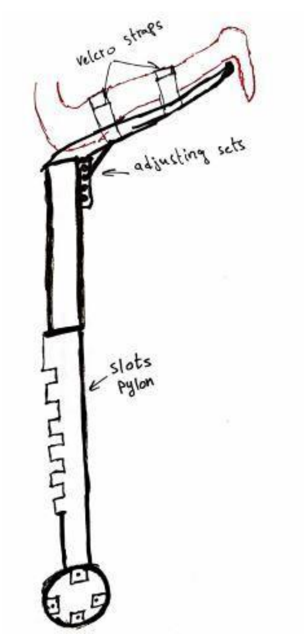


Figure 17: Final Sketch 7

This design is built to improve the comfortability of the leg and can be adjusted easily to make sure that the leg is comfortable. The leg is not much movable and thus helps it not to hurt. However, this design is relatively heavier compared with other designs.

4.8 Design #8: Bio Inspired-2 Side Screw Pylon

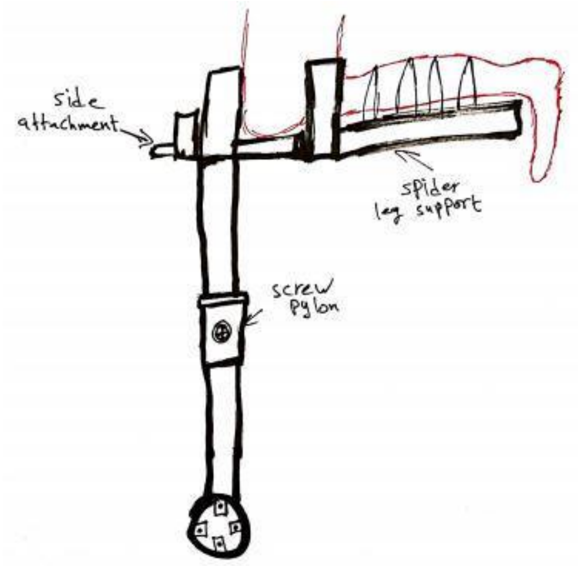


Figure 18: Final Sketch 8

This design is heavy but very comfortable among other. The screw pylon helps in adjusting the design up and down thus making very movable. It also allows sideways adjustment and the client can put in whatever angle he or she desires.

4.9 Design #9: Bio Inspired-3 Telescoping Pylon

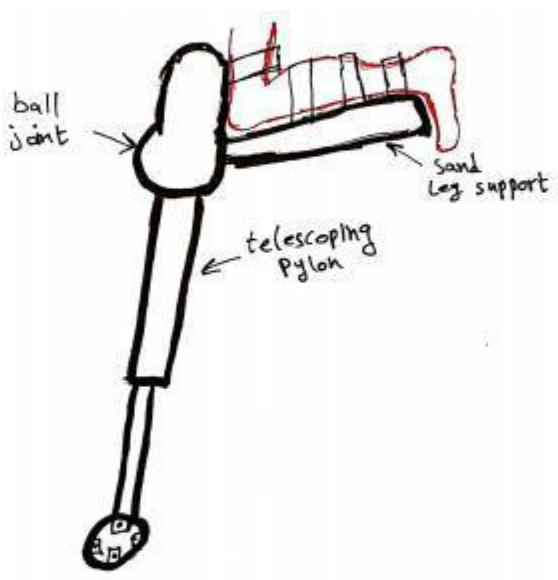


Figure 19: Final Sketch 9

This design is light and comfortable and highly movable. It allows change of position of the leg and the client can as well adjust it in any angle. The telescoping pylon is very comfortable, and it also allows up and down adjustment.

4.10 Design #10: Three Velcro Straps Double Crutches Pylon

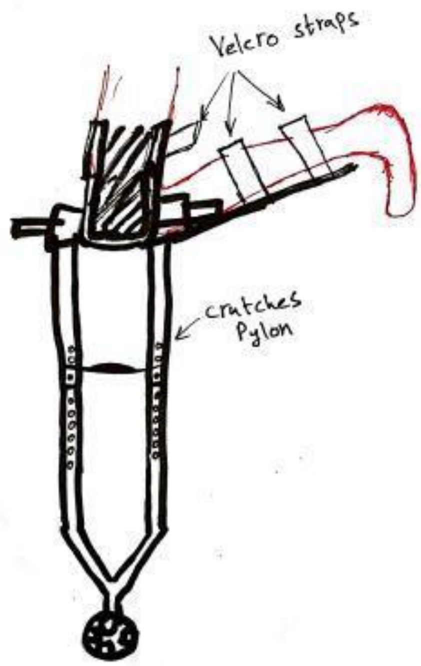


Figure 20: Final Sketch 10

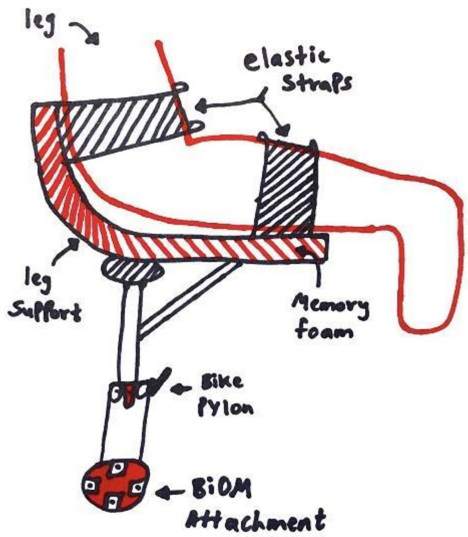
This design is among the most suitable designs however heavy. Usually the leg is comfortable, but it is not well movable like other designs. The crutches help the leg to stay in position and helps it not to hurt.

5 DESIGN SELECTED – First Semester

This chapter will provide detailed information on the best design which team will implement. The engineering and customer requirements that were critically analyzed for each of the ten designs are; safety, cost, comfort, modulus of elasticity, durability, quick attachment, lightweight, and stability amongst others. Decision matrix and Pugh Chart was largely used in the selection of the best design. Design three has the best combinations of these requirements, and it will be the focus of chapter 5.

5.1 Rationale for Design Selection

After considering each of these five designs carefully, the team came to a decision to choose design three as the winning design, shown in **Error! Reference source not found.**. The design is very adjustable, and this increases the level of comfort ability to the user. The team therefore considered the design that will be most suitable for the user and the one that will be most likable.



.

Figure 21: Final Sketch 3

6 REFERENCES

[1] “Prosthetics,” *Prosthetics - OrthoMedics Orthotic & Prosthetic Services | Omaha, Nebraska*. [Online]. Available: https://www.orthomedics.us/services. [Accessed: 17-Sep-2018].

[2] L. Frossard, E. Haggstrom, K. Hagberg, and R. Branemark, “Load applied on bone anchored transfemoral prosthesis: Characterization of a prosthesis: A pilot study,” *The Journal of Rehabilitation Research and Development*, vol. 50, no. 5, p. 619, 2013.

[3] iWALK Free. (2018). *Crutches: Introducing the iWALK 2.0 Hands Free Crutch*. [online] Available at: https://iwalk-free.com/product-introduction/#problem [Accessed 19 Oct. 2018].

[4] Hub.chainreactioncycles.com. (2018). *Seat Clamps buying guide - Chain Reaction Cycles*. [online] Available at: http://hub.chainreactioncycles.com/buying-guides/components/seat-clamps-buying-guide/ [Accessed 19 Oct. 2018].

[5] Chainreactioncycles.com. (2018). *Hope Seat Clamp & QR | Chain Reaction Cycles*. [online] Available at: http://www.chainreactioncycles.com/us/en/hope-seat-clamp-qr/rp-prod80495 [Accessed 19 Oct. 2018].

[6] Patents.google.com. (2018). *US8006711B2 - Trekking pole clamp and methods - Google Patents*. [online] Available at: https://patents.google.com/patent/US8006711B2/en [Accessed 19 Oct. 2018].

[7] Patents.google.com. (2018). *US4509741A - Height adjustable crutch - Google Patents*. [online] Available at: https://patents.google.com/patent/US4509741A/en [Accessed 19 Oct. 2018].

[8]

[9]

[10] Breg, Inc. (2018). *T Scope® Premier Post-Op Knee Brace – Breg, Inc.*. [online] Available at: https://www.breg.com/products/knee-bracing/post-op/t-scope-premier-post-op-knee-brace/ [Accessed 19 Oct. 2018].

[11]

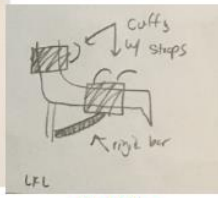
[12]

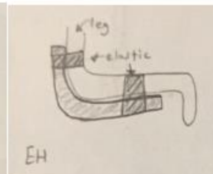
[13]

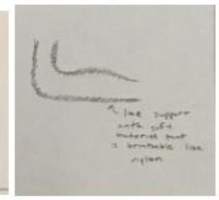
7 APPENDICES

7.1 Appendix A: Subsystem Pugh Charts

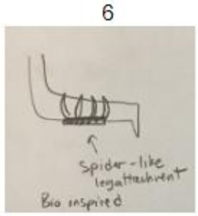
Table 4: Leg Support Pugh Chart

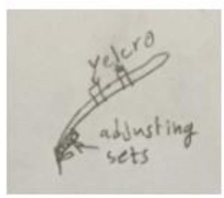


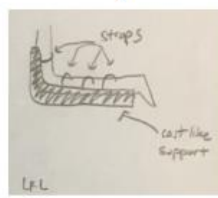




Criteria	DATUM (1) DATUM	2 Rigid Bar	3 El Hefe	4 Ball/Joint	5 The Cloud
Safety	0	0	0	-1	-1
Durable	0	1	1	-1	-1
Light Weight	0	0	-1	1	1
Adjustable	0	0	0	0	0
Quick Attachment	0	1	1	0	0
Comfortable	0	0	1	1	1
Number better: S+	+0	+2	+3	+2	+2
Number worse: S-	0	0	-1	-2	-2
Number same: S0	6	4	2	2	2

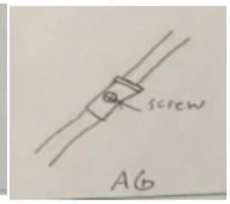


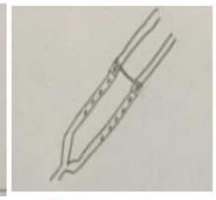
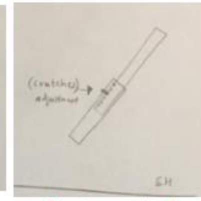
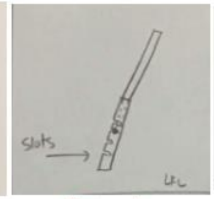




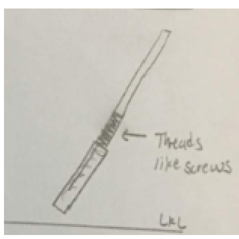
Criteria	6 The Spider	7 Straps	8 The Cast	9 Bowl of Sand
Safety	-1	0	1	-1
Durable	0	0	1	0
Light Weight	-1	1	-1	-1
Adjustable	1	1	0	-1
Quick Attachment	0	0	0	-1
Comfortable	0	0	0	1
Number better: S+	+1	+2	+2	+1
Number worse: S-	-2	0	-1	-4
Number same: S0	3	4	3	1

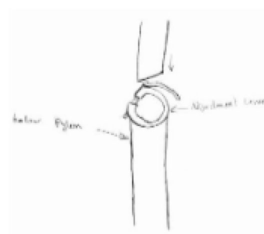
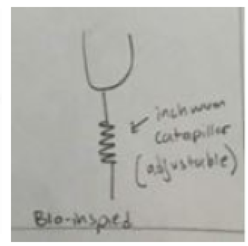
Table 5: Pylon Pugh Chart



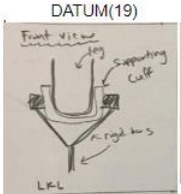
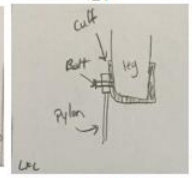
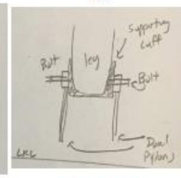
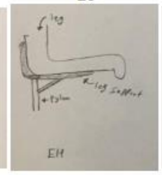
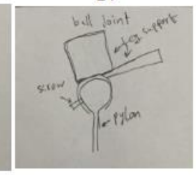
	DATUM(10)	11	12	13	14
Criteria	Telescoping rod pylon	Screw pylon	Crutches pylon	Crutches pylon2	Slots pylon
Safety	0	1	1	1	0
Durable	0	1	1	0	1
Light Weight	0	0	-1	0	0
Adjustable	0	0	-1	-1	-1
Quick Attachment	0	-1	-1	-1	0
Stable	0	1	1	0	0
Quick Adjustment	0	0	0	0	1
Number better: S+	+0	+3	+3	+1	+2
Number worse: S-	0	-1	-3	-2	-1
Number same: S0	7	3	1	4	4



	15	16	17	18
Criteria	Thread pylon	Hiking pylon	Bike pylon	Catapiller pylon
Safety	-1	1	1	-1
Durable	0	0	1	0
Light Weight	0	1	1	0
Adjustable	1	1	1	0
Quick Attachment	0	0	0	1
Stable	-1	1	1	-1
Quick Adjustment	1	1	1	0
Number better: S+	+2	+5	+6	+1
Number worse: S-	-2	0	0	-2
Number same: S0	3	2	1	4

Table 6: Attachment Pugh Chart

	DATUM(19)	20	21	22	23	24
						
Criteria	DATUM	Under Knee	Parallel	Double up	Truss	Ball Joint
Safety	0	-1	0	1	1	0
Durable	0	0	0	1	1	0
Light Weight	0	1	1	-1	0	0
Quick attachment	0	-1	1	0	1	-1
Stable	0	-1	0	1	1	0
Number better: S+	+0	+1	+2	+3	+4	+0
Number worse: S-	0	-3	0	-1	0	-1
Number same: S0	5	1	3	1	1	4

7.1.1 *Appendix B: Subsystem Decision Matrices*

Table 7: Attachment Decision Matrix

SET 1		Sketch 19		Sketch 20		Sketch 21	
Criteria	Weight (%)	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score
Safety	25%	40	10	60	15	30	7.5
Durable	17%	40	6.8	60	10.2	40	6.8
Quick Attachment	15%	20	3	50	7.5	60	9
Lightweight	18%	40	7.2	60	10.8	50	9
Stability	25%	50	12.5	20	5	60	15
Total	**100%**		**39.5**		**48.5**		**47.3**

SET 1		Sketch 22		Sketch 23		Sketch 24	
Criteria	Weight (%)	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score
Safety	25%	80	20	90	22.5	60	15
Durable	17%	50	8.5	60	10.2	70	11.9
Quick Attachment	15%	60	9	70	10.5	30	4.5
Lightweight	18%	60	10.8	50	9	60	10.8
Stability	25%	70	17.5	80	20	40	10
Total	**100%**		**65.8**		**72.2**		**52.2**

Table 8: Pylon Decision Matrix

SET 2		Sketch 10		Sketch 11		Sketch 12		Sketch 13		Sketch 14	
Criteria	Weight (%)	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score
Safety	23%	50	11.5	60	13.8	100	23	75	17.25	20	4.6
Durable	25%	20	5	50	12.5	90	22.5	60	15	30	7.5
Lightweight	20%	90	18	80	16	70	14	80	16	70	14
Adjustable	22%	80	17.6	20	4.4	70	15.4	95	20.9	85	18.7
Quick attachment	10%	80	8	50	5	60	6	70	7	55	5.5
Total	**100%**		**60.1**		**51.7**		**80.9**		**76.15**		**50.3**

SET 2		Sketch 15		Sketch 16		Sketch 17		Sketch 18	
Criteria	Weight (%)	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score
Safety	23%	40	9.2	90	20.7	100	23	20	4.6
Durable	25%	30	7.5	60	15	70	17.5	35	8.75
Lightweight	20%	90	18	90	18	90	18	70	14
Adjustable	22%	75	16.5	80	17.6	90	19.8	20	4.4
Quick attachment	10%	85	8.5	80	8	80	8	75	7.5
Total	**100%**		**59.7**		**79.3**		**86.3**		**39.25**

Table 9: Leg Support Decision Matrix

SET 3		Sketch 1		Sketch 2		Sketch 3		Sketch 4		Sketch 5	
Criteria	Weight (%)	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score
Safety	15%	60	9	90	13.5	100	15	30	4.5	40	6
Durable	15%	50	7.5	80	12	90	13.5	50	7.5	30	4.5
Lightweight	10%	80	8	70	7	40	4	100	10	80	8
Adjustable	19%	60	11.4	40	7.6	50	9.5	80	15.2	0	0
Quick Attachment	19%	40	7.6	80	15.2	90	17.1	70	13.3	30	5.7
Comfortable	22%	80	17.6	80	17.6	90	19.8	90	19.8	100	22
Total	**100%**		**61.1**		**72.9**		**78.9**		**70.3**		**46.2**

SET 3		Sketch 6		Sketch 7		Sketch 8		Sketch 9	
Criteria	Weight (%)	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score
Safety	15%	40	6	80	12	80	12	20	3
Durable	15%	60	9	75	11.25	80	12	30	4.5
Lightweight	10%	90	9	25	2.5	30	3	10	1
Adjustable	19%	40	7.6	90	17.1	75	14.25	85	16.15
Quick Attachment	19%	80	15.2	85	16.15	85	16.15	50	9.5
Comfortable	22%	70	15.4	70	15.4	90	19.8	80	17.6
Total	**100%**		**62.2**		**74.4**		**77.2**		**51.75**

7.1.2 Appendix B: Final Design Sketches Decision Matrix

Table 10: Final Designs Decision Matrix

SET 1		Final Sketch 1		Final Sketch 2		Final Sketch 3		Final Sketch 4		Final Sketch 5	
Criteria	Weight (%)	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score
Safety	17%	80	13.6	70	11.9	80	13.6	60	10.2	80	13.6
Durable	15%	85	12.75	75	11.25	90	13.5	70	10.5	75	11.25
Quick Attachment	10%	60	6	70	7	70	7	70	7	70	7
Lightweight	16%	30	4.8	50	8	40	6.4	70	11.2	70	11.2
Stable	13%	70	9.1	50	6.5	75	9.75	50	6.5	70	9.1
Adjustable	14%	90	12.6	75	10.5	80	11.2	80	11.2	75	10.5
Comfortable	15%	80	12	60	9	90	13.5	90	13.5	75	11.25
Total	100%		70.85		64.15		74.95		70.1		73.9

SET 1		Final Sketch 6		Final Sketch 7		Final Sketch 8		Final Sketch 9		Final Sketch 10	
Criteria	Weight (%)	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score
Safety	17%	40	6.8	25	4.25	60	10.2	60	10.2	70	11.9
Durable	15%	45	6.75	30	4.5	70	10.5	55	8.25	75	11.25
Quick Attachment	10%	10	1	55	5.5	40	4	40	4	50	5
Lightweight	16%	80	12.8	50	8	70	11.2	10	1.6	25	4
Stable	13%	30	3.9	20	2.6	50	6.5	60	7.8	90	11.7
Adjustable	14%	55	7.7	40	5.6	50	7	70	9.8	45	6.3
Comfortable	15%	60	9	45	6.75	60	9	80	12	70	10.5
Total	100%		47.95		37.2		58.4		53.65		60.65

7.2 Appendix C: Final Designs

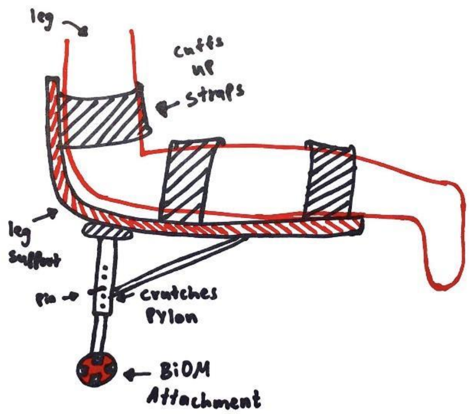


Figure 22: Final Sketch 1

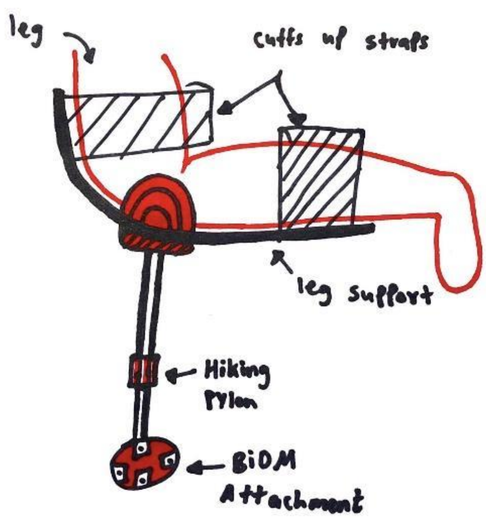


Figure 23: Final Sketch 2

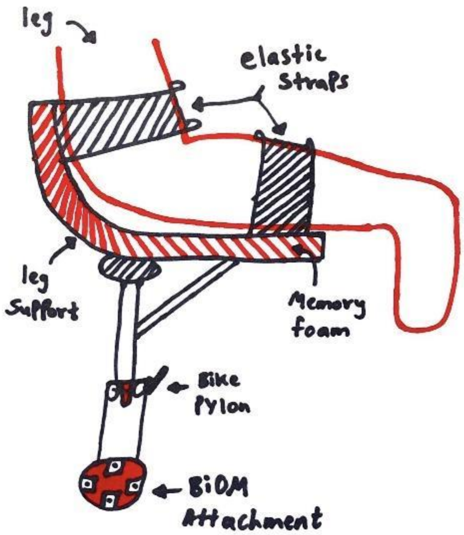


Figure 24: Final Sketch 3

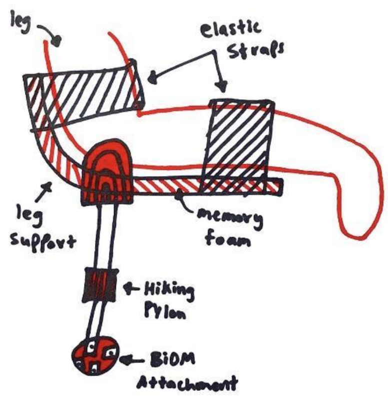


Figure 25: Final Sketch 4

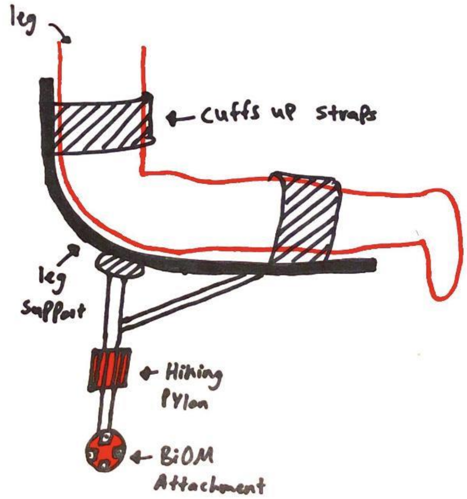


Figure 26: Final Sketch 5

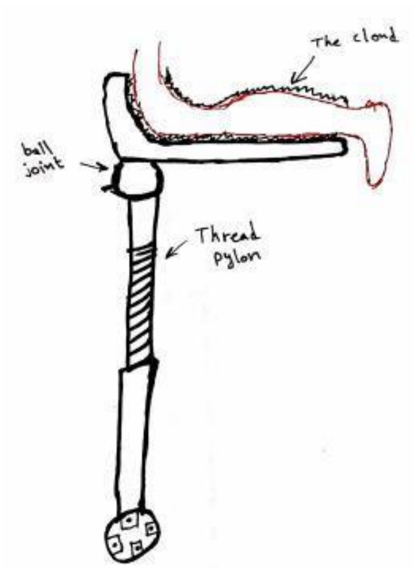


Figure 27: Final Sketch 6

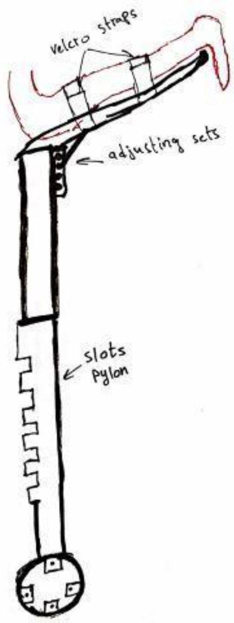


Figure 28: Final Sketch 7

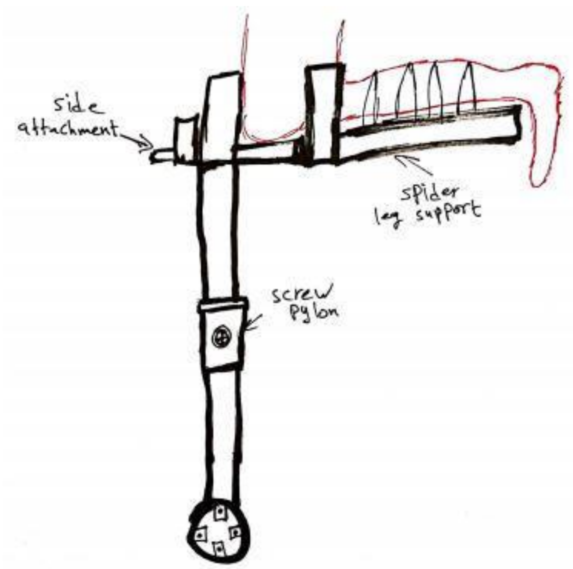


Figure 29: Final Sketch 8

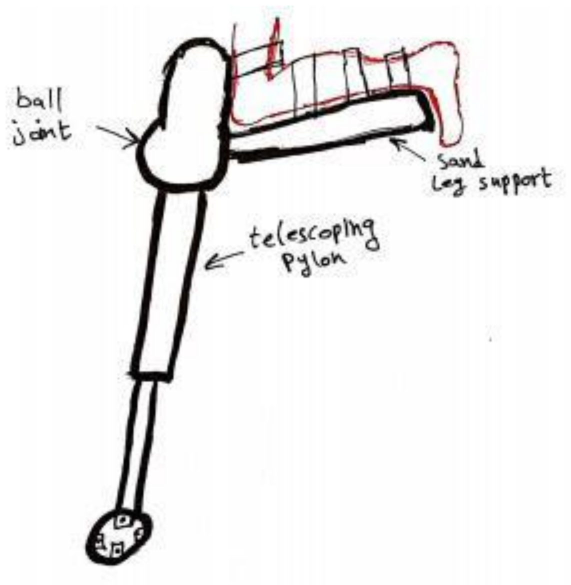


Figure 30: Final Sketch 9

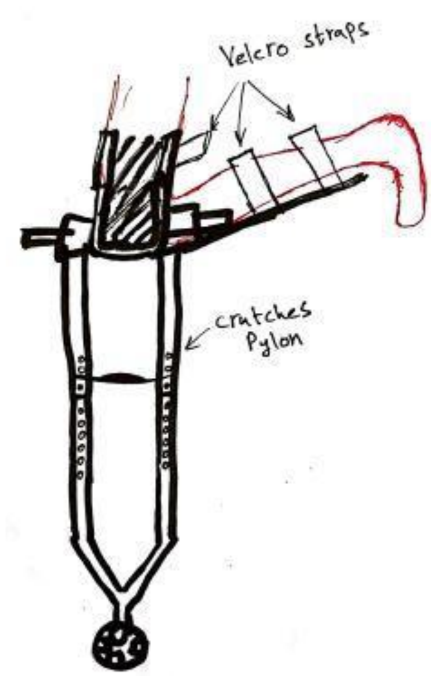


Figure 31: Final Sketch 10