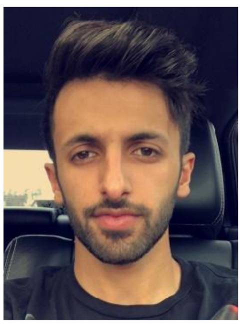
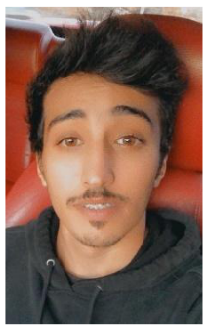
Design of a non-invasive Hip Exoskeleton (Team 19F03 - HipA)

Final Proposal

Team members:

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EXECUTIVE SUMMARY

Team 19F03 project's is to design Hip Exoskeleton for children to assist their ability to walk. In general exoskeleton is a wearable device that can help and assist individuals with neuromuscular disorder. Hip exoskeleton is a device that assists the lower body of a person to help stabilization and walking performance. The team's target is children from four to sixteen years old also will focus on the mechanical aspect of the hip exoskeleton such as the frame, motors and design in general. There are different requirements that the team focused in order to develop a design that functions effectively and improve the design. These requirements include the customer and the engineering requirements. These requirements serve to fulfil the deficiencies that were identified in the existing devices.

Purpose:

The purpose of this project is to facilitate stabilization in children with cerebral palsy and decrease the metabolic cost of walking in children.

Goal:

The project goal is to focuses on developing a hip exoskeleton, using motors, and sensors to improve the user's hip movements and strength. In addition to deliver a design that meets all customer's needs and engineering requirements.

The design:

The design comprises of three subsystems pelvic, thigh and actuator subsystems. These subsystems will collaborate with the signal produced by the body to provide adequate support to the hip joints of the user. The team is only focusing on the mechanical aspect of this project for the electrical component will be provided by the client.

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1.0 BACKGROUND

1.1 Introduction

Exoskeletons are wearable devices that function in alongside the user's body parts. The design of an exoskeleton depends on various factors such as the purpose and the target body parts that requires support. The team will develop a lightweight and cost-effective exoskeleton by adjusting and improvements on the existing hip exoskeletons [2]. The purpose of making this exoskeleton from the existing design is to help support walking at the hip joint. Exoskeletons are used in different sectors such as healthcare, sports, military and rehabilitation facilities. They are used to assists individuals with hip and back issues to walk and maintain a stable posture. The previous design of the exoskeleton is robotic and costly because of the components used in the manufacturing. The new design will be cost effective, highly flexible to accommodate different ages and sizes of the users [10]. It also has systems that allow ease of wearing and removing. The hip exoskeleton system is used as assistive technology to persons with neuromuscular deficiencies. It will be used to assist the disabled walk again and also enable individuals to correct their posture from the hip area. Other applications include enhancement of occupation safety in manufacturing and military operations to enhance the strength of the users. Other uses of the device encompass assisting individuals with neuromuscular disorders to function normally in the context of walking and working [4].

1.2 Project Description

> NAU's Biomechatronics Lab focuses on developing wearable robotics (exoskeletons) to improve the mobility of people with walking impairment. New devices are tested by comparing the exo-assisted metabolic cost of walking with the unassisted metabolic demand. The hip exoskeleton will be used to test the optimal amount of joint torque assistance needed at the hip to decrease the metabolic cost of walking in children.

The project will focus only on the mechanical design and movement of the exoskeleton based off hip joint range of motion. The device comprises of a system with motors that collaborate with the signal produced by the body to provide adequate support to the hip joints of the user. The project involves the design, prototyping and development plan for a hip exoskeleton device. The exoskeleton in this case is an electro-mechanical technology for assisting children with Cerebral Palsy and neuromuscular disorder. The hip exoskeleton will be used to assists children walk and to enable to correct their posture from the hip area. The movement aspect of the device is accomplished by using motors to help provide the needed power to support hip movement. The frame will support the motors, pelvic and the thigh brace.

2.0 REQUIREMENTS

There are different requirements that the team focused on in order to develop a design that functions effectively and improve the design. These requirements include the customer and the engineering requirements. These requirements serve to fulfil the deficiencies that were identified in the existing devices.

2.1 Customer Requirements (CRs)

After examining the customer needs in the context of a hip exoskeleton, the team identified the customer requirements as indicated in table 1 below. The most important CR's are to provide flexible moving points and a lightweight device, because it will allow the individual to be more stable when using the exoskeleton. The other customer requirement for the device is comfortability. The target users are individuals with walking problems and should therefore feel comfortable when using the device [7]. The other customer requirement is cost. The device should meet the financial targets of the customers. Rigidity, strength and durability are other aspects of the customer needs that the device targets to meet.

Table 1: Customer Requirements

C.Rs	**Description**
Lightweight Design	0.75 kg or less
Flexible for all sizes.	Sliding metal frames for adjustment
Reduced skin irritation	Fabric interface on the interior of the exoskeleton
Strong Device	Use of Carbon on the frames (high modulus of elasticity).
Non-invasive	No contact between the metal bars and the human skin
Comfort	Less than 20-40 seconds to on/off, and reduced irritation to skin
Simple system	Uses actuators on the hips to facilitate functionality

2.2 Engineering Requirements (ERs)

The team created the engineering requirements based on the customers' requirements. The engineering requirements is the interpretation of the customer requirements on the design. Engineering requirements are derived from the customer needs and are more detailed according to engineering perspective [9]. The team examined the existing designs and their objectives. Specific acceptable tolerances were designated for each of the physical parameters and work was carried out to meet the customer expectations within the acceptable tolerances [11]. The engineering requirements that should fulfil the customer requirements are shown in table 2 below.

Table 2: Engineering Requirements

ER*	Target value	Tolerances	Description
Weight	7 lbs.	0.5lb	Weight of 4.5–9 lbs.
Strength	200 Gpa	5 Gpa	Material's Modulus of Elasticity
Force	100 N	10 N	Needed to actuate the device
Yield Strength	210 Gpa	3 Gpa	Choosing the proper materials
Shear Modulus	80 Gpa	5 Gpa	Calculate deformation
Young's Modulus	215 Gpa	2 Gpa	Measuring abilities of materials
Cost	$553	$400	Cost effective
Torque	8 Nm	2 Nm	8 Nm out of the motor
Range of Motion	50 degrees	2 degrees	Hip joint from 150-390 degrees

**Engineering Requirements.*

2.3 Functional Decomposition

The purpose of this project is to design and implement a Hip exoskeleton. The design was motivated by the need to develop affordable and non-invasive device. The hip joints will be actuated by DC motors [1]. Carbon fiber frames are used for the pelvic and thigh support. The sensors are located on the hip joints to acquire data from the human input.

2.3.1 Black Box Model

All body movement signals are generated by the by the hip joints. The input is the human activity that initiates the pelvic movement which transfers the signals to the sensors in the hip area. The body perceives the movement of the pelvic and the control signal from the brain reaches the hip muscles [3]. The hip muscles is another input that requires energy to increase the strength. The electrical energy is the energy input and the outputs are the hip movement and the brain signal.

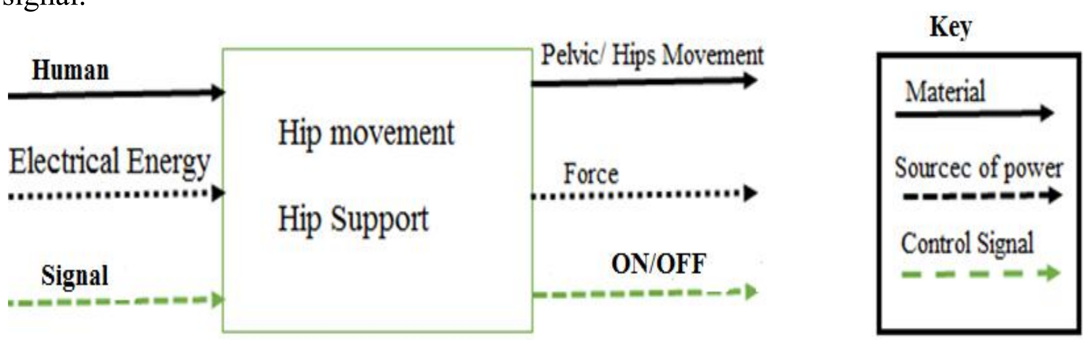


Figure 1: Black Box

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

Hip Movement is initiated by the body movement. Sensors identifies the hip movement and generates a signal that is transferred to the actuators to initiate a respective movement. The electric power is controlled based on the present movement of the exoskeleton and the required strength. The feedback method for power control and the exoskeleton movement with the required force.

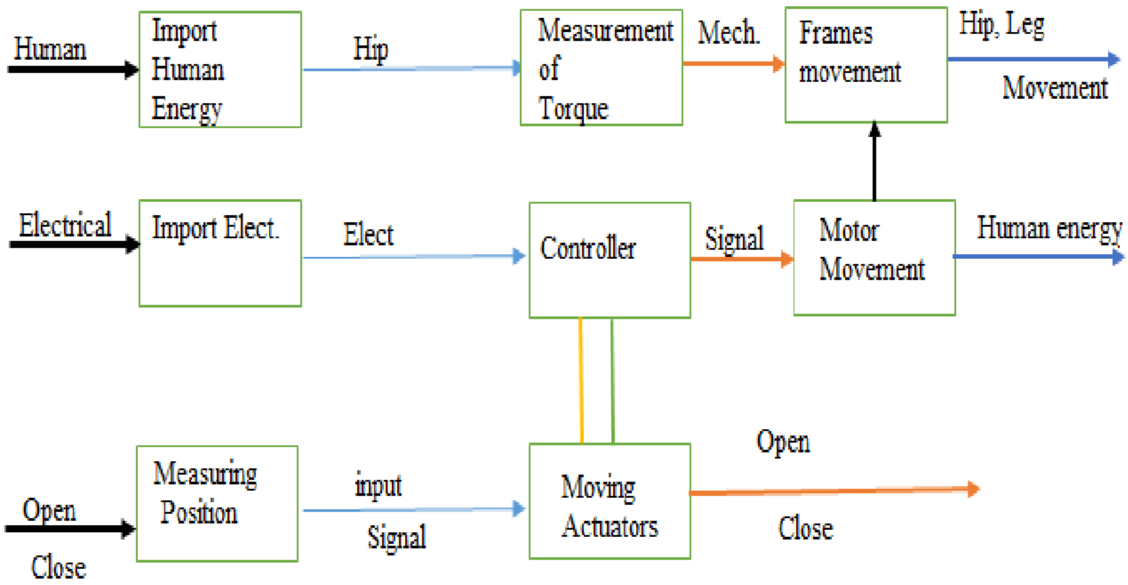


Figure 2: Functional Model

2.4 House of Quality (HoQ).

QFD is House of Quality, which determines the relationship between the engineering requirements and customer requirements. Engineering requirements are the technical aspects of the project according to the client requirements and customer requirements are basically the project information provided by the client [9]. As the Engineering requirements have developed from the customer requirements, therefore, it is necessary to make the relation between ER's and CR's and identify the effect of CR on ER. QFD is a matrix in which customer requirement and engineering requirement relate to each other and assign a value according to the importance in the corresponding matrix [14]. From the QFD, we obtained the targeted values of engineering requirements and determine the importance of each engineering requirement with the help of absolute technical importance and relative technical importance. QFD table is shown in Appendix D.

2.5 Standards, Codes, and Regulations

The standards, codes and regulations will be used in this design project is ASME Y14.5M-2004 drawing standards. American Society of Mechanical Engineering (ASME) standards, codes and regulations will apply for this design in SolidWorks dimensions, tolerancing, and dimensioning the final design. for the safety of the device ASNI/AAMI HE 74:2001 standards and codes will be used to deliver a safe design to the client.

Table 3: Standards of Practice as Applied to this Project

Standard Number or Code	**Title of Standard**	**How it applies to Project**
ASME Y14.5M-2004	Dimensioning and tolerancing	Helps in dimensioning and tolerancing the final design
ASNI/AAMI HE 74:2001	Human Factors Design Process for Medical Devices	Helps in the design of how the device with interface with the user in a safe manner.

These codes will help provide the standards dimension in order to build the project and help the team delivering a project that complies with a known standards and code. In addition, these codes will help to provide the standards safe design that interface with human in a proper way.

3.0. TESTING PROCEDURES (TPS)

The testing procedure that the team will work on next semester will be discussed in this section. In addition to more testing procedure will be discovered next semester when the team start the building on the design.

3.1 Testing Procedure 1: Weight

3.1.1 Testing Procedure 1: Objective

The objective of this testing procedure will be to design an exoskeleton device with weight range between 4.5 lbs. to 9 lbs. For the testing procedure, team members will use scale to measure the weight of the device. Therefore, the test aims at establishing the appropriate weight range that an exoskeleton can support without breakages or damage.

3.1.2 Testing Procedure 1: Resources Required

The device weight should be ranging between 4.5 lbs. to 9 lbs. The results will then be analyzed using analysis charts and statistical tools on excel.

3.1.3 Resting Procedure 1: Schedule

Task Name	Start Date	End Date
Buying a home scale	02/14/2020	02/19/2019
Testing the exoskeleton on the home scale	02/20/2020	02/23/2020
Analysis of the Results	02/24/2020	02/28/2020

3.2 Testing Procedure 2: Designing an adjustable exoskeleton

3.2.1 Testing Procedure 1: Objective

The aim of this testing process is to determine the flexibility of the exoskeleton device. This objective is achieved by testing the adjustability of the device using persons of different sizes.

3.2.2 Testing Procedure 2: Resources Required

People with different height and hip sizes are subjected to test. The length of the exoskeleton is increased or decreased depending on the size of the person's limb. Also, the hip size of the exoskeleton is increased or decreased depending on the size of the person.

3.2.3 Resting Procedure 1: Schedule

Task Name	Start Date	End Date
Selection of the Sample population	02/14/2020	02/19/2020
Testing the exoskeleton on the sample population for height and hip adjustability.	02/20/2020	02/23/2020
Analysis of the Results	02/24/2020	02/28/2020

3.3 Testing Procedure 2: Strength

3.3.1 Testing Procedure 1: Objective

The exoskeleton is required to support different weight ranging between 45 lbs. to 350 lbs.. for the testing procedure, team members will test the device on people with different weights to check the strength of the device if the device can support the user or not. If the device didn't support, team members will work on solving the issue.

3.3.2 Testing Procedure 2: Resources Required

The device should accommodate the weight of the patients ranging between 45lbs. to 350 lbs. in this case, individuals with weights ranging between 45 lbs. to 350 lbs. are tested on the exoskeleton.

3.3.3 Resting Procedure 1: Schedule

Task Name	Start Date	End Date
Buying material	02/14/2020	02/19/2020
Testing the strength of the materials	02/20/2020	02/23/2020
Analysis of the Results	02/24/2020	02/28/2020

3.4 Testing Procedure 2: Range of Motion

3.4.1 Testing Procedure 1: Objective

The objective of this testing procedure will be to design an exoskeleton device with degree of freedom ranging between 25-90 degrees. For the testing procedure, team members will test the device by protractor to check if the users are able to move their legs to the left and right. In case of failure, team members will work in solving the issue.

3.4.2 Testing Procedure 2: Resources Required

The device should give the ability to the user to have the ability to move their legs to the left and right. The result will then be analyzed using analysis charts and statistical tools on excel.

3.4.3 Resting Procedure 1: Schedule

Task Name	Start Date	End Date
Selection of the Sample population.	02/14/2020	02/19/2020
Testing the exoskeleton on the sample population for range of motion.	02/20/2020	02/23/2020
Analysis of the Results	02/24/2020	02/28/2020

3.5 Testing Procedure 2: Cost

3.5.1 Testing Procedure 1: Objective

The objective of this testing procedure will be to check if the prices that we estimated are correct or not. Team members worked on the bill of materials. The estimated price was 1070$ and the tolerance is 200$. Therefore, the project budget is 2250$. However, the team members are trying to use the least amount of money so it can meet the Engineering requirements.

3.5.2 Testing Procedure 2: Resources Required

The device should cost the least amount of money as much as possible. Thus, the device meets the Engineering requirements. The result will then be analyzed using the analysis charts and statistical tools on excel.

3.5.3 Resting Procedure 1: Schedule

Task Name	Start Date	End Date
Bill of materials	02/14/2020	02/19/2020
Testing if the bill of materials is correct or not	02/20/2020	02/23/2020
Analysis of the Results	02/24/2020	02/28/2020

3.6 Testing Procedure 2: Force

3.6.1 Testing Procedure 1: Objective

The objective of this testing procedure will be to check if the device can actuate or not. Force testing is a way of determining how an object will react when it is subjected to tensile or compressive loads by testing the device on individuals with different weights to check if the device is able to do 100N force.

3.6.2 Testing Procedure 2: Resources Required

The device should do 100N of force to actuate. Thus, the device meets the ER requirements. The result will then be analyzed using the analysis charts and statistical tools on excel.

3.6.3 Resting Procedure 1: Schedule

Task Name	Start Date	End Date
Selection of the Sample population	02/14/2020	02/19/2020
Testing the exoskeleton on the sample population for actuation.	02/20/2020	02/23/2020
Analysis of the Results	02/24/2020	02/28/2020

3.7 Testing Procedure 2: Yield Strength

3.7.1 Testing Procedure 1: Objective

The objective of this testing procedure will be to check the device by testing the stress at which a specific amount of materials deformation is produced and can indicate the limit point of the elasticity behavior and choosing the proper materials so, The tolerance value it is 3 Gpa and the target value it is 210 Gpa.

3.7.2 Testing Procedure 2: Resources Required

The materials that we will use it should not yield of the elasticity until 210 Gpa. so, the device meets the engineering requirements. The result will be analyzed using the analysis by excel calculation.

3.7.3 Resting Procedure 1: Schedule

Task Name	Start Date	End Date
Selection of the Sample population	02/14/2020	02/19/2020
Testing the exoskeleton on the sample population for yield strength	02/20/2020	02/23/2020
Analysis of the Results	02/24/2020	02/28/2020

3.8 Testing Procedure 2: Shear Modulus

3.8.1 Testing Procedure 1: Objective

The objective of this testing procedure will be to measure the stiffness of the materials that we will use it for our device by testing the device deformation of a solid when it experiences a force parallel to one of its surfaces while its opposite face .So, we have to calculate the deformation of the shear modulus. The tolerance value it is 5 Gpa and our target value 80 Gpa.

3.8.2 Testing Procedure 2: Resources Required

The materials that we will use it should be stiffness and suffer a 80 Gpa. As long as the device meets the Engineering requirements. So, the result will be analyzed by using hand and many apps calculations.

3.8.3 Resting Procedure 1: Schedule

Task Name	Start Date	End Date
Selection of the Sample population	02/14/2020	02/19/2020
Testing the exoskeleton on the sample population for *shear modulus*	02/20/2020	02/23/2020
Analysis of the Results	02/24/2020	02/28/2020

3.9 Testing Procedure 2: Young's Modulus

3.9.1 Testing Procedure 1: Objective

The objective of this testing procedure will be to measuring the ability of the materials that we will use it with our device by testing a solid material will undergo when a small load is applied to it in compression or extension. So, the tolerance value 2 Gpa and the target value it is 215 Gpa.

3.9.2 Testing Procedure 2: Resources Required

The materials that we will use it has tolerate the load that will be applying to it until a value of 215 Gpa. Thus, the device meets the engineering requirements. The result will be calculated by Excel or any other apps.

3.9.3 Resting Procedure 1: Schedule

Task Name	Start Date	End Date
Selection of the Sample population	02/14/2020	02/19/2020
Testing the exoskeleton on the sample population for *Young's Modulus*	02/20/2020	02/23/2020
Analysis of the Results	02/24/2020	02/28/2020

3.10 Testing Procedure 2: Torque

3.10.1 Testing Procedure 1: Objective

The objective of this testing procedure will be to check if the motor that we will use it through our device can be torquing 8 Nm out of the motor by testing the motor with our device and see then it is work or not. Thus, the tolerance value it is 2 Nm and the target value it is 8 Nm.

3.10.2 Testing Procedure 2: Resources Required

The motor should do 8 Nm of torquing to work. Thus, the device meets the Engineering requirements. The result will then be analyzed using the analysis by hand or on excel.

3.10.3 Resting Procedure 1: Schedule

Task Name	Start Date	End Date
Selection of the Sample population	02/14/2020	02/19/2020
Testing the exoskeleton on the sample population for Torque	02/20/2020	02/23/2020
Analysis of the Results	02/24/2020	02/28/2020

4.0 RISK ANALYSIS AND MITIGATION

In every design there must be some points of critical failure. When designing a project critical failure must be taken into consideration and solved to deliver a high-quality design to the client. In this section the top ten critical design potential failure for hip exoskeleton is discussed and solution for each failure in addition to risks and trade of analysis. Using FMEA will help in focusing on the ten top potential critical failure for this design. (see appendix E for full FMEA)

4.1 Critical Failures

4.1.1 Potential Critical Failure 1: Inefficiency of hip actuators (motors) (224 RPN)

The presence of foreign particles such as dust and metallic particles in the motor cage could affect the effectiveness of the motor. The foreign particles can be acquired during the installation process [8]. The device failure that might result from this aspect entail the motor stalling, which could hinder the user's hip movement. The causes of this failure can be identified through the physical examination of the motor parts for foreign particles.

4.1.2 Potential Critical Failure 2: Presence of cracks on support frames. (147 RPN)

Cracks of the metal frames are some of the causes of weaknesses on the exoskeleton. The presence of cracks on the support frames can contribute to breakage and inability of the exoskeleton to support different weights [7]. This failure can be detected through the physical examination of the metal frames to identify any cracks and testing the mechanical properties of the metal frames.

4.1.3 Potential Critical Failure 3: Lose hip brace. (96 RPN)

The hip and thigh braces will be used to support the hips and thighs of the user. They are required to support the respective parts effectively in order to ensure efficiency and safety of the exoskeleton. Lose braces can hinder the safety of devices and pose safety risks to the user. This failure can be mitigated through accurate and precise measurements of the length and diameters of the braces to minimize excesses.

4.1.4 Potential Critical Failure 4: Failure of the actuators (175 RPN)

The functioning of the actuators depends on the signal received from the sensors. Failure of the actuators can be caused by the failure of the sensors due to lack of testing and calibration. This risk can be mitigated by calibration of the sensors on the pelvic device and precise installation to ensure accurate movement detection.

4.1.5 Potential Critical Failure 5: Failure of the belt (128 RPN)

The belt will be used for holding the hip frame to make the frame fit perfectly to the users. The belt sometimes gets tears apart from the everyday uses. The best way to avoid this type of problems is to make sure that buying the best product.

4.1.6 Potential Critical Failure 6: Failure of the sensors (108 RPN)

Sensors in this design is used for detection of movement and force in order to actuate the motors. Sensors may suffer from several issues to make them not work properly. Sensors may not be mounted correctly, and this will give wrong reading and the whole system not to function as needed. Debris may interface with sensor and provide wrong reading. All those failures will be can be fixed by using cover for sensors and make sure that sensors placed correctly and test them before wearing the exoskeleton.

4.1.7 Potential Critical Failure 7: Failure of the pads (128 RPN)

The pads will be used in the hip brace to make it comfortable for the user. The pads can get saggy by daily use for the exoskeleton. However, the pads should be in high quality in order to not get compressed and provide the right comfortability.

4.1.8 Potential Critical Failure 8: Failure of the thigh frame (140 RPN)

The thigh frame will be attached in the thigh area in order to make the device work properly. One thing can get the failure is deformation of the brace. Using the right materials that have the calculated ER target for Shear modulus will provide help preventing deformation.

4.1.9 Potential Critical Failure 9: Failure of the thigh frame connector (90 RPN)

Thigh frame connector may suffer from braking or high load and this may break the thigh brace. This failure may be prevented by using high quality materials for connectors and make the right tests for connector.

4.1.10 Potential Critical Failure 10: Failure of the brace adjustment (84 RPN)

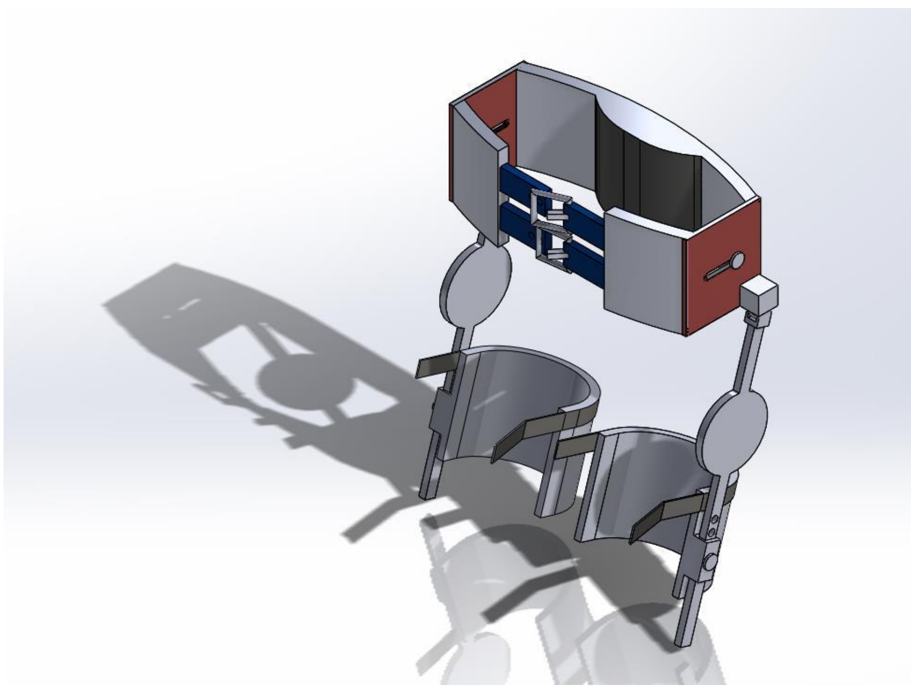
The adjustment of the device will be attached in many parts of our device in order to make that work. Many aspects can get the failure is affects the device adjustment Seems like breaking, Heating. However, the materials should be of high quality in order to make an adjustment device.

4.2 Risks and Trade-offs Analysis

The critical risks failures of the device are correlated. Failure of one of the parts of the exoskeleton can lead to safety concerns among the users. The mitigation of the first risk will facilitate the mitigation of the critical failure 4. Critical failures 2 and 3 serve the purpose of limiting the strength of the device. Therefore, mitigation of risk 2 can delay the mitigation of the risk 4 because the mitigation of risk 2 will require the frames to be removed for testing of mechanical properties and examination for cracks.

5.0 DESIGN SELECTED

Below is the CAD model of the team's design. This design may have some slight changes during next semester after doing the testing procedure



Figurer 3: isometric view

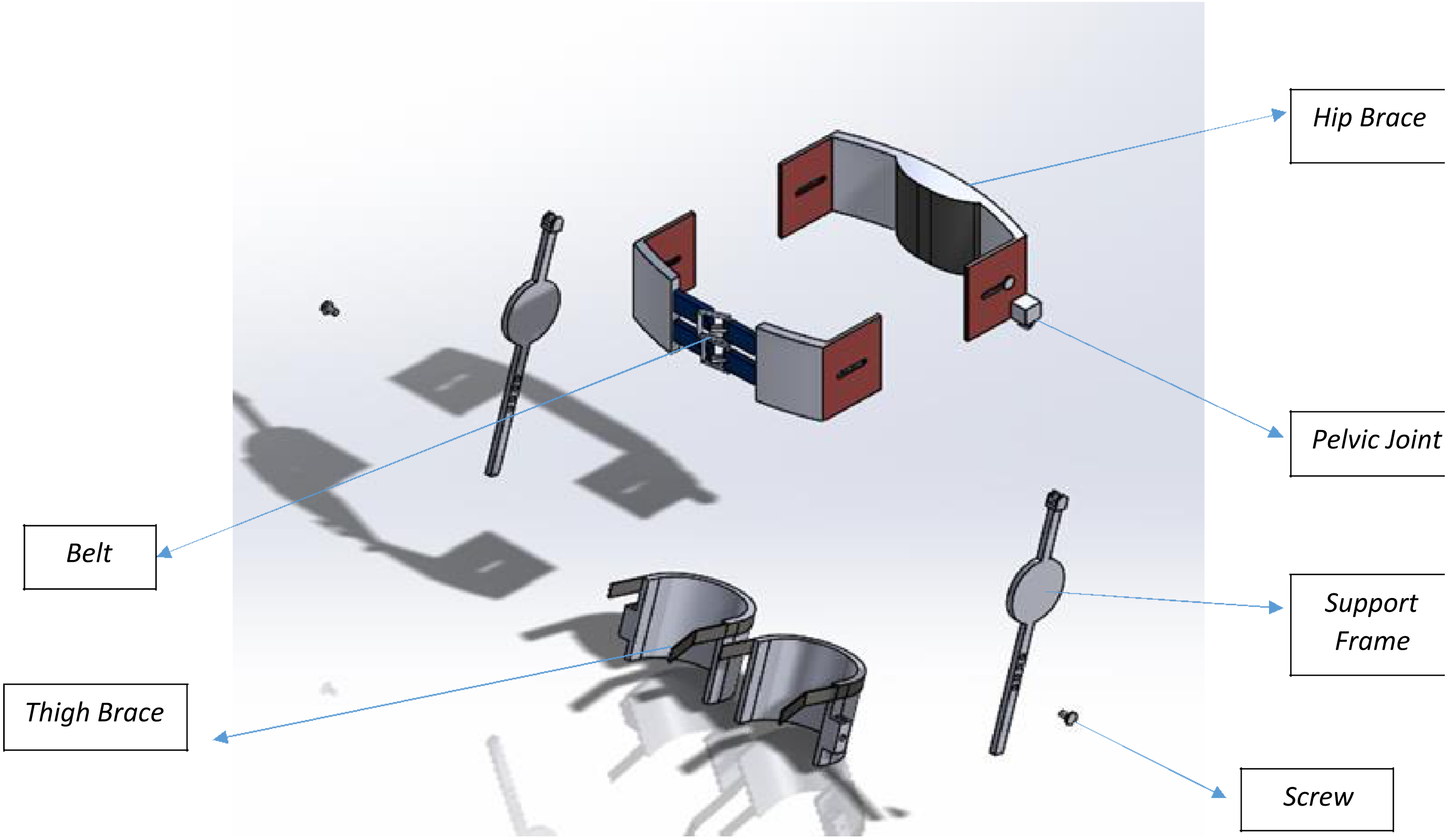


Figure 3: Exploded view

Figure 4: Prototype Design

GORE

5.1 Design Description

The exoskeleton design comprises of the following subsystems that include the pelvic design, the thigh design and the actuators. The actuators facilitate joint movement at the hip. The actuators receive signals from the sensors on the hip joint to create a movement that minimizes the energy requirements for the user to move. The pelvic design is the main focus of the project. It comprises of various elements that include the torque sensors, the hip braces and the support frame
[15]. The sensors function in terms of acquisition and transfer of hip joint movement signals to the actuators to facilitate a proportional movement. The frames on the thighs and hip support the hips and thighs during movement to ensure the safety and comfort of the user [16]. Scotch yoke mechanism allows continuous unidirectional motor rotation. In this case, the movement of the hip actuators is activated by the hip joint. Therefore, slight movement of the hip joint contributes to motor actuations on the hips, which causes the movement of the thighs joint. Hence, the user requires less energy to initiate movement.

The materials that the team are using in this design are carbon fiber for hip brace, thigh brace and the supporting frame for providing strong rigid frame to the device. For the belt that used in the hip and thigh brace the team using a high-quality fabric belts to ensure comfortability and tight fit for the user. For the hip brace interior surface, the team is going with a foam pads that withstand heavy duty climate change. Lastly for the motor the team is using a motor that can provide up till 30% torque of actual human hip torque. (See Appendix A: for full Bill of Materials)

5.2 Implementation Plan

The implementation of the design will involve three sections/stages. The first section of the implementation process will be the development of the designs for three subsystems; the pelvic design, the support frames and the braces. The second part of the design implementation will involve the development of the three subsections using the different components. The assembly of the hip frame, the sensors, the support frames, and the braces will be accomplished during this stage. The final stage of the implementation plant will be testing the assembled designs for different aspects such as adjustability, strength and weight. This step is the fabrication of the prototype and creating a proof-of-concept. After testing the design’s prototype, the next step will be making physical and operational changes to the system to suit the needs of the customers. The bill of materials is shown in Appendix A.

Building the device should start by purchasing the right materials, then adjusting the size to fit in the right place. The belt will be connected to the hip brace so that can be flexible on the sizing of the users. Pelvic joint will be attached to the hip brace. Then the support frame which is one of the major parts will be attached to both hip and thigh braces. (See Appendix B)

6.0 CONCLUSIONS

Exoskeletons are wearable devices that function in alongside the user's body parts. The design of an exoskeleton depends on various factors such as the purpose and the target body parts that requires support. The purpose of making this exoskeleton from the existing design is to ensure affordability, comfort and efficiency when functioning. Exoskeletons are used in different sectors such as healthcare, sports, military and rehabilitation facilities. They are used to assist individuals with hip and back issues to walk and maintain a stable posture. The devices comprise of a system with motors that collaborate with the signal produced by the body to provide adequate support to the hip joints of the user. The ultimate purpose of the design will be acting as an amplifier that augment, reinforce and restore movement of the user.

7.0 REFERENCES

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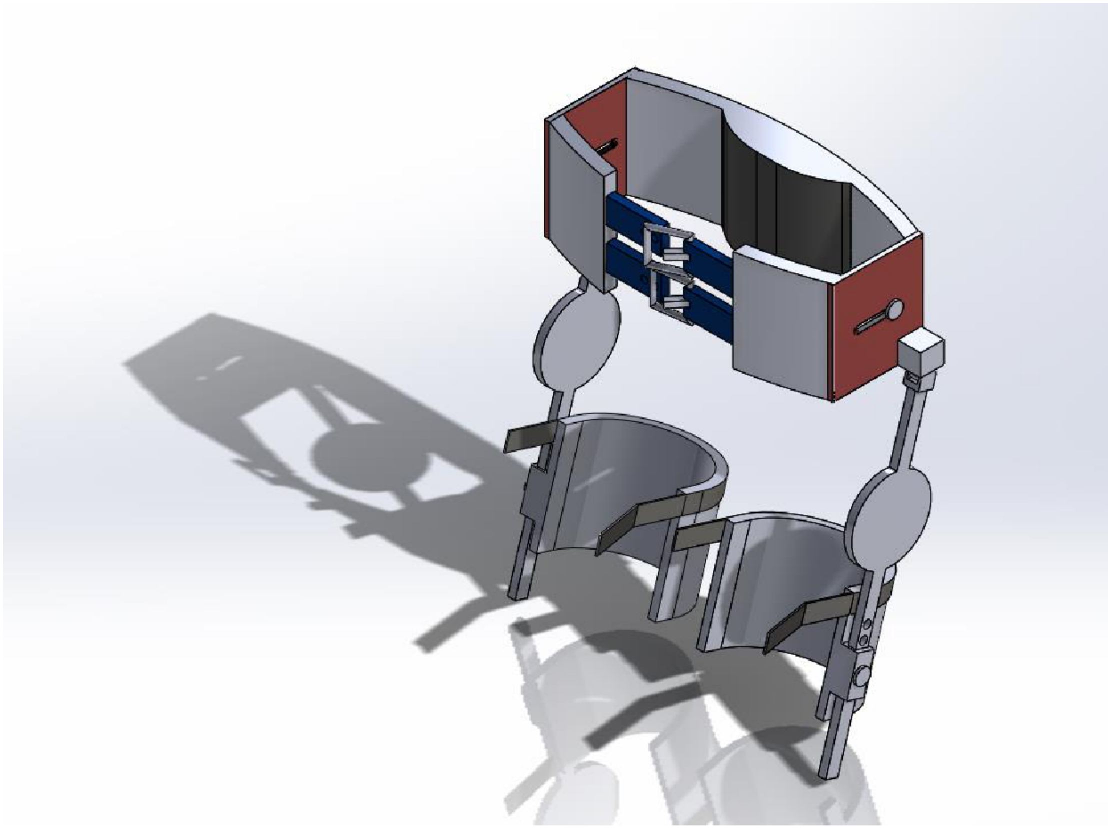
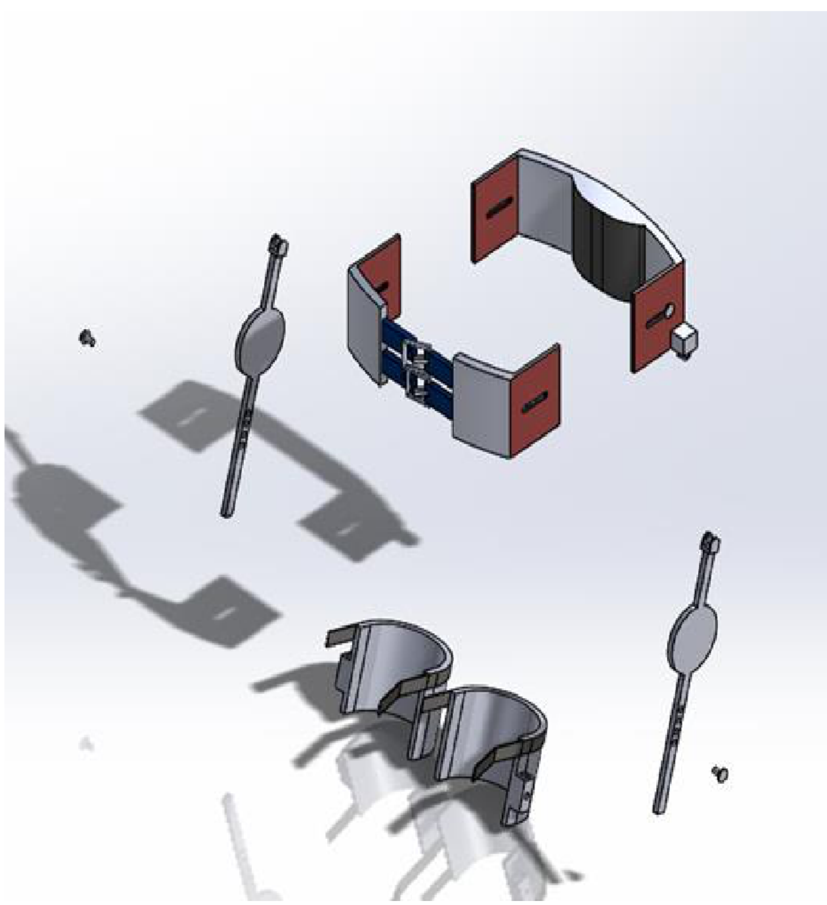
8.0 APPENDICES

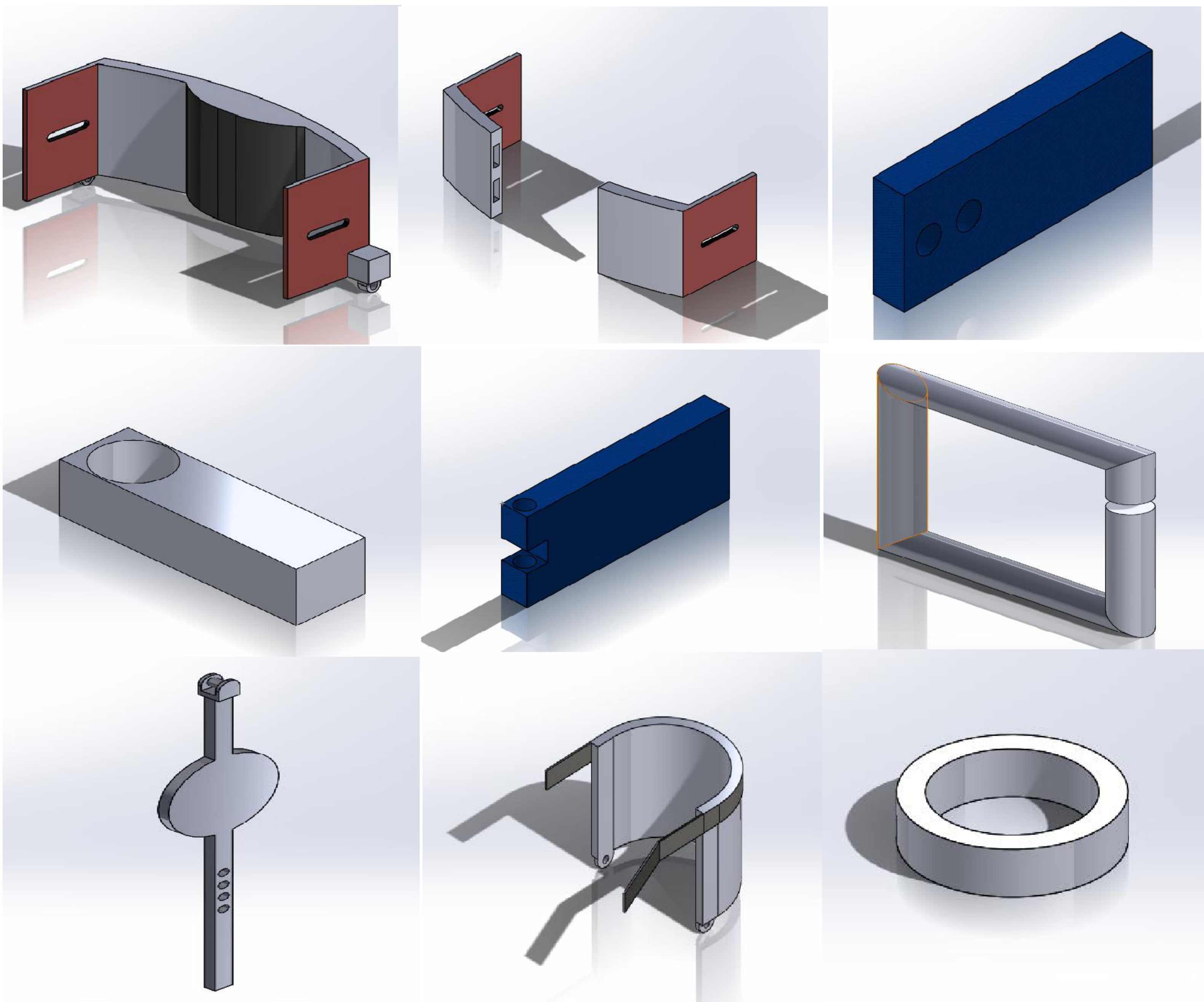
8.1 Appendix A: Bill of Materials

Part #	Part Name	Qty	Description	Functions	Material	Dimensions	Cost	Link
1	Frame	2	Contains holes at different parts for holding other parts	Hips and legs support	Carbon Fiber/ Aluminum	4 in each	$115	https://www.amazon.com/s?k=4+inch+carbon+fiber+tube&crid=10OJXQW4290WU&sprefix=carbon+fiber%2Btube+4+in%2Caps%2C215&ref=nb sb ss i 1 22
2	Arrestors	3	2-for thighs and 1 for pelvic area support	Support to the thighs and hips	PVC	2 in each	$5	https://www.amazon.com/VIVOSUN-Black-White-Panda-Film/dp/B018VI6ZUQ/ref=sr 1 fkmr0 1?keywords=PVC+Film+%2F+PVC+Sheet+%2F+PVC+Sheeting+Arrestors&qid=1573866743&sr=8-1-fkmr0
3	Belts	2	2 -belts on the pelvic brace	Hold it to each other	textile	4-7 in each	$9	https://www.amazon.com/School-Uniform-Nickle-Military-Belt/dp/B00SVNK8C8/ref=zg bs 2478144011 5? encoding=UTF8&psc=1&refRID=MZGQZ6FEWEYNCZ42A7JQ
4	Small Motors	2	Hip and knee joints actuation	Actuators	Carbon casing	19mm	$126	https://www.ebay.com/p/5023000986?iid=254127397657&chn=ps&norover=1&mkevt=1&mkrid=711-117182-37290-0&mkcid=2&itemid=254127397657&targetid=483851302053&device=c&mktype=pla&googleloc=9030087&poi=&campaignid=8085362828&mkgroupid=83728992216&rlsatarget=pla-483851302053&abcId=1139446&merchantid=6296724&gclid=Cj0KCQiAtrnuBRDXARIsABiN-7D6PbeejL6PQI2ixfiNsKPkxUiloz92o_328ji52_koTEPoRpZb5L8aAky9EALw wcB
5	Sensors	2	Placed on the pelvic component.	Signal detection on the hips.		5mm	$19	https://www.radwell.com/Shop?source=GoogleShopping&IgnoreRedirect=true&ItemSingleId=61935098&utm source=google&utm medium=cpc&adpos=1o2&scid=scplp61935098&sc_intid=61935098&gclid=Cj0KCQiAtrnuBRDXARIsABiN-7CAPD2aM5ot9HAN0A59oHCD5qmq8CgDVVWeStj26HxRaJuL4HxVZMsaAvtWEALw wcB

8.2 Appendix B: CAD Design models

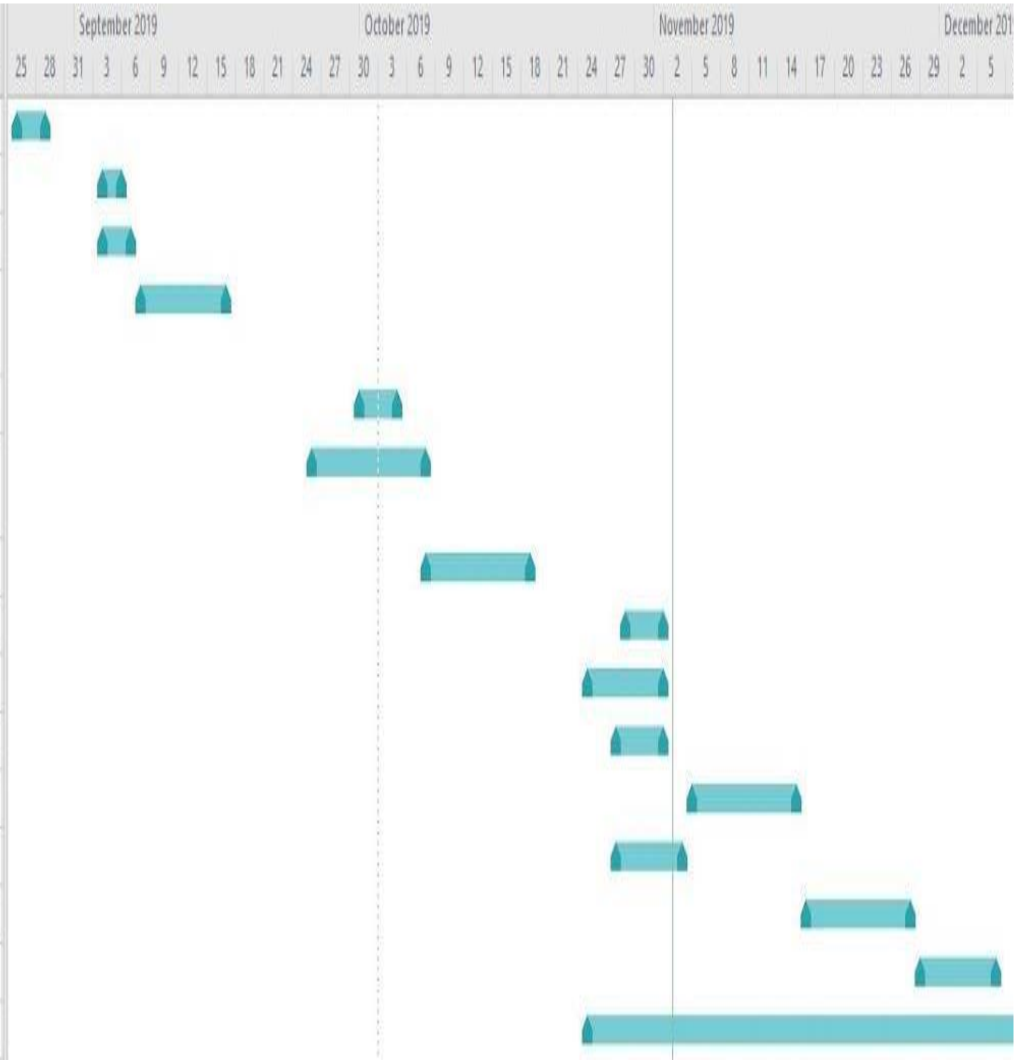






8.3 Appendix C: Schedule

	Task Name	Start	Finish	Task Owner
1	Project signup	Mon 8/26/19	Wed 8/28/19	Dr, Sarah
2	Team charter	Wed 9/4/19	Thu 9/5/19	Mohammed
3	Solid work	Wed 9/4/19	Fri 9/6/19	Individual
4	Presentation 1: CNs/Ers and Background	Sun 9/8/19	Mon 9/16/19	Meshal
5	Self-Learning	Tue 10/1/19	Fri 10/4/19	Individual
6	Presentation 2: Concept Gen and Eval	Wed 9/25/19	Mon 10/7/19	Abdullah
7	Preliminary Report	Tue 10/8/19	Fri 10/18/19	Lahdan
8	Analyses Team Memo	Tue 10/29/19	Fri 11/1/19	Meshal
9	Website Check 1	Fri 10/25/19	Fri 11/1/19	Mohammed
10	Presentation 3: Final presentation	Mon 10/28/19	Fri 11/1/19	Abdullah
11	Final Report	Tue 11/5/19	Fri 11/15/19	Mohammed
12	Final BOM/CAD Package	Mon 10/28/19	Sun 11/3/19	Lahdan
13	Analytical Report	Sun 11/17/19	Wed 11/27/1	Abdullah
14	Prototype demo	Fri 11/29/19	Fri 12/6/19	Lahdan
15	Website Check 2	Fri 10/25/19	Mon 12/9/19	Mohammed



8.4 Appendix D: House of Quality

House of Quality (HoQ)

Customer Requirement	Weight	Engineering Requirement	Weight	Flexural Strength	Force	Yield Strength	Cost	Shear Modulus	Young Modulus	Torque
Light weight	7		9	5	9	9	5	8	5	9
Low Mobility	3		2	9	3	3	3	9	7	3
Adjustable size	9		5	3	1	3	6	6	1	1
Comfortable	8		7	4	1	7	8	3	5	2
Reliability	9		1	8	2	9	9	2	3	5
Durabiilty	9		3	3	1	1	1	5	9	8
Ease of Wearing	4		7	8	7	1	3	1	2	3
Range of Motions	9		6	9	3	2	1	3	1	1
Absolute Technical Importance (ATI)			**288**	**333**	**171**	**267**	**273**	**255**	**230**	**235**
Relative Technical Importance (RTI)			14%	16%	8%	13%	13%	12%	11%	11%
Target ER values			80N	200 Gpa	100N	210Gpa	$2,500	80Gpa	215Gpa	20N.m
Tolerances of Ers			2	5	10	3	500	5	2	2
Testing Procedure (TP#)			6	4	5	3	8	1	2	7

8.5 Appendix E: Failure Modes and Effects Analysis

Product Name: Hip Exoskeleton A	Development Team: Team Hip Exoskeleton A	Page No 1 of 1
System Name:		FMEA Number:1
Subsystem Name		Date: 11/14/2019
Component Name		

subsystems	Part # and Functions	Potential Failure Mode	Potential Effect(s) of Failure	Severity (S)	Potential Causes and Mechanisms of Failure	Occurance (O)	Current Design Controls Test	Detection (D)	RPN	Recommended Action
		tear	not wearable	8	daily use	2	visualization	8	128	
		loosen	not wearable	3	bad materials	4	visualization	2	24	
	belt	mounting	not wearable	3	bad sizing	2	visualization	4	24	choose the right materials
		loosen	hard to adjust	6	poor dimensions	4	visualization	4	96	
Hip brace		mounting	hard to wear	5	bad sizing	2	visualization	5	50	
		screw wear	hard to adjust	4	breakage	3	visualization	4	48	
	adjusment	sizing	not wearable	7	poor dimensions	6	visualization	2	84	have proper dimensions and size
		sagging	not comfortable	6	bad materials	5	visualization	4	120	
		tears	not comfortable	3	bad materials	2	inspection	3	18	
	pad	mounting	not comfortable	4	poor dimensions	4	inspection	2	32	choose the right materials
		point of connection	no movement	3	bad sizing	3	inspection	3	27	
		mounting	no movement	4	bad dimension	4	inspection	3	48	
		loosen	bad movement	4	bad dimension	5	inspection	2	40	
	mount (actuator)	lower support frame	not comfortable	4	bad sizing	3	inspection	2	24	choose the right materials
support frame		sizing	not comfortable	4	wrong hole sizing	4	visualization	3	48	
		loosen	not comfortable	4	bad dimension	3	inspection	2	24	
		crack	not wearable	7	bad materials	3	inspection	7	147	
	adjusment	screw wear	not wearable	4	brakage	5	inspection	3	60	have proper dimensions and size
		joint connection	no movement	3	joint not greased	5	inspection	3	45	
	mount (hip brace)	angle of movement	not comfortable	5	joint not greased	3	inspection	4	60	choose strong joint
		tear	not wearable	8	daily use	2	inspection	8	128	
		loosen	not wearable	3	bad materials	4	inspection	2	24	
	belt	mounting	not wearable	3	bad sizing	2	inspection	4	24	choose the right materials
		loosen	hard to adjust	7	poor dimensions	5	inspection	4	140	
Thigh Brace		connector	hard to wear	6	bad sizing	5	inspection	3	90	
		screw wear	hard to adjust	4	bad materials	3	inspection	4	48	
	adjusment	sizing	not wearable	7	poor dimensions	5	inspection	2	70	proper sizing and dimensioning
		sagging	not comfortable	6	bad materials	5	inspection	4	120	
		tears	not comfortable	3	bad materials	2	inspection	3	18	
	pad	mounting	not comfortable	4	poor dimensions	4	inspection	2	32	choose the right materials
		no power	device not woking	7	bad wiring	4	inspection	8	224	
		efficency	consume huge power	7	bad motor selection	5	inspection	4	140	
		wear	sound	4	no maintainance	3	inspection	2	24	
		high friction	heat	4	no maintainance	5	inspection	3	60	
Actuators	motor	weight	increase wieght	3	increase weight	2	weighting	1	6	choose the right motor with respect to ER req
		sealent	motor not working	4	water escape into housing	3	inspection	2	24	
		size	not comfortable	4	large size	1	inspection	3	12	
	housing	debris	device not working	7	bad sealent	5	inspection	5	175	make sure of the sealent of housing
		debris	device not woking properly	6	debris escape to sensors	6	inspection	3	108	
	sensors	mounting	device not working properly	4	bad mounting	3	inspection	3	36	mount sensor correctly and test before start