FINAL PROJECT – DP 141530

DEVELOPMENT OF LOWER LIMB EXOSKELETON DESIGN AS PROPOSED TOOL TO SUPPORT POST STROKE PATIENTS

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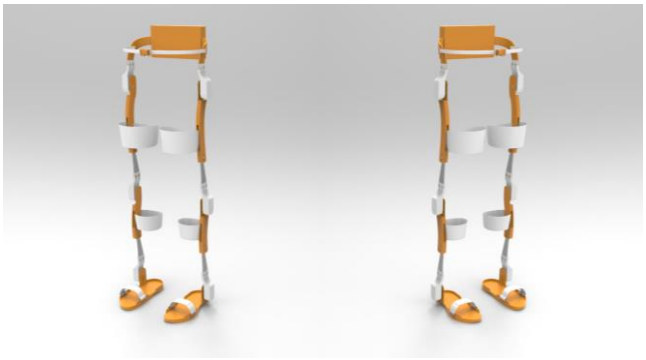
Institut Teknologi Sepuluh Nopember
2018



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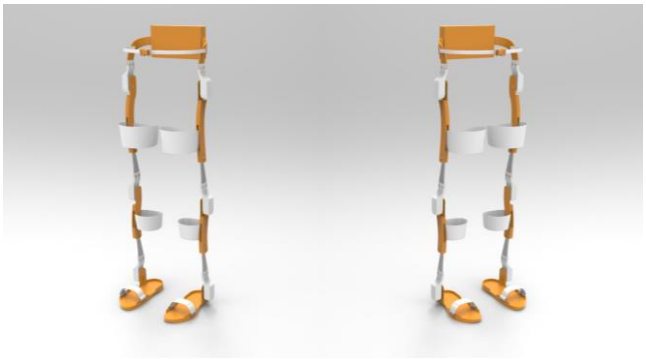

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LETTER OF APPROVAL

DEVELOPMENT OF LOWER LIMB EXOSKELETON DESIGN AS PROPOSED TOOL TO SUPPORT POST STROKE PATIENTS

FINAL PROJECT (DP 141530)

submitted to partial fulfillment of requirement for the award of the degree of

Bachelor of Technology in Industrial Product Design

Bachelor Degree at Industrial Product Design Department

Faculty of Architecture, Design and Planning

Institut Teknologi Sepuluh Nopember

By;

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PLAGIARSM STATEMENT

I am a student of Industrial Product Design Department, Faculty of Architecture Design and Planning, Institut Teknologi Speuluh Nopember, Surabaya,

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Hereby, I declare that the Final Report I created under the tittle **DEVELOPMENT OF LOWER LIMB EXOSKELETON DESIGN AS PROPOSED TOOL TO SUPPORT POST STROKE PATIENTS** is:

1. Not a duplication of published papers or have been used to obtain a degree at another university, except in parts of the source of information shall be cited or quoted in the proper manner.
2. Created and resolved on its own, using the results data of the final project implementation in the project.

Thus I make this statement and if it proves not to meet what has been stated above, then I am willing to report this final project cancellation.

Surabaya, February 1st 2018

Writer,

Faiqoh Agustin

3412100171

ABSTRACT

Stroke has become a leading cause of death and paralysis in some countries such as Indonesia. Based on the Basic Health Research (Riskesdas) during 2007-2013, the prevalence rate of stroke has gradually increased from 8.3 became 12.1. Ischemic stroke takes a part of the 85% of it and contributes a high number of the paralysis as the result of the stroke attack. According to Riskesdas, the post stroke patients also came from low-economical background, so it might be difficult for the patients to afford post treatments to cure the effects such as the therapy and several equipment.

Exoskeleton as one of the supporting tools which is used after the stroke attack playing an important role to help the post stroke patient in the daily life. Almost of this product were imported from the other countries, so the price is higher enough for consumers with low economical background. In this condition, a lower cost exoskeleton product is a major demand for post stroke patients.

Some methods were used in designing the exoskeleton as supporting tools for post stroke patients. A deep interview was done to get the problems and need of the user. In addition, the user's activities well identify by having a shadowing. On the other hand, the design of the product tremendously developed by a brainstorming process. Usability testing of the model is completed to confirm the compatibility of the product for the user.

As the result of the implemented methods, the needs and opportunity of the design will be identified by the design concept including the adjustable system, replicable outer and local fabrication. The low cost product accommodates the needs of post stroke to have an assisting tools with lower cost than the current product. Furthermore, the lightweight design executes to accomplish the excessive appearance of the exoskeleton.

Keywords: exoskeleton, post-stroke, lower limb

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Surabaya, February 2018

Author

TABLE OF CONTENTS

FIGURES

TABLE

CHAPTER 1. INTRODUCTION

1.1 Background

Stroke has become a leading cause of death in some countries such as Indonesia. Based on the Basic Health Research (Riskesdas) during 2007-2013, the prevalence rate of stroke in Indonesia gradually increased from 8.3 became 12.1. Moreover, according to the Agency for Health Research and Development, this disease was ranked as the highest cause of death in 2014 with a percentage of 21%. In addition, this type of disease also leave post effect after the attack which is known as paralysis.

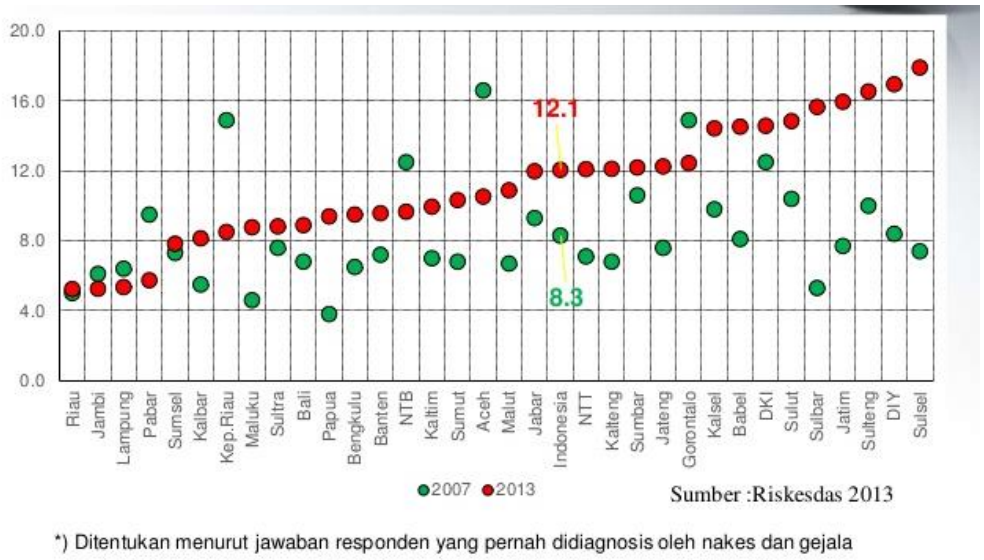


Figure 1 Prevalence rate graphic of post stroke in Indonesia
Source: www.depkes.go.id

Stroke occurs when there is no blood flow to an area of the brain. This condition will lead to the absent of oxygen into the brain, and it progressively make the cells begin to die. As the result of that condition, the abilities controlled by the area of brain such as memory and muscle control will be deliberately vanished. This disease is divided into two major types which is hemorrhagic and ischemic. Hemorrhagic stroke is caused by the weakened blood vessel leak and make blood spills around the brain then damage cells or tissue in the brain, while Ischemic stroke occurs when a blood vessel carrying blood to the brain is blocked by a blood clot. Based on the National Stroke Association, hemorrhagic strokes are less common, in fact only 15 % of all strokes are hemorrhagic, but they are responsible

for about 40 percent of all stroke deaths. On the other hand, ischemic stroke takes a part on the 85% and it contributes high number of paralysis as the cutting-edge of the stroke attack.

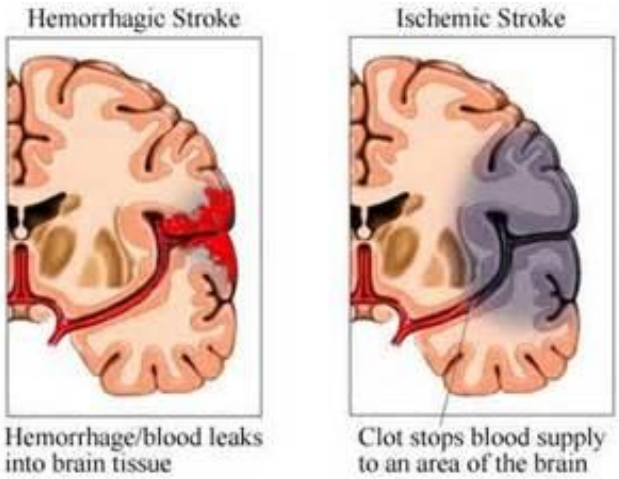


Figure 2 Prevalence rate graphic of post stroke in Indonesia
Source: www.wjmc.org

Stroke is known as one of the most significant causes of disability in adults. Damage to the motor cortex often results in paralysis. Patients with paralysis will have difficulties to do a short or long movement because the weak muscle. This condition then leads to difficulties of the patients to perform daily living activities such as walking, sitting and eating, etc.

Post stroke paralysis could be helped by an exoskeleton as supporting tool. An exoskeleton is a common treatment to holds the foot in a neutral position and help the patients to move the lower leg. Almost medical product such as exoskeleton is imported from other countries because the production process rarely could be found in developing country such as Indonesia. By having the imported products, the cost itself will more than the expected.

On the other hand, as the production process of the exoskeleton in Indonesia is limited, the needs of the patients itself is quite difficult to accommodate. Herdiman et all (2011) mentioned that based on the user's testimony, the current exoskeleton is not friendly to use. The weight of the design is the major cause of discomfort for the user. In addition, a stiff-joining system is also problematical things to overcome by the post stroke patients. According to that condition, post stroke tend to choose a

stick or crutch instead of exoskeleton as supporting tool to help the daily living activities.

According to the current condition mentioned above, an opportunity to developing the design of an exoskeleton for post stroke patients which can meet the user's need is a major demand to supporting the daily living activities.

1.2 Problem Formulation

According to the previous explanation, the problems in this research can be summarized as follows:

1. As the user has different condition and leg measurement, so design of the exoskeleton need to be adjustable to fit the user's lower leg
2. The current design of the exoskeleton looks bold and scary for the user
3. The current exoskeleton product produced by overseas stakeholder which cause a high-cost and difficult to afford by the post stroke patients so it needs to create an effective cost exoskeleton (<20.000.000 IDR)

1.3 Objectives

Based on the background mentioned in the previous subchapter, this research is proposed to:

1. create an adjustable exoskeleton to fit the user
2. enhancing the user's confidence by having a lightweight exoskeleton
3. overcome the high-cost imported exoskeleton product by having an effective-cost product (<20.000.000 IDR) which can be supported by rapid prototyping fabrication

1.4 Benefits

The research is acquired to give the following benefits:

1. creating an exoskeleton to support the drop foot of post stroke patients which is affordable
2. protecting the weak leg of post stroke patients
3. enhancing user's confidence while using the exoskeleton to do daily living activities

1.5 Scope of Research

This research is considered to be reliable under the certain research scopes. This research limits to:

1. patients with post stroke paralysis
2. exoskeleton only support lower leg

CHAPTER 2. LITERATURE REVIEW

2.1 Stroke

2.1.1 Definition of Stroke

The word “stroke” was likely first introduced into medicine in 1689 by William Cole in A Physico-Medical Essay Concerning the Late Frequencies of Apoplexies (Cole W, 1868). Stroke is classically characterized as a neurological deficit attributed to an acute focal injury of the central nervous system (CNS) by a vascular cause, including cerebral infarction, intracerebral hemorrhage (ICH), and subarachnoid hemorrhage (SAH), and is a major cause of disability and death worldwide (Easton JD et all, 2009). Based on Riskesdas 2013, Stroke is a disease on the brain in which cause the disorder function of nerve. Impaired the nerve function in stroke is caused by a blood disorder including a blood clot or leaked blood vessel.

American Heart Association defined stroke as a disease which occurs when a blood vessel bringing blood and oxygen to the brain gets blocked or ruptures. When this happens, brain cells don’t get the blood and oxygen that they need to survive. This causes nerve cells stop working and die within minutes. Then, the part of the body they control can’t function either. The effects of stroke may be permanent depending on how many cells are lost and the location of the broken cells in the brain.

2.1.2 Type of Stroke

Stroke is divided into two main types:

a. Ischemic stroke

   In an ischemic stroke a blood vessel becomes blocked, usually by a blood clot and a portion of the brain becomes deprived of oxygen and will stop functioning. Ischemic strokes account for 80% of all strokes. Rapid diagnosis and treatment of acute ischemic strokes is essential to reduce death and disability from stroke.

b. A hemorrhagic stroke happens when an artery in the brain leaks blood or ruptures (breaks open). The leaked blood puts too much pressure on brain cells, which damages them. High blood pressure and aneurysms—balloon-like bulges in an artery that can stretch and burst—are examples of conditions that can cause a hemorrhagic stroke.

   There are two types of hemorrhagic strokes:

- Intracerebral hemorrhage is the most common type of hemorrhagic stroke. It occurs when an artery in the brain bursts, flooding the surrounding tissue with blood.
- Subarachnoid hemorrhage is a less common type of hemorrhagic stroke. It refers to bleeding in the area between the brain and the thin tissues that cover it. In an ischemic stroke a blood vessel becomes blocked, usually by a blood clot and a portion of the brain becomes deprived of oxygen and will stop functioning. Ischemic strokes account for 80% of all strokes.

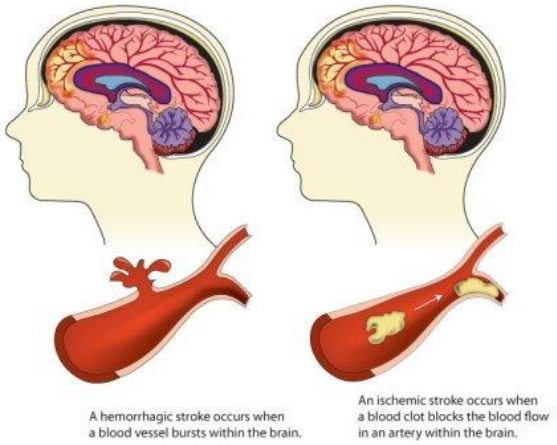


Figure 3 Types of Stroke
Source: https://www.cdc.gov/stroke/types_of_stroke.htm

2.1.3 Stroke Symptoms

Most people do not pay attention to some symptoms which might leading to stroke. The National Institute of Neurological Disorders and Stroke notes these major signs of stroke:

a. Sudden numbness or weakness of the face, arm or leg, especially on one side of the body
b. Sudden confusion, trouble speaking or understanding
c. Sudden trouble seeing in one or both eyes
d. Sudden trouble walking, dizziness, loss of balance or coordination
e. Sudden severe headache with no known cause

2.1.5 Paralysis after Stroke

The types and degrees of disability that follow a stroke depend upon which area of the brain is damaged. Generally, stroke can cause five types of disabilities: paralysis or problems controlling movement; sensory disturbances including pain; problems using or understanding language; problems with thinking and memory; and emotional disturbances.

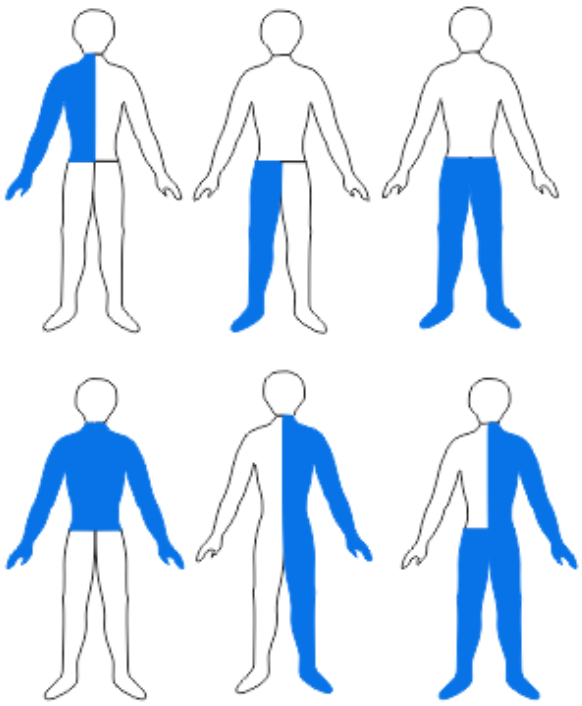


Figure 4 Paralysis after Stroke

2.1.4 Lower Limbs Gait after Stroke

The ability to walk independently is a prerequisite for most daily activities. The major requirements for successful walking (Forssberg 1982) are:

- support of body mass by lower limbs
- propulsion of the body in the intended direction
- the production of a basic locomotor rhythm
- dynamic balance control of the moving body
- flexibility, i.e. the ability to adapt the movement to changing environmental demands and goals.

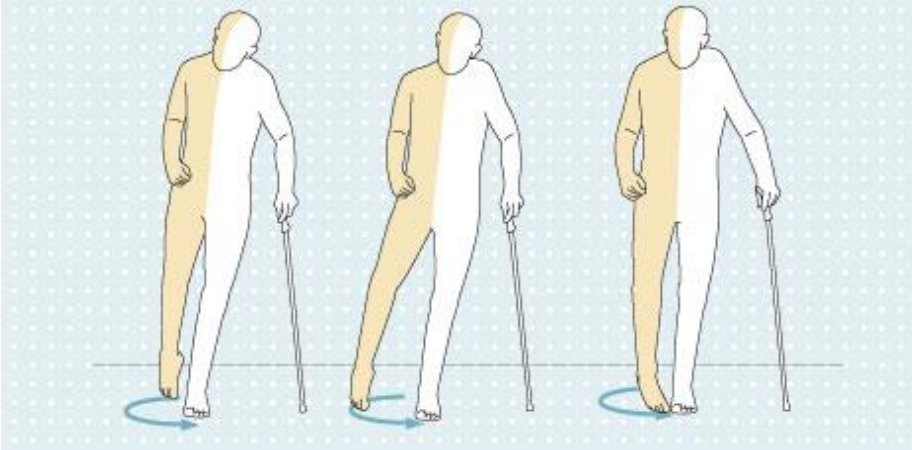


Figure 5 Walking condition of post stroke patient
Source: http://www.ebay.com

In contrast with that condition, post stroke people have some difficulties on walking by themselves. Major contributors to walking dysfunction after stroke is caused by muscle weakness and paralysis, poor motor control and soft tissue contracture.

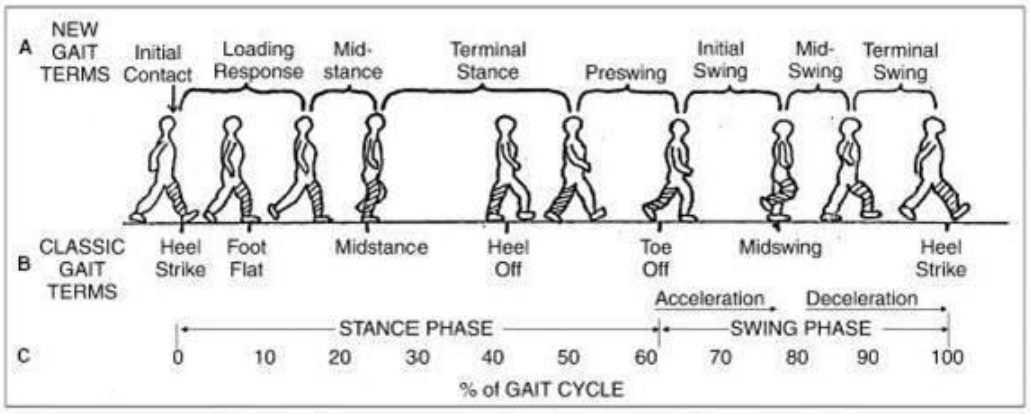


Figure 6 Gait cycle
Source: http://www.physio-pedia.com/Gait

There are the typical kinematic deviations and adaptations of post stroke patients:

- Initial stance (heel/foot contact and loading)
  a. Limited ankle dorsiflexion - decreased activation of anterior tibial muscles; contracture and/or stiffness of calf muscles with premature activation.
  b. Lack of knee flexion (knee hyperextension) - contracture of soleus ; limited control of quadriceps 0-15°
- Mid-stance

a. Lack of knee extension (knee remains flexed 10-150 with excessive ankle dorsiflexion) - decreased activation of calf muscles to control movement of shank forward at ankle (ankle dorsiflexion); limited synergic activation of lower limb extensor muscles.
b. Stiffening of knee (hyperextension). This interferes with preparation for push-off - contracture of soleus; an adaptation to fear of limb collapse due to weakness of muscles controlling the knee.
c. Limited hip extension and ankle dorsiflexion with failure to progress body mass forward over the foot - contracture of soleus.
d. Excessive lateral pelvic shift - decreased ability to activate stance hip abductors and control hip and knee extensors.

- Late stance (pre-swing)
  a. Lack of knee flexion and ankle plantarflexion, prerequisites for push-off and preparation for swing - weakness of calf muscles.
- Early and mid-swing
  a. Limited knee flexion normally 35-40° increasing to 60° for swing and toe clearance - increased stiffness in or unopposed activity of two-joint rectus femoris ; decreased activation of hamstrings.
- Late swing (preparation for heel contact and loading)
  a. Limited knee extension and ankle dorsiflexion jeopardizing heel contact and weight-acceptance - contracted or stiff calf muscles; decreased dorsiflexion activity

2.2 Anthropometry Data

Products can be deemed successful only when people are able to use them well. This is in accordance with the fundamental principle of ergonomics which is to fit the task to the human (Kroemer and Grandjean, 1997). As exoskeleton is a product which will be in contact with human bosy so it needs to be fit properly. Here is the following anthropometric data of Indonesian that will be used as reference in designing the exoskeleton:

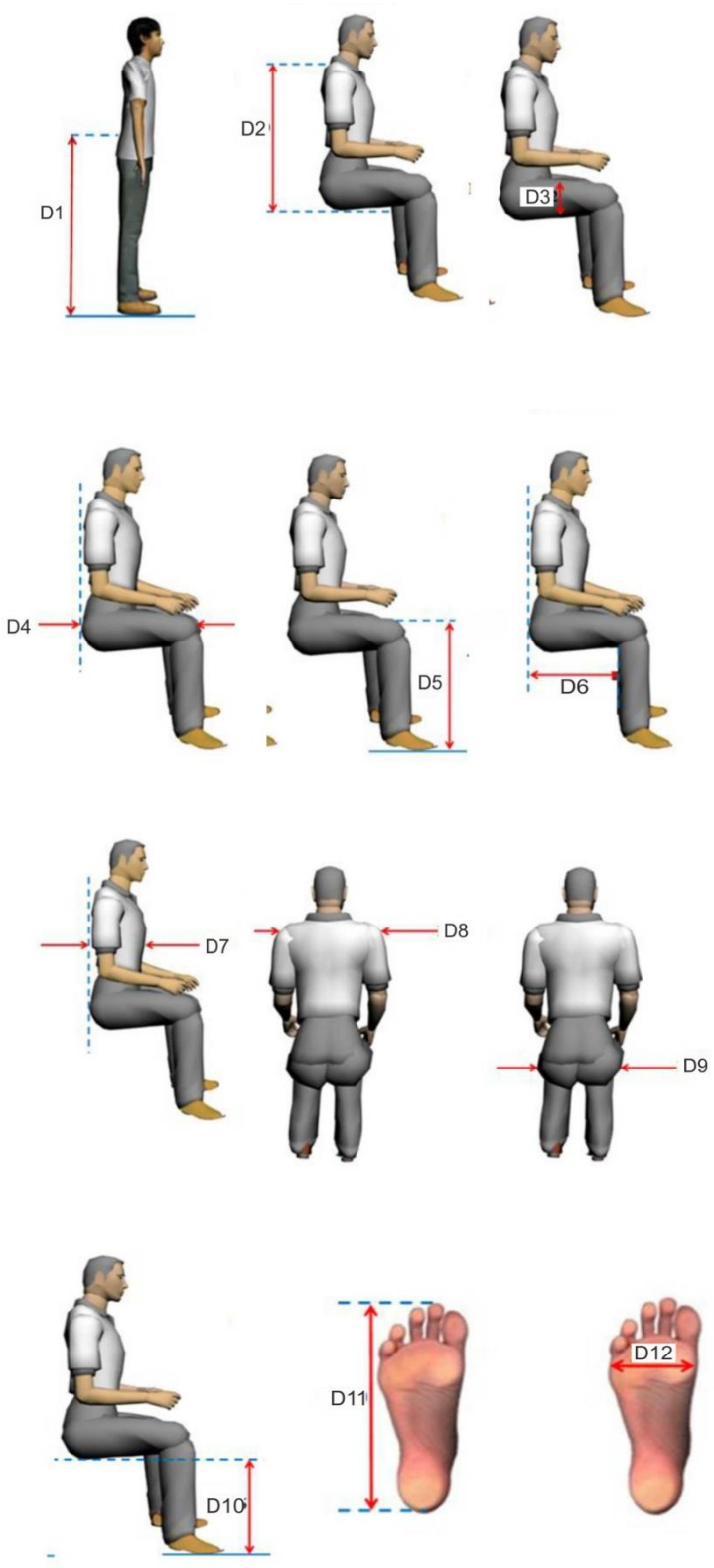


Figure 7 Body measurement in standing position

Anthropometric data of Indonesian adults were summarized as follows:

Table 1 Human dimension

Dimension	5th	50th	95th
D1	91.67	93.32	94.96
D2	59.37	61.01	62.66
D3	17.14	18.79	20.43
D4	50.48	52.12	53.77
D5	50.38	52.02	53.67
D6	37.34	38.98	40.63
D7	22.9	24.55	26.19
D8	42.22	43.86	45.51
D9	33.96	35.61	37.25
D10	41.44	43.09	44.73
D11	22.2	23.84	25.49
D12	7.67	9.32	10.96

Source: http://antropometriindonesia.org /index.php/detail/sub/3/4/0/dimensi_antropometri

2.4.1 **Definition of the exoskeleton**

The exoskeleton is part of the mechanical exoskeleton used to help, restore, improve and improve the functioning of the body's motion system

2.4.1.1 Application of Human Exoskeleton

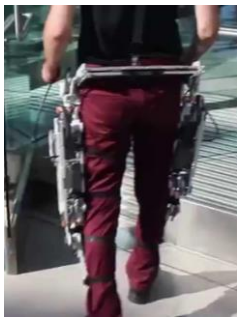
Exoskeleton is a tool for physical therapy exercises that are generally used to help lighten one's movement especially in construction world but exoskeleton also used for medical. Physical therapy exercises routinely performed by stroke survivors have shown positive results in increased lower limb capability, functional mobility (balance and walking) and quality of life (Dalgas et al., 2008; Motl and Gosney, 2008). Some kinds of medical acts that use exoskeleton for rehabilitation problems such as patients with cerebral palsy, spinal disorders, and stroke also have a different approach. In this design, exoskeleton is used for post-stroke patients.

Eksoskeleton itself is generally applied between the two body parts of the upper body (upper limb) and the lower body (lower limb).

3.4.1.2 Lower limb types:

Table 2 Types of Exoskeleton

Type Exoskeleton	Note
 Figure 8 powered-exoskeleton	*powered-exoskeleton*
 Figure 9 Knee powered-exoskeleton	*Knee powered-exoskeleton*
 Figure 10 Knee ankle powered-exoskeleton	*Knee ankle powered-exoskeleton*
 Figure 11 Hip powered-exoskeleton	*Hip powered-exoskeleton*

 Figure 12 Hip knee powered-exoskeleton	*Hip knee powered-exoskeleton*
 Figure 13 Hip knee ankle powered-exoskeleton	*Hip knee ankle powered-exoskeleton*

2.4 Prospect of Rapid Prototyping

In recent years, rapid prototyping technology (RPT) has been implemented in many spheres of industry, particularly in the area of product development. Existing processes provide the capability to rapidly produce a tangible solid part, directly from three dimensional CAD data from a range of materials such as photo curable resin, powders and paper. RPT is a technology that let us transform digital designs into 3-dimensional solid objects for production of machine parts, models, prototypes, and molds. It builds solid objects one layer at a time, producing high quality models overnight instead of taking weeks or months.

They are made up of different processes some of which are:

a. stereo lithography (SL)
b. selective laser sintering (SLS)
c. laminated object manufacturing (LOM)
d. fused deposition model (FDM)
e. direct shell production (DSP)
f. 3D Printing

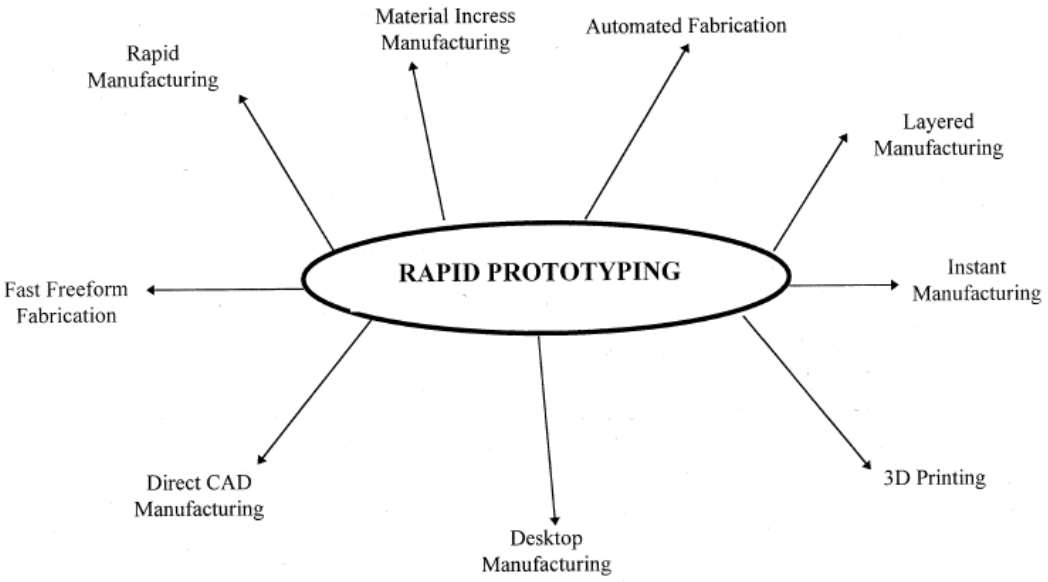


Figure 14 Rapid prototyping scheme

2.4.1 3D Printing

3D printing, also known as additive manufacturing (AM), refers to processes used to create a three-dimensional object in which successive layers of material are formed under computer control to create an object. 3D printable models may be created with a computer-aided design (CAD) package, via a 3D scanner, or by a plain digital camera and photogrammetry software. 3D printed models created with CAD result in reduced errors and can be corrected before printing, allowing verification in the design of the object before it is printed (wikipedia.com)

2.4.3.1 Trend of 3D Printing

The existence of 3D printing technology has begun in some forms since the 1980s. This technology currently is used as the alternative in making products. However, the technology has not been capable enough or cost-effective for most end-product or high-volume commercial manufacturing. An emerging class of mid-level 3D printers is starting to offer many high-end system features at lower price points. In a recent survey of more than 100 industrial manufacturers, two-thirds were already using 3D printing.

Figure 1: Prototyping has driven the adoption of 3D printing so far. Future opportunities 3D printers chiefly used for prototyping.

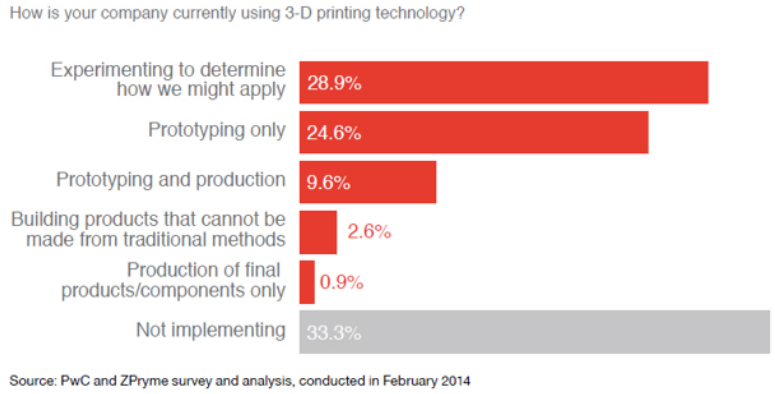


Figure 15 Implementation of 3D Printing

In addition, 3D printing also is approached by some industry sectors to enhance the design and manufacturing strategies. Technology for 3D printing advanced through three areas: printers and printing methods, software to design and print, and materials used in printing. Here, the uses of 3D printing in industrial sector.

2.4.3.2 Materials for 3D Printing

Filament is the material used in the printing process or the material which is extruded in 3D engines Print. Here is the following types of material for 3D Printing:

Table 3 Material of 3D Printing

No.	Material	Description
1.	 Figure 16 PLA (Polylactic Acid)	PLA filament is one of two types of materials which commonly used in 3D print process besides filament ABS. PLA filament has several advantages such as: odorless, low-warp, and requires a low heat bed. In addition, the PLA filament is an environmentally friendly material, made from corn starch which is a renewable resource and requires less energy to process than the traditional plastic (petroleum-based). Extruder Temperature : 180^0 – 220^0C

		Bed Temperature : 20^0 – 55^0C Bed Adhesion : Blue Painters Tape Diameter Filament : 1.75mm, 3mm
2.	 Figure 17 ABS (Acrylonitrile Butadiene Strene)	ABS is a filament material commonly used in 3D print process besides PLA filament. It is used to create 3D models which are durable and withstand higher temperatures. When compared with PLA filament, filament ABS tends to be a bit iffy but more tenacious. This materials will be shiny if it is combined with acetone. Extruder Temperature : 220^0 – 235^0C Bed Temperature : 80^0 – 110^0C Bed Adhesion : Kapton Tape/Hairspray Diameter Filament : 1.75mm, 3mm
3.	 Figure 18 PET (PETG, PETT) Polyethylene Terephthalate	PET filament strength better than PLA filament. Unlike filament ABS, barely curved (warps) and does not cause odors or smoke when printed, PET Filament is/i943 not biodegradable, but 100% filament PET can be updated. Extruder Temperatur : 230^0 – 255^0C Bed Temepratur : 55^0 – 75^0C Bed Ahesion : Blue Painters Tape Diameter Filament : 1.75mm, 3mm

2.4.2 Laser Cutting

Laser cutting is a technology that uses a laser to cut materials, and is typically used for industrial manufacturing applications, but is also starting to be used by schools, small businesses, and hobbyists. Laser cutting works by directing the output of a high-power laser most commonly through optics. The laser optics and CNC (computer numerical control) are used to direct the

material or the laser beam generated. A typical commercial laser for cutting materials involved a motion control system to follow a CNC or G-code of the pattern to be cut onto the material. The focused laser beam is directed at the material, which then either melts, burns, vaporizes away, or is blown away by a jet of gas,[1] leaving an edge with a high-quality surface finish. Industrial laser cutters are used to cut flat-sheet material as well as structural and piping materials.

Table 4 Material for Laser Cutting

No	Material	Material thickness				
		0.51 mm	1.0 mm	2.0 mm	3.2 mm	6.4 mm
1	Stainless steel	1000	1000	1000	1500	2500
2	Aluminum	1000	1000	1000	3800	10000
3	Mild steel	-	400	-	500	-
4	Titanium	250	210	210	-	-
5	Plywood	-	-	-	-	650
6	Boron/epoxy	-	-	-	3000	-

2.1.1 Material

Some materials need to be considered in making the exoskeleton. Herewith the material iformation which can be used as the reference of the major frame of the exoskeleton:

Table 5 Materials of Exoskeleton

Material	***Strenght***		***Density*** (kg/m^3)
	δy (mpa)	δts (mpa)	
 Figure 19 Aluminium Sumber : http://byjus.com/chemistry/occurrence-and-extraction-of-aluminium/	500	600	2950

 Figure 20 Steel Sumber : http://acmebrassplating.com/iron-steel-stainless-steel-finishes/	18	18	300-500
 Figure 21 Stainless Steel Sumber : http://www.thomasnet.com/articles/custom-manufacturing-fabricating/steel-fabricating-process	860	502	502
 Figure 22 Carbon Sumber : http://www.fiberglassfiber.com/Item/list.asp?id=158	-	3000	1630

2.4.3 Technical Aspect

A wide range of systems and supporting devices in developing / designing footwork exoskeleton and must be adapted to the concept and needs of the design object.

2.1.2 Actuator

The propulsion system used varies greatly which is the center of propulsion degrees of freedom in the joint robot. Large actuators are used, adapted to the size of the device, the torque and power required for the exoskeleton to move according to predetermined requirements

a. Motor DC

DC motor is a type of motor that is most often used in electronics, especially on robot systems. The reason for the use of a DC motor is in the direction of rotation that can be controlled easily both clockwise and counter-clockwise. DC motor currently used is often servo and stepper.

b. Motor *Servo*

Servo motor is a DC motor with a closed loop system where the rotor position will be informed back to the servo motor circuit which means the encoder system is embedded in the servo device. Motor consisting of DC motor, series of gear, potentiometer, and control circuit.

Figure 23 Motor servo

- **Motor *Stepper***

The stepper motor is an electromechanical device that works by converting electronic pulses into discrete mechanical motions. The stepper motor moves based on the money pulse given to the motor. Therefore, to drive the motor required a stepper motor controller that generates periodic pulses

Figure 24 Motor Stepper

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CHAPTER 3. RESEARCH METHODOLOGY

3.1 Research Scheme

Some methods will be used in designing the exoskeleton for post stroke patient. The research methodology is summarized on the flowchart given as follows

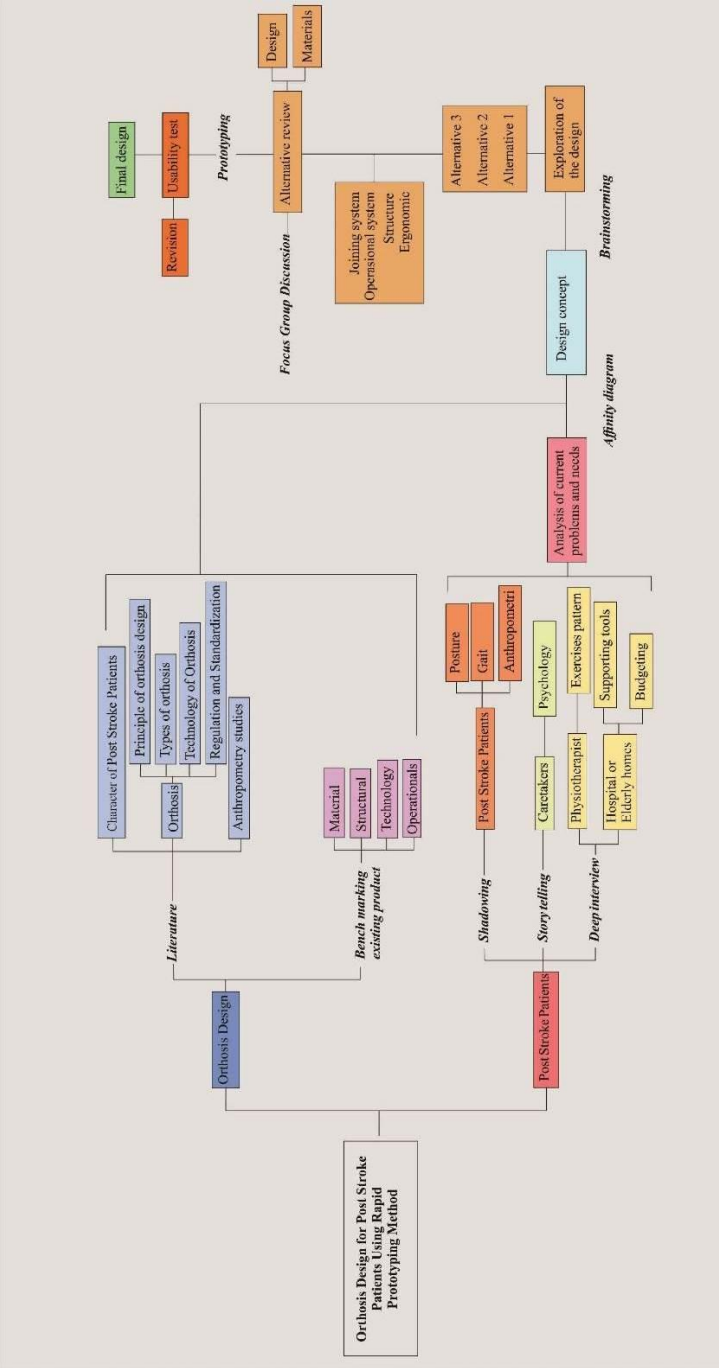


Figure 25 Research methodology

The research method basically will be divided into 4 major steps including preliminary data collection, problem analysis, design and prototyping. Exoskeleton and post stroke itself will be the main focus in the preliminary data collection. A literature review on exoskeleton and products bench marking have been done to get a better understanding about the exoskeleton itself. On the other hand, an intensive observation by having shadowing, storytelling and deep interview was executed to identify further problems and needs of the post stroke patients and its stake holder. After the primary problems and needs is evaluated, the process leads to designing the solution's concept. In addition, the chosen design will be prepared to have a prototyping process. As the cutting edge, a final design will be an output of the usability testing of the selected prototype.

3.2 Data Collection

The data collection in this project will be carried out to gather all of the information regarding the current existing of exoskeleton design. The data collection process will be divided into two major types which includes:

a. Primary data

Table 6 Shadowing

Method : Shadowing	
Subject	Post stroke patients
Place	Panti Werdha Hargo Dedali, Surabaya
Time and duration	Tuesday, at 21st March 2017, 08.00-12.00
Objective	To identify the activities of the patients
From the observation, some information which can be obtained including: • The user's activities • The problem during activities • User's design prevalence	

Shadowing which is also known as fly-on-the-wall observation is used to get the data about the activities of the user by having an observation without taking a part on their activities. The shadowing activities was held on

Tuesday, at 21st March 2017. This activities took a place at Panti Werdha Hargo Dedali, Surabaya.

Figure 26 the activity at Panti Werdha Hargo Dedali

1. Deep interview

Deep interview was done in order to get the information about the current treatment for post stroke patients at the hospital. The interview was done at RS Dr. Soetomo, Surabaya. In addition, the interview also will involving the therapist to know more about the acceptable rehabilitation exercise for the patient.

Figure 27 the interview at RS Dr. Soetomo, Surabaya

Table 7 Interview

Method : Interview 1	
Subject	Stakeholder-doctor (hospital)
Place	RS Dr. Soetomo, Surabaya
Time and duration	2nd May 2017, 08.00-13.00
Objective	To know the hospital regulation and current condition & assistance for post stroke patients
From the observation, some information which can be obtained including: • The hospital regulation, budgeting • The current treatment for post stroke patients	

Figure 28 *the interview at* RS Dr. Soetomo, Surabaya

Table 8 Interview 2

Method : Deep interview	
Subject	Stakeholder-exoskeleton maker (hospital)
Place	RS Dr. Soetomo, Surabaya
Time and duration	2nd May 2017, 08.00-13.00
Objective	To know the production process of the exoskeleton in hospital

From the observation, some information which can be obtained including: • The material needed to make exoskeleton • The process of exoskeleton making in the hospital

2. Story telling

In addition to the previous method to know more about the patient's activities, this method also could be used to get a deep information about their daily lives. People who live with the post stroke patients or the care takers will easily tell the stories which can be used to identify some of the problem from different perspectives.

Table 9 Story Telling

Method: Story telling	
Subject	Caretaker
Place	Panti Werdha Hargo Dedali, Surabaya
Time and duration	Tuesday, at 21st March 2017, 08.00-12.00
Objective	To know the daily activities and lifestyle of the patients
From the storytelling, some information which can be obtained including: • The daily activities of the patients • The lifestyle of the patients	

b. Secondary data

1. Literature review

Some data such as post stroke symptoms, gait pattern, anthropometry and exoskeleton itself were gathered by having the literature review from journals, books and websites. Later, this data can support the primary data to reinforce the design concept.

2. Benchmarking

Benchmarking will be used as the comparison between several exoskeleton products in the market. In this approach, some important points such as product details, materials and cost, will indicate the advantages and disadvantages of each product and lead to influence the design concept as well.

3. Affinity diagram

Based on the data gathered, there will be some difficulties in compiling it into the information which match the design problems and needs. Affinity diagramming externalize and meaningfully cluster observations and insights from research. This method helps to identify the current data and head it into the interesting point of view. Also, it helps to capture research-backed insights, observations, concerns, or requirements on individual sticky notes, so that the design implication of each can be fully considered on its own. Notes are then clustered based on affinity, which form into research-based themes. So the data will be group based on the issues which is familiar and connecting each other's.

4. Brainstorming

Brainstorming has traditionally been used to spur creativity with the intention of generating concepts and ideas regarding a specific topic. In this project, brainstorming will be used to generate the ideas into product alternatives. As the cutting edge, this research will sum up 3 alternatives and 1 final design.

5. Prototyping

After the alternative design selected, it will be execute by having the prototyping. This process will help to do the usability test with the post stroke patient. Then the data could be used as the additional review to improve the current design.

CHAPTER 4. DESIGN STUDIES AND ANALYSIS

4.1 Condition of Post Stoke Patients

Post stroke patients had some level of paralysis which can be classified in some different ways. The condition related in this research will be limited to the injury level of having weakness in a leg but still be able to walk in short distance with braces or assistive device. The identification of post stroke condition include:

a. Posture Analysis of Post Stroke Patient

People with post stroke syndrome has different posture in compare with normal people. The abnormal posturing is happened because of the leg or arm's involuntary flexion or extension. Several differences of the abnormal posturing between normal people and post stroke patients can be shown as follows:

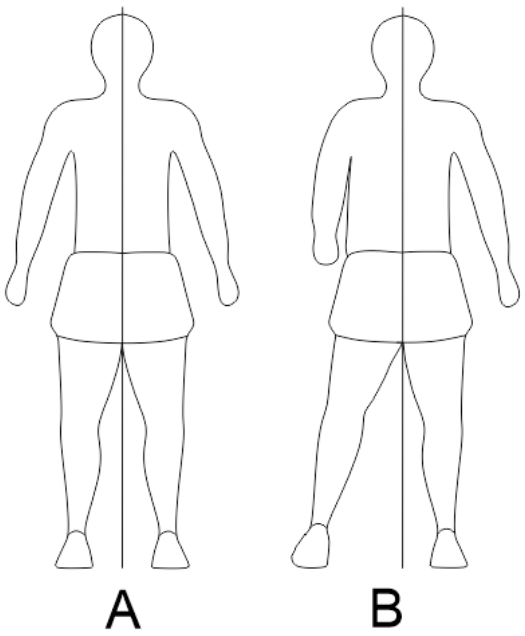


Figure 29 (a) posture of normal people (b) posture of post stroke

According to the picture it can be seen that the post stroke patient had unbalance posture condition. The injured leg will stay away from the center of the body. In addition, the foot tend to drop as the result of the weakness in the front muscle of the leg.

Table 10 Condition of Post Stroke

Based on the observation, the posture of post stroke patients can be described:

Picture	Condition
  Figure 30 Condition of Post Stroke	Hemiplegia posture • HEAD: Lateral flexion toward the involved side with rotation away from the involved side. • UPPER EXTREMITY : Scapula - depression, retraction Shoulder - adduction, internal rotation Elbow - flexion Forearm - pronation Wrist - flexion, ulnar deviation Fingers – flexion • TRUNK : Lateral flexion toward the involved side • LOWER EXTREMITY : Pelvis - posterior elevation, retraction Hip - internal rotation, adduction, extension Knee - extension Ankle - plantar flexion, supination, inversion Toes – flexion, clawing

b. Gait

Patients who have experienced a stroke and have functional gait patterns that differ from those observed in healthy persons. It is also associated with an increased risk of falling. Normal gait tends to be symmetrical, both spatially and temporally, with interlimb differences from vertical force of the body. According to the observation, here the difference between normal foot and drop foot during walking.

Table 11 Difference between normal and drop foot

No	Normal foot	Drop foot
1.	The foot moves forwards (swing phase)	The swing phase may involve bending the leg at the knee to lift the foot away, rather like climbing stairs
2.	The foot touches the ground. This is usually first with the heel (initial contact, sometimes called heel strike or foot strike) and then forwards on to the ball of the foot	The initial contact is not with the feet but with the whole of the foot which 'slaps' or plants on to the floor at once
3.	The foot pushes off and leaves the ground again (terminal contact, or 'foot off').	The 'foot off' motion does not function properly at all and a walking stick or cane may be needed to help lift the foot.

Anthropometry Analysis

a. Critical Point

In designing the exoskeleton for post stroke patients, there were some critical point of the leg part which is needed to consider. A correct measurement in the critical point definitely effecting the amenities of the exoskeleton.

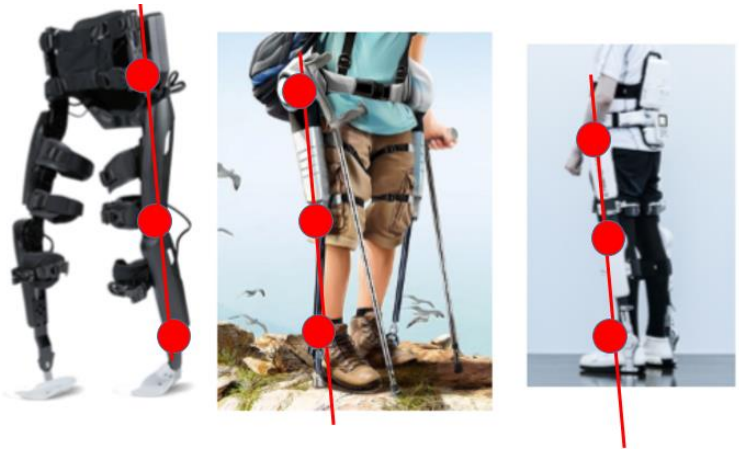


Figure 31 Critical Point

The critical point were mention as follows:

a. Foot length
b. Foot wide
c. Knee to foot length
d. Upper shank diameter
e. Lower shank diameter

4.3 Analysis of User Need

Based on the observation from the user, it could be summarized that some variables need to be considered as the product will have a total contact with user's leg. Those variable can be identified as follows:

Table 12 User Needs

No	Aspect	Need	Description
1	Function	Maximum accuracy	The maximum accuracy is needed because the difference in measurement of each people's leg. The maximum accuracy will support the alignment of the foot in comfortable position

		Skin-friendly	Most of the part of the exoskeleton will have a maximum contact with the user, so the skin-friendly material is needed. The material such as fabric could be used as the finishing of the exoskeleton to avoid skin from damage
2	Aesthetic	Lightweight	Lightweight exoskeleton product is the solution needed to resolve the current exoskeleton product which is has more than 1-2 kg in weight
3	Value	Independent operational setting	In order to enhance the independent of post stroke patients, the need for easy operational setting to use the exoskeleton is needed
		Enhancing Confidence	People with post stroke syndrome were mostly come around more than 40 years old whose still need to have good appearance in order to socialize with other people

4.3 Activities Studies

The activities of post stroke patients need to be considered in order to keep the patient in well condition. The identification of activities which might be done by the post stroke patients and some consideration that need to be concerned is divided as follows:

4.3.1 Study Activities

Indoor activities mentioned some activities inside home which is usually have done by post stroke patients, as follows:

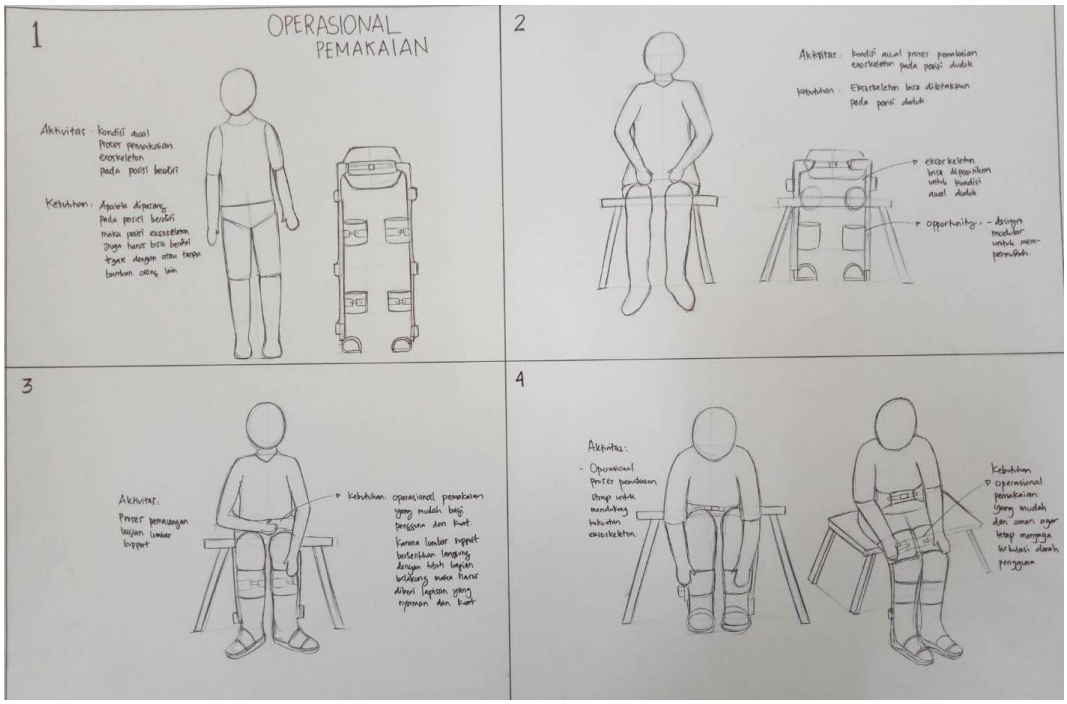


Figure 32 Activities Studies

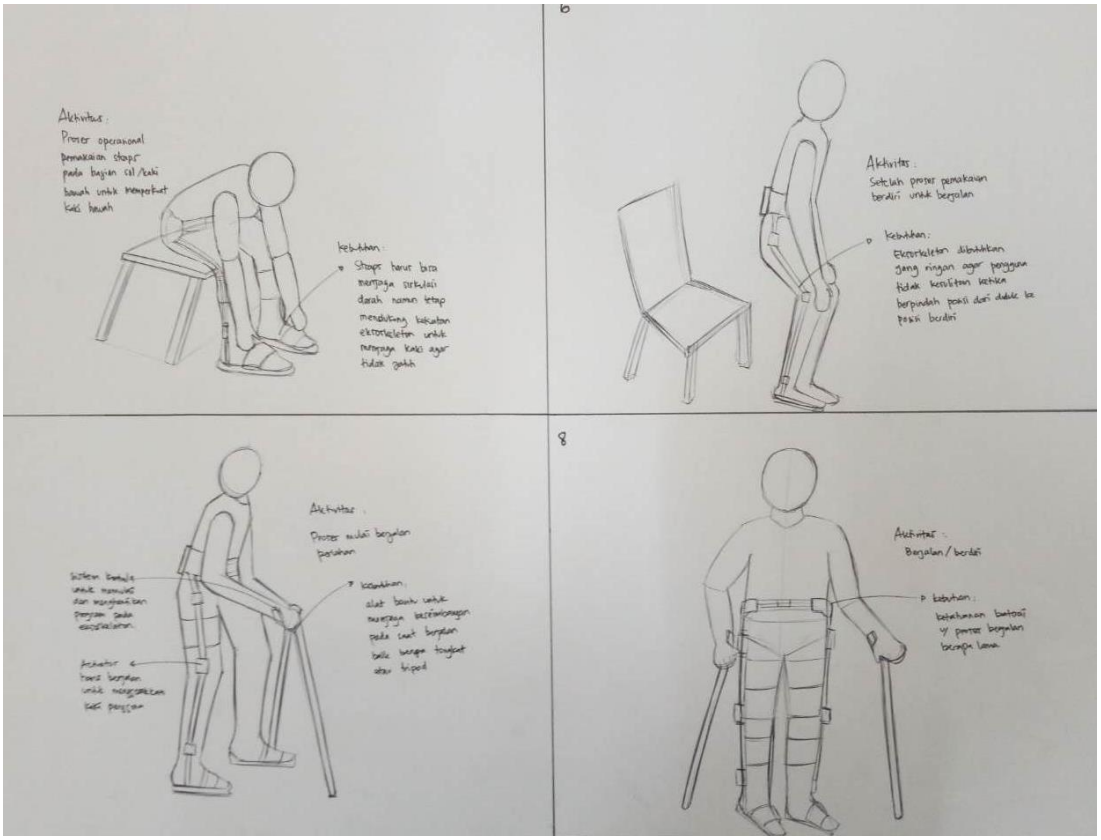


Figure 33 Activities Studies

Based on the breakdown of the activities which done by the post stroke patients at home, it can be marked that the most frequent activities to do is walking in short distance. In order to complement the condition, an exoskeleton is proposed to support the post stroke patients to accommodate a short distance mobility at home. As for the future development of the proposed exoskeleton will take in the outdoor activities as consideration.

4.4 Benchmarking Product

Exoskeleton product for post stroke syndrome such as foot drop recently is developed by many countries in the world. A comparison of the recent exoskeleton product was summarized as follows:

Figure 34 Existing Product

According to the existing products aforementioned, the various exoskeleton could be differ based on the production base, cost, materials, sizing type, technology used, product structural and the operational.

4.5 Production Analysis

Production is an important process which need to be considered in some ways. Based on the observation from the hospital and the information from literature studies, the making process of exoskeleton included manual and 3D printing process described as follows:

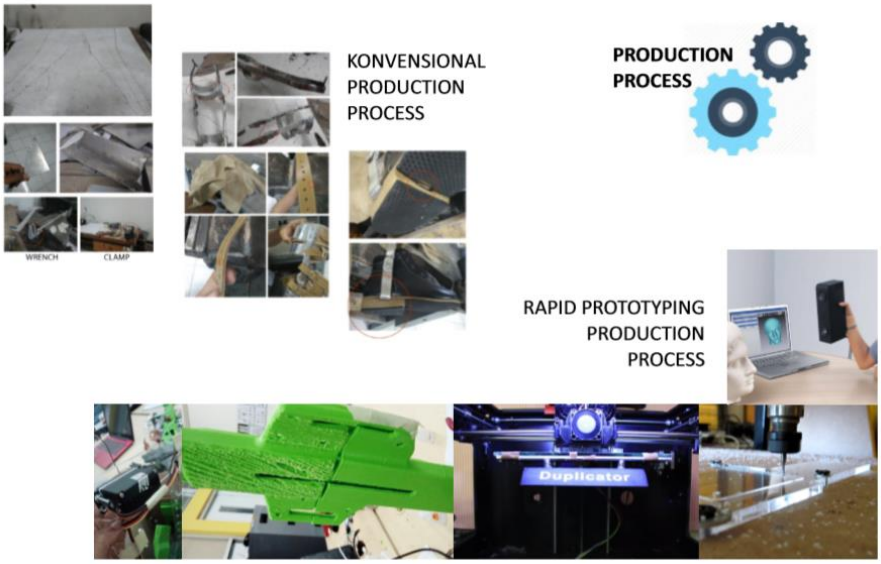


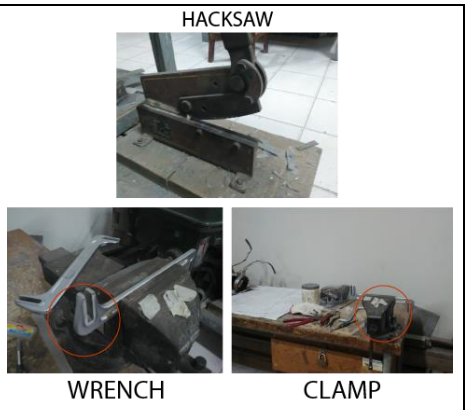
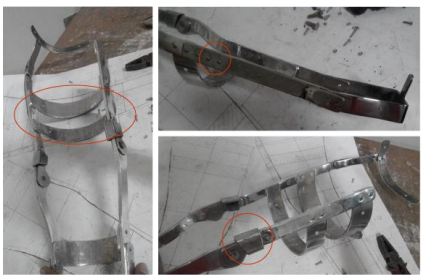
Figure 35 Production Process

4.8.1 Manual Production

Indoor activities mentioned some activities inside home which is usually have done by post stroke patients, as follows:

Table 13 Manual Production Process

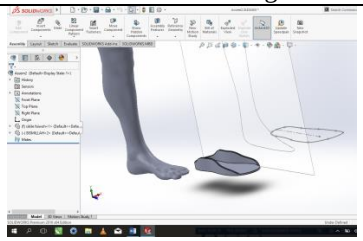
No	Process	Consideration	Picture
1	Measure the patients' leg	Measurement tolerance (approx. 1-2 mm)	 Figure 36 Measurement of leg
2	Preparing the material used	Type of material	 Figure 37 Material used

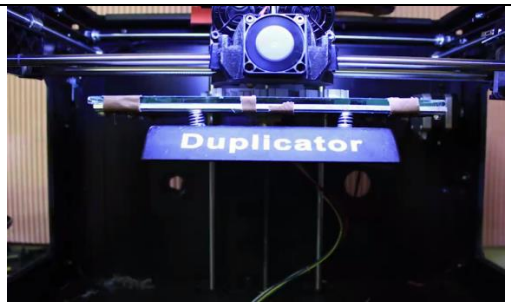
3	Cutting the material	Measurement tolerance (approx. 1-2 mm)	 Figure 38 The tools
4	Shaping the material	Measurement tolerance (approx. 1-2 mm)	 Figure 39 Duplicated leg to help shaping
5	Settle down the joining system	The joining system used need to be suitable with the side support	 Figure 40 Joining system
6	Making the Strap/Belt	Type of material used to contact with skin, measurement tolerance	 Figure 41 Strapping

7	Attach the metal support with the shoes	measurement tolerance, shoes size tolerance	 Figure 42 Shoes attachment
8	Finishing	Finishing used sander mechine	 Figure 43 Finishing

4.8.2 3D Printing Production

In the other hand, a production process to make an exoskeleton use can a 3D printing.

No	Process	Consideration	Picture
1	Measurement of patient's leg using 3D scanner	Detail every part of the leg	 Figure 44 Measurement using 3D scanner
2	3D Modelling	Making 3D modeling	 Figure 45 Modelling the design

3	Printing	Type of the filament and tolerance	 Figure 46 Printing the design
4	Assembly	The tolerance of each part	 Figure 47 Assembling the part
5	Finishing	Comfortable material used to contact with skin	 Figure 48 Finishing materials

Indoor activities mentioned some activities inside home which is usually have done by post stroke patients, as follows:

Table 14 difference between manual and 3D printing

No	Indicator	Manual production	3D Printing
1	Accuracy	Low accuracy	High accuracy
2	Time	Approx. 2 weeks	Approx. 1 week
3	Resource	3-4 human resources	1-2 human resources
4	Machinery	More than 3 machineries	Not more than two machineries
5	Material	Difficult to get	Easy to get
6	Finishing	Need finishing	Need finishing

Based on above comparison, it can be conclude than 3D printing process is much effective rather than manual production, so the proposed production process for the exoskeleton in this project will use the 3D printing.

4.4 Operational Analysis

Indoor activities mentioned some activities inside home which is usually have done by post stroke patients, as follows:

a. Leg Belt

The existing belt used in the current exoskeleton used a belt which made by a fiber. An elastic or adjustable fiber material is needed to keep the exoskeleton following the contour of the lower leg.

Figure 49 Belt

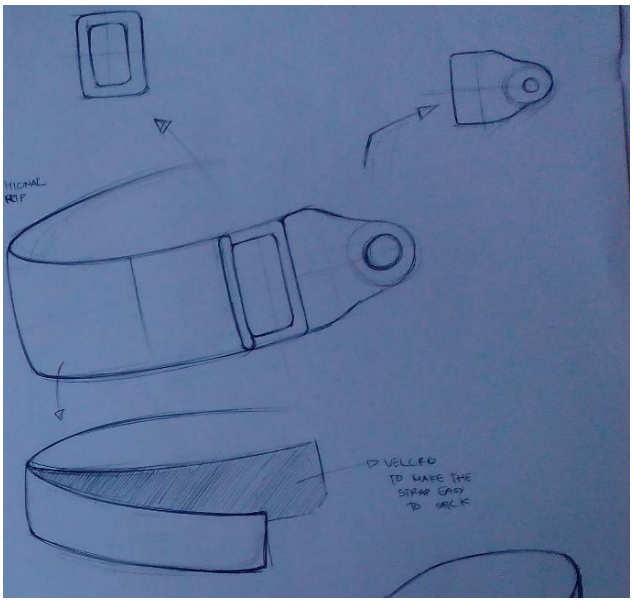


Figure 50 Belt sketch for AFO

b. Hip Belt

Hip Belt is used to comforting the middle part of the body while using the exoskeleton. As it is used as the main point to keep the exoskeleton balance, so

the design needed to be strong and comfy for the user. In addition to that, it is a demand to make it adjustable to deal with different hip measurement of the user.

Figure 51 Belt

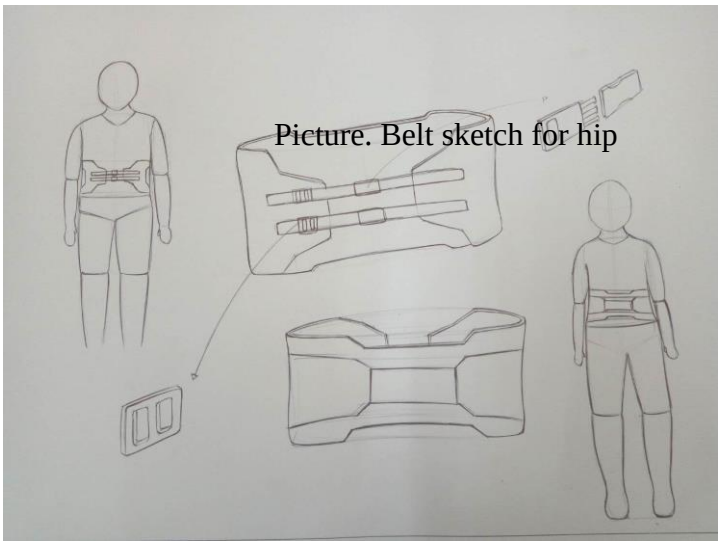


Figure 52 Belt sketch

c. Joint System

The joining system needs for foot drop exoskeleton is the one which need a rotational motion, so it will allow the dorsiflexion movement. Mostly the joint with total rotation movement is on the knee joint.

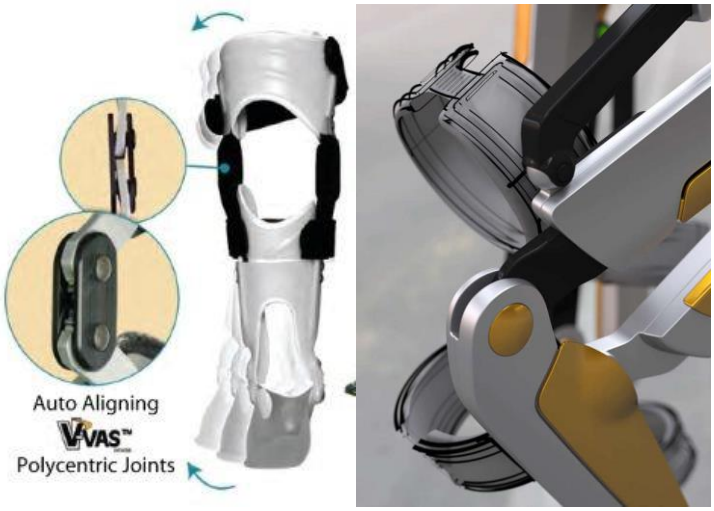


Figure 53 Joining system in KAFO

4.4 Material Analysis

There are some materials which can be used for the exoskeleton. In order to have an effective exoskeleton, some material requirements need to be fulfilled. As an example, steel is commonly used as the material for the exoskeleton in the market because of its strength and rigidness. However, aside of the material's strength and rigidness, herewith the characteristics of feasible materials which can be used as the material for exoskeleton:

Table 15 Material analysis

Material Aspect	Description
Strength	Consider maximum load
Stiffness	Force to displacement ratio
Durability	Ability to withstand a continuous load
Density	Weight per unit volume
Corrosion resistance	Durability of corrosion
Fabrication	The application and engineering formation

In addition to the material aspect which is a crucial factor in designing the exoskeleton, herewith the comparisons graph of several material related to the material aspect such as density, strength, and stiffness.

4.6 Design Development

4.6.1 Inspiration Board

Inspirational board is used to get the inspiration of exoskeleton system as much as possible. The inspiration may not only came from the foot exoskeleton but also from hand or other kind of products. The inspirational board can be seen as follows:

Figure 54 Inspiration Board

4.6.2 Styling Board

Styling board is used to get an insight about some exiting shapes of the exoskeleton which meet the requirements.

Figure 55 Styling Board

Based on the styling board, the exoskeleton refers to have a simple design and following the natural form of human leg. On the other hand, as the contour might following the

natural shape of human leg which is curvy, designer need to pay attention to the strength and manufacturing factor.

4.6.3 Color and Impression

Based on the healthcare color studies, some color such as blue, green, light blue, black and others were used in healthcare product. To make the exoskeleton looks like a patients care items so the color which will be used in this product is blue.

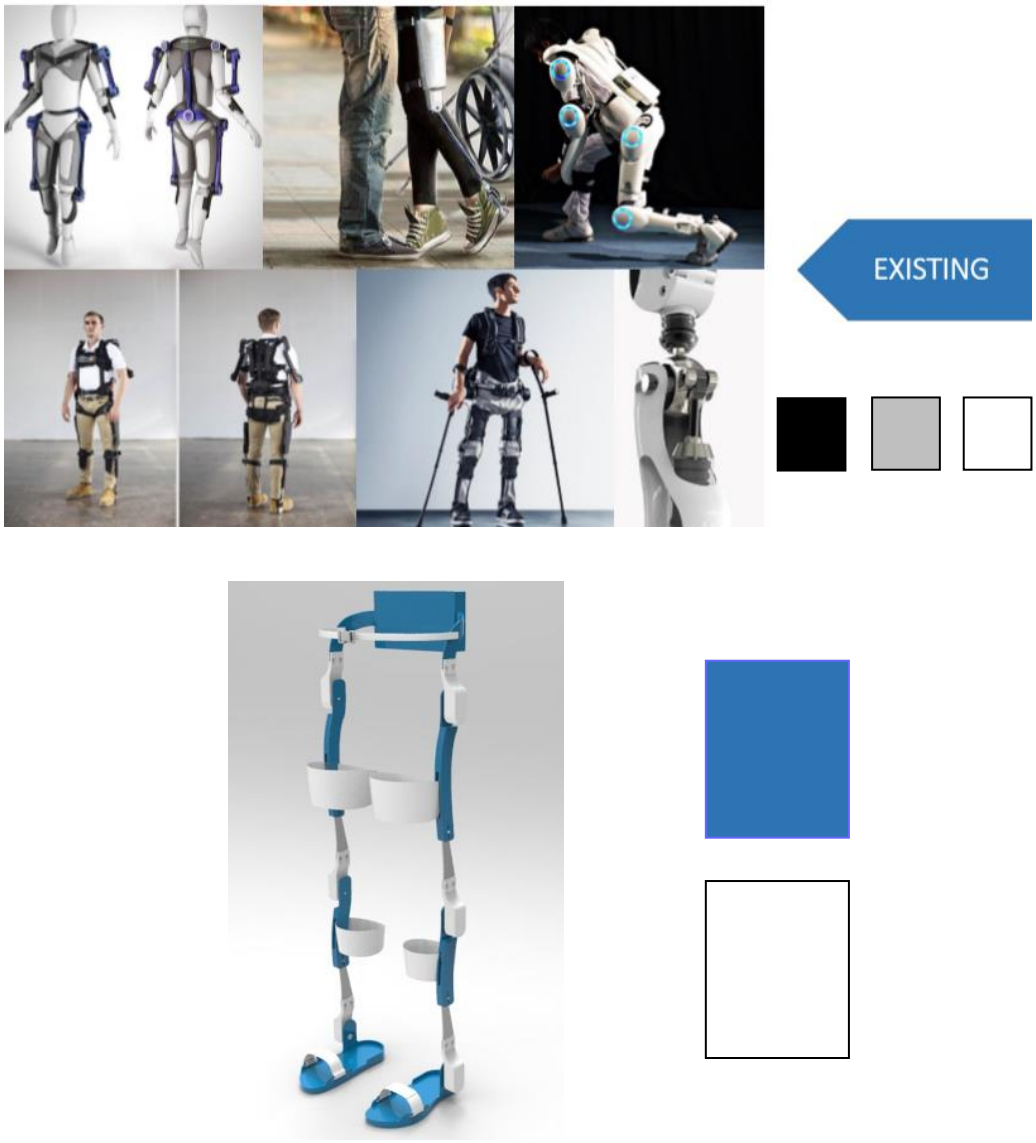


Figure 57 Color studies 1

The blue color used is determined that the exoskeleton as personal or patient care items, so that is why blue color is used in this design. Second, the white color combined with the blue color makes a lightweight impression of the product.

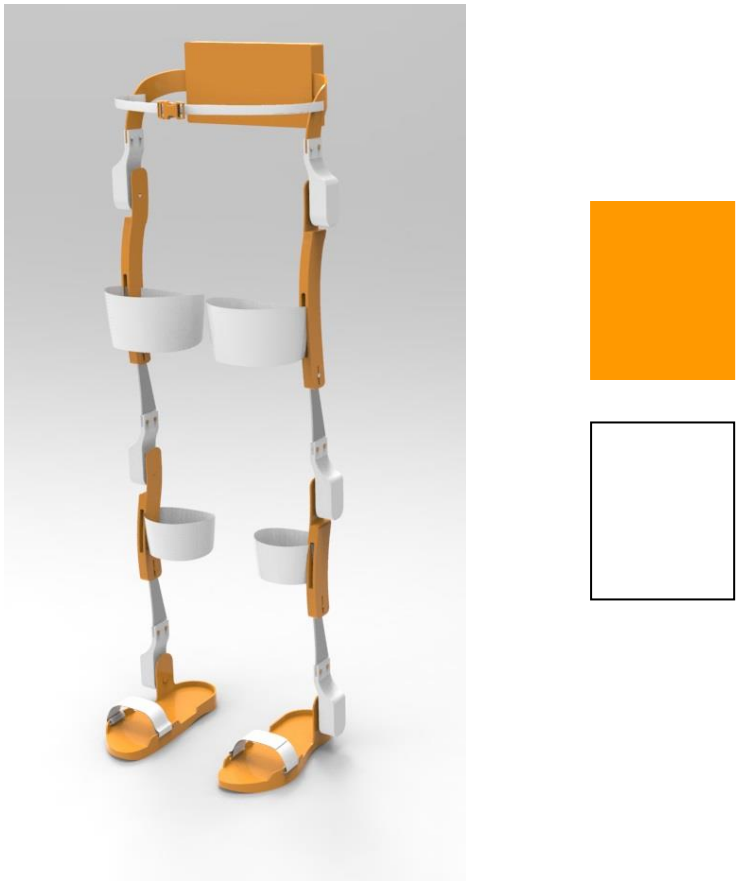


Figure 58 Color studies 2

The orange color used is determined that the exoskeleton as an items which can encourage, spirit and cherish the user, so that is why orange color is used in this design. In addition, the white color combined with the blue color makes a lightweight impression of the product.

5.3 Brainstorming Sketches

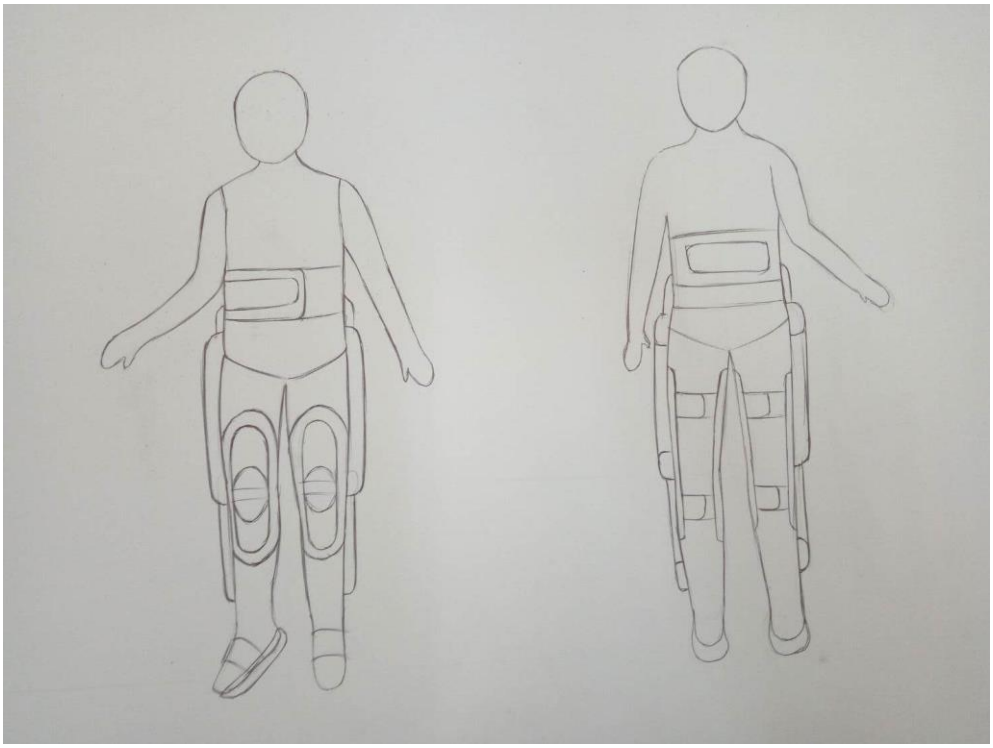


Figure 56 Brainstorming 1

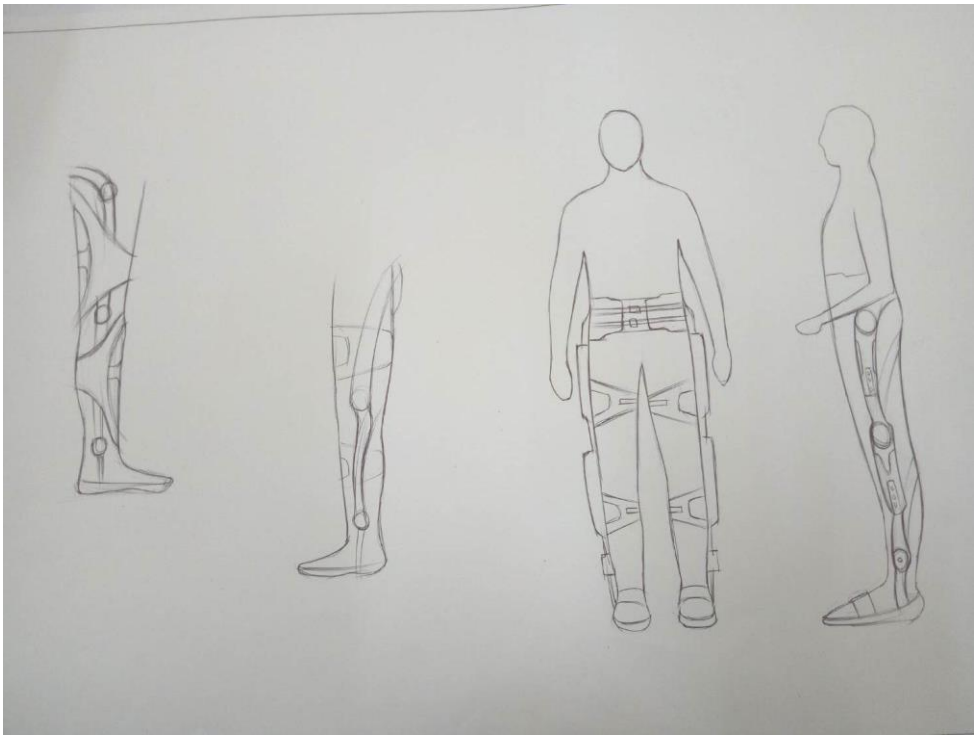


Figure 57 Brainstorming 2

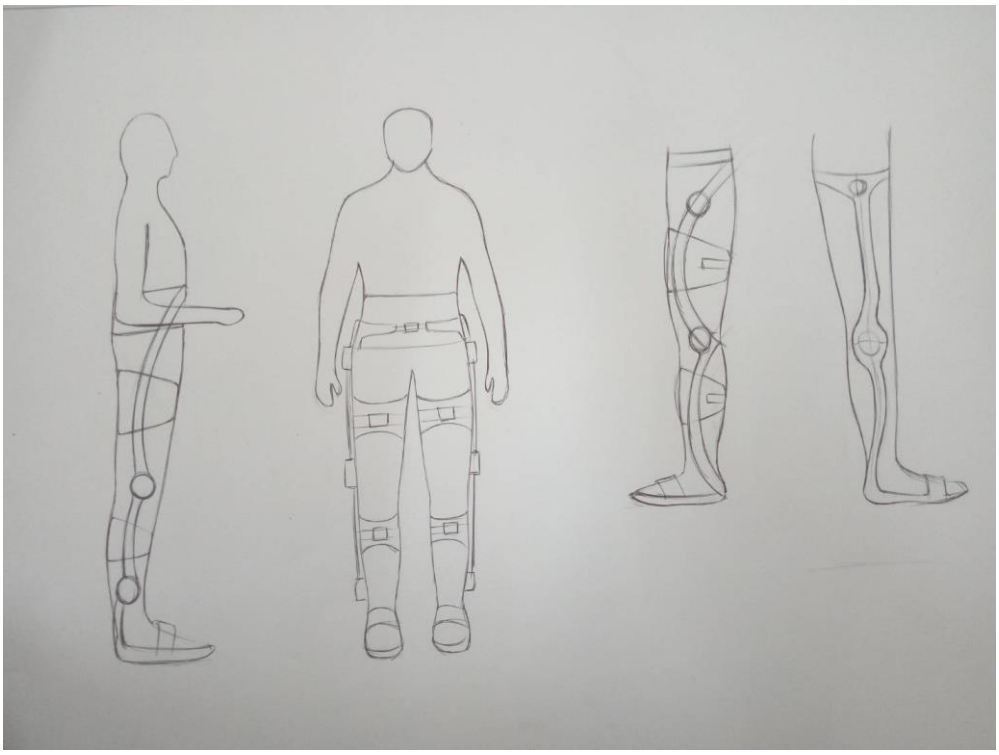


Figure 58 Brainstorming 3

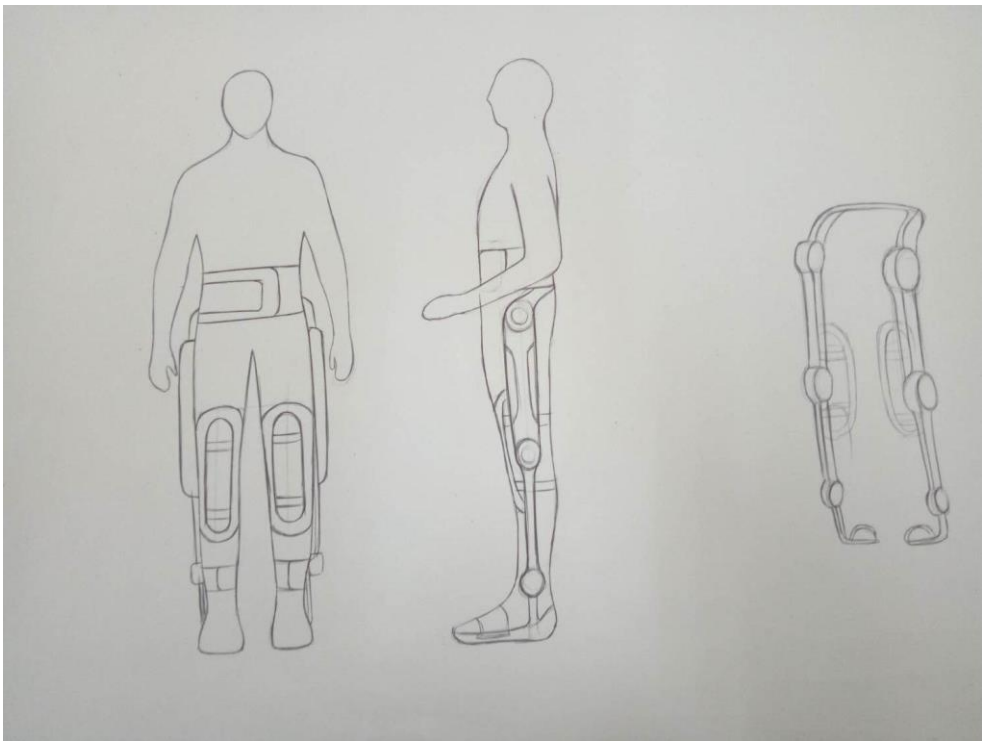


Figure 59 Brainstorming 4

4.7 Market Analysis (STP)

A market analysis including segmentation, targeting and positioning determining the market target for the product. The brief explanation regarding the segmentation, targeting and positioning of the product as follows:

4.7.1 Segmentation

Segmentation analysis describe the demographical, psychographic and behavioral condition, as the result is the user's need

Table 16 Demographic segmentation

No.	Demographic type	Market segment
1	Gender	Male and female
2	Location	East Java
3	Income	IDR <2.000.000
4	Social status	Low - Middle economical background
5	Age	30-70 years old

Table 17 Psychographic segmentation

No.	Psychographic **type**	Market segment
1	Hobbies	Reading, Travelling
2	Lifestyle	People who start to concern about a healthy lifestyle
3	Social circle	Having a circle with co-workers, old friends and neighborhood
4	Cost sensitivity	Have a caution on high price product. People tend to have a lower cost but also put the functional product as the main concern

4.7.2 Targeting

The user target for this product are the people who have foot drop syndrome after the stroke attack. Both man and woman with an age range around 30-70 years old proposed to be the potential target as people at the age tend to have high possibility of stroke attack. An exoskeleton as proposed tool will be used to accommodate the user in short distance activities at home.

4.7.3 Positioning

As the current exoskeleton product having the same features, herewith the additional positioning analysis which can help determine the design concept of the exoskeleton for drop foot based on some aspects include positioning in cost market, product character and weight.

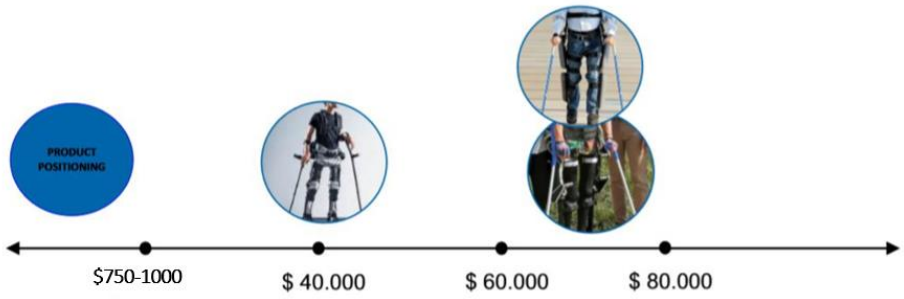


Figure 60 positioning based on cost

The product position based on the cost is arranged to have a price lower than IDR 20.000.000.

Based on the product character, the exoskeleton is determined to be in position between rigid and flexible. The flexibility of the product will support the foot drop during the dorsiflexion. In the other hand, a rigid part will be helpful to avoid the foot drop from falling as the fall will be worse the condition of foot drop.

No	Component	Total
1	Design	4,000,000.00
2	Material	3,000,000.00
3	Servo	9,000,000.00
4	Battery	1,600,000.00
5	Wiring	200,000.00
6	Control	300,000.00
7	Safety	400,000.00
Total		18,500,000.00

4.8 Technical Analysis

During the research, technical experiment is executed with a simple layout for the gait cycle pattern. Servos were used as the main actuators.

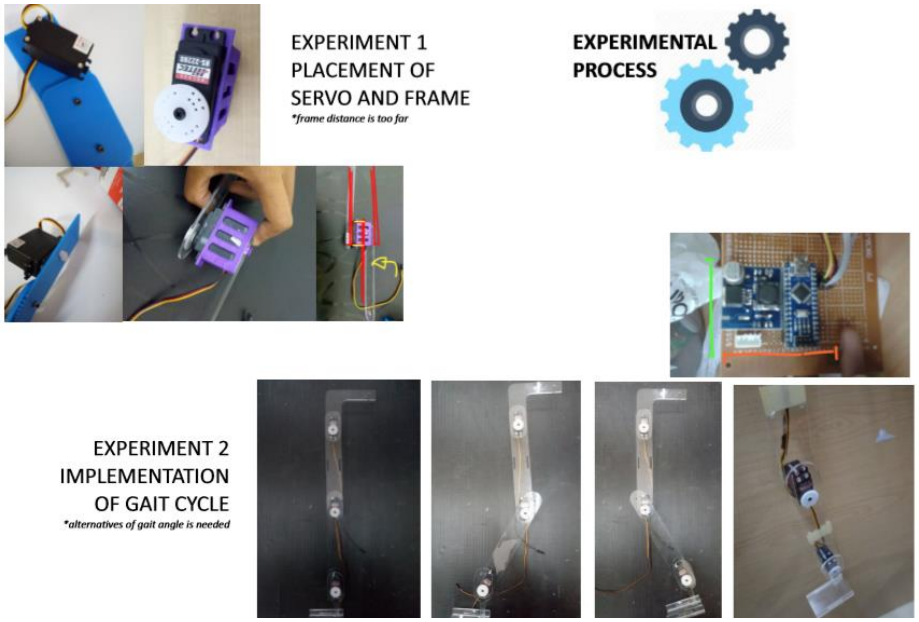


Figure 61 technical analysis

The walking gait angle itself can be summarized as follows

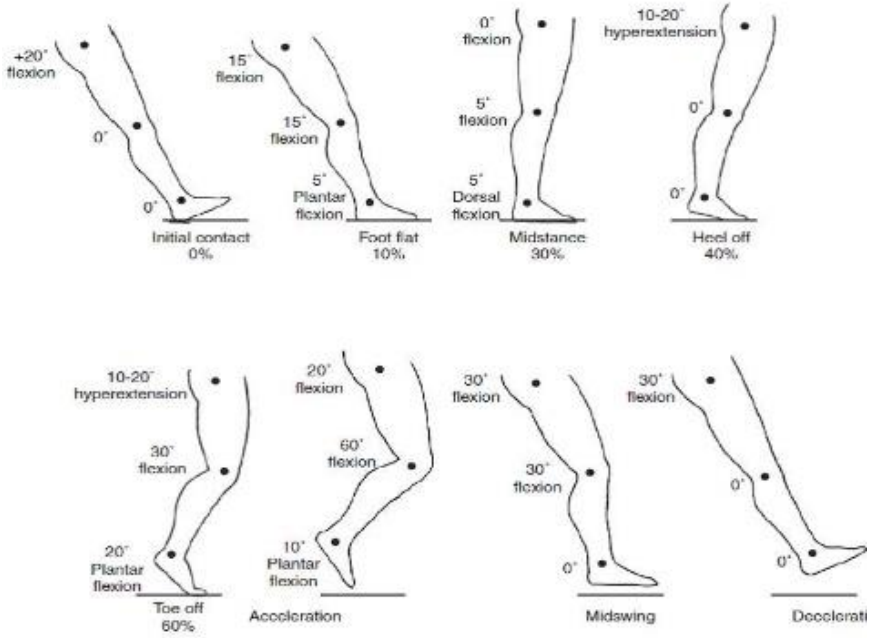


Figure 62 gait pattern

From the first experiment, the gait perform is not quite sooth because the initial frame of the gait is not enough to create a data of walking just like a normal people. Thus, the designer then try the second technical experiment performing the gait data by making a reverse gait pattern. In addition, the main frame was created with a double foundation to make the main frame stronger.

Figure 63 technical experiment

CHAPTER 5. DESIGN CONCEPT

5.1 Design Concept

Based on the design process aforementioned, the design concept of this exoskeleton could be summarize as follows:

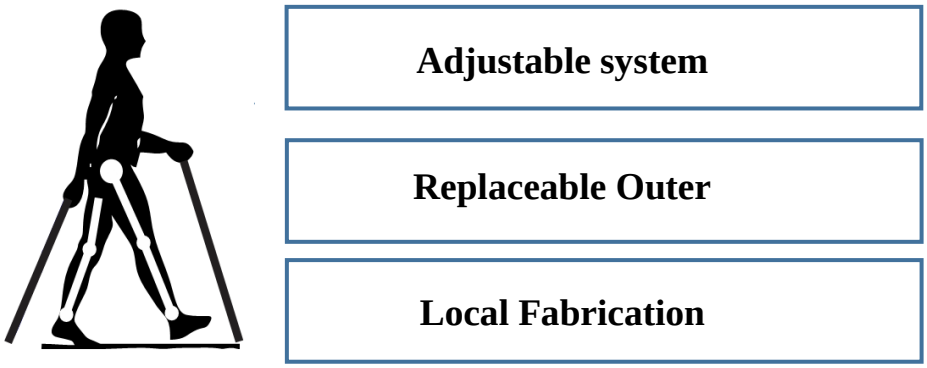


Figure 64 design concept

1. **Adjustable system**

   The adjustable system is needed due to a demand of different anthropometry and condition of post stroke patients. This system enable the frame to be adjusted to suit the patient's measurement.

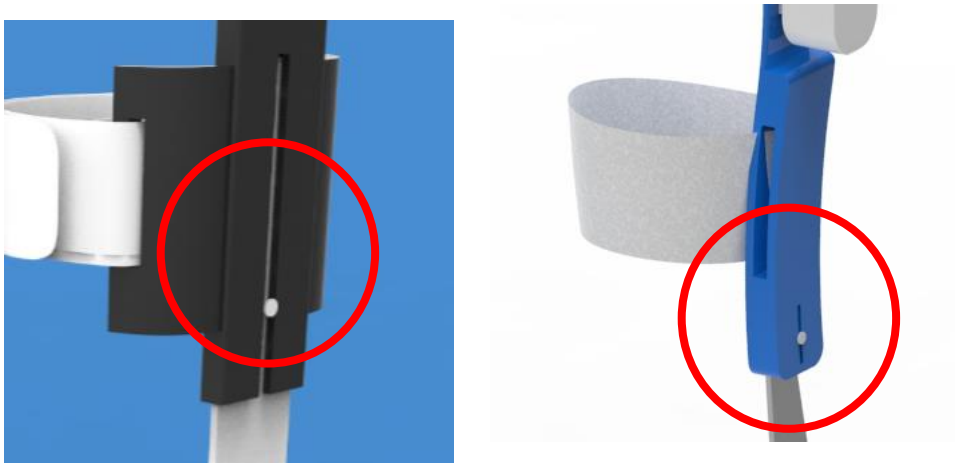


Figure 65 adjustable system

2. **Replaceable outer**

   The replaceable outer has 2 major function. The main function is to covering the frame. In addition to that, it is also used to protect the foundation part as its exoskeleton fall.

   Changing the outer is also improving the visual looks of the exoskeleton while the user is boring use the current outer

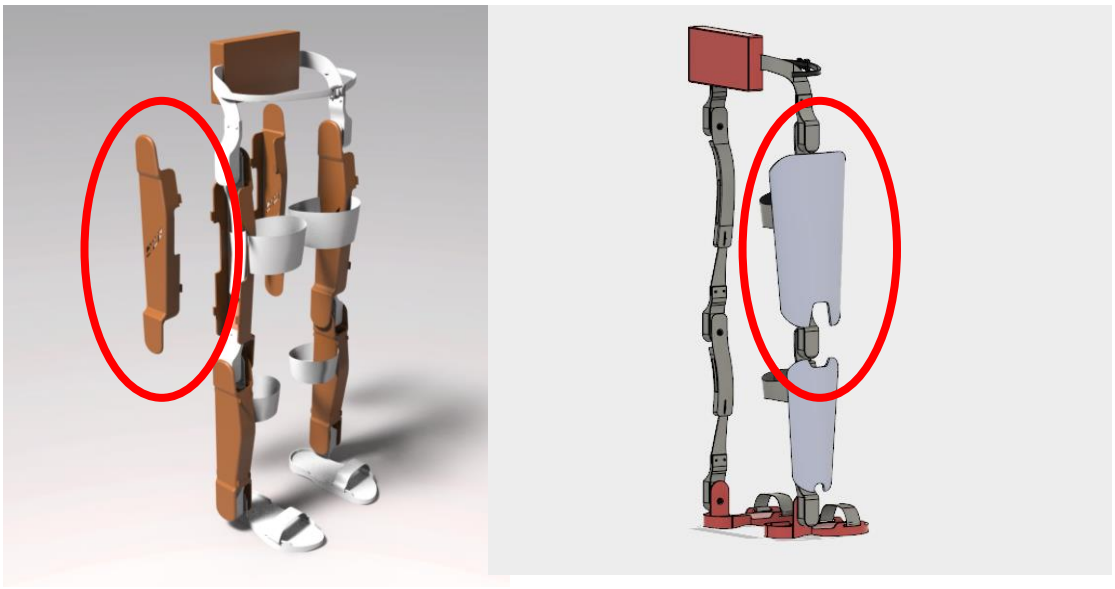
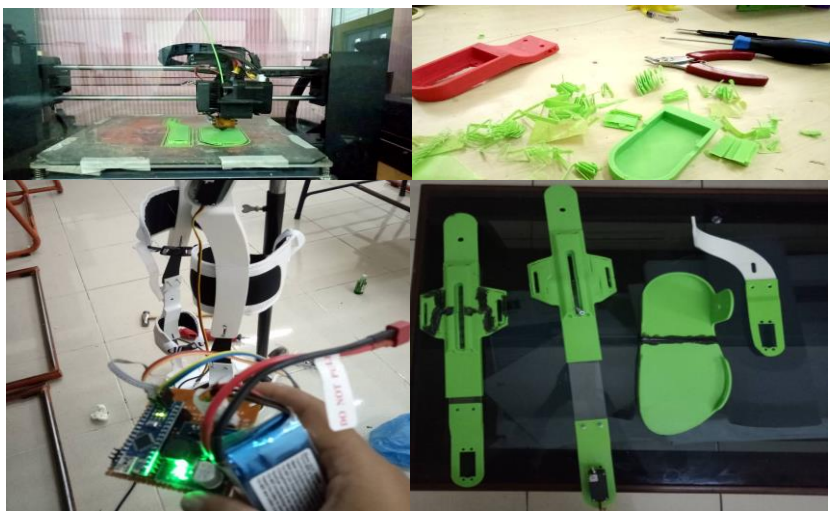


Figure 66 replaceable outer

3. Local fabrication

As the current exoskeleton is mostly were imported from developed countries which cut off to the higher cost of payment, so the demand of exoskeleton which can be fabricated locally is constantly increased. In this project, designer use the 3d printing to create a rapid prototyping of the exoskeleton. Not only 3D printing, a cutting is also proceed to make the additional framing.



5.2 Design Output

5.2.1 Design Alternative 1

Design alternative 1 has a simple frame shape, having a frame that still straight or not yet having a shape that can follow the shape of human limb contours. Design alternative 1 has not an outer which can protect the main frame and give the impression of anesthetic on the frame. Design alternative 1 shown at the figure 69 and figure 70 below.

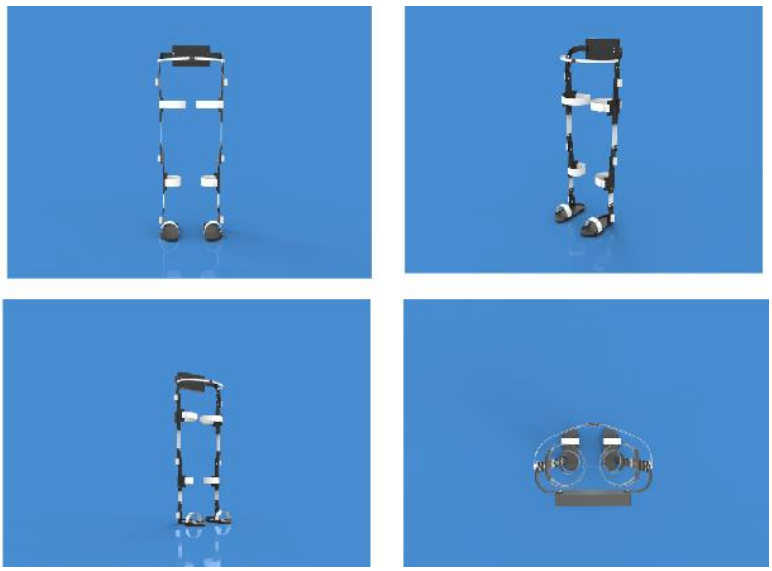


Figure 68 alternative 1

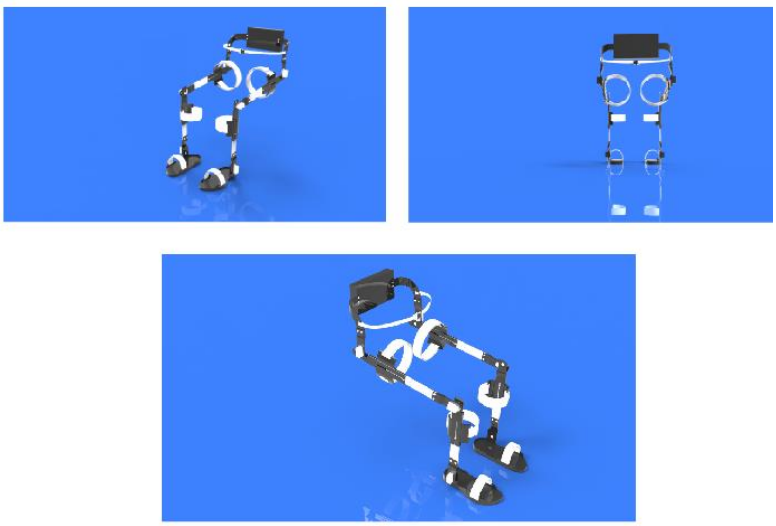


Figure 69 perspective alternative 1

5.2.2 Design Alternative 2

Design alternative 2 has a something different from the design alternative 1. Design alternative 2 has a frame that follow the shape of human limb contours. But, in the design alternative 2 cannot be perfectly curved. Besides, the adjustable system in the design alternative 2 has a flexible system which user can adjust the size according to the desire size or it can be adjusted to suit the user's measurement

Figure 71 alternative 2

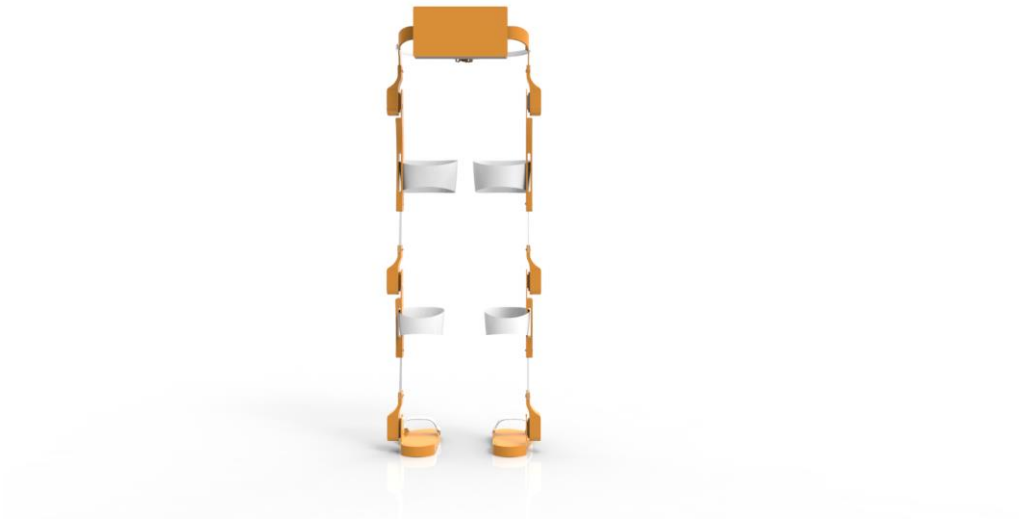


Figure 70 Alternative 2

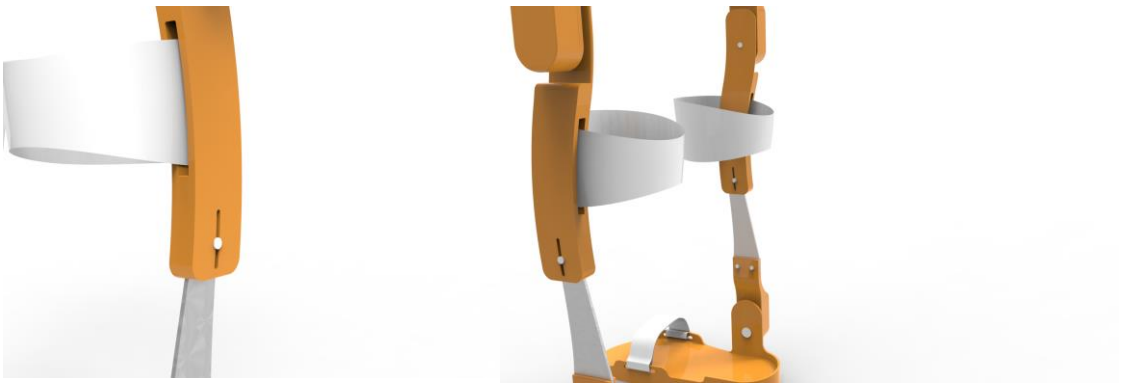


Figure 71 detail of adjustable

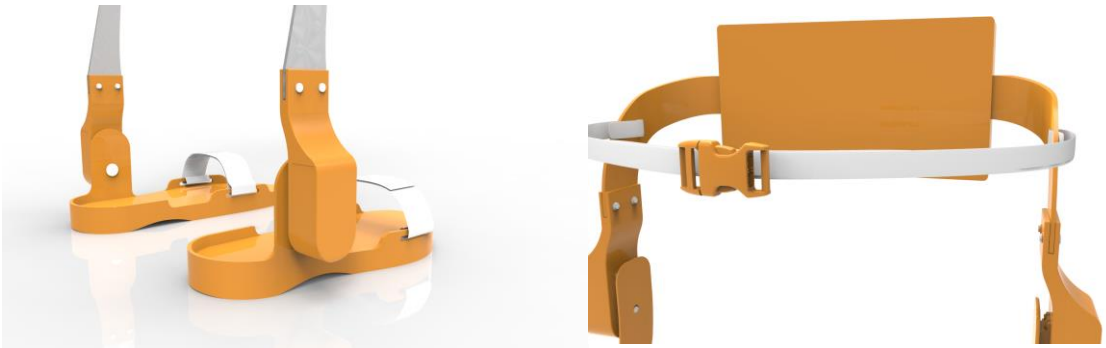


Figure 72 details of foot and upper part

5.2.3 Design Alternative 3

Design alternative 3 has a better model than two ones' design alternative before. In the design alternative 3 also has a frame that can follow the human limb contours as design alternative 2. The adjustable system of design alternative 3 also the same as design alternative 2 so that the user can freely adjust the size according to the desire size. But, in terms of look, design alternative 3 has an outer or a cover that can protect the main frame from the collision, light pressure and give the anesthetic effect of the frame. The outer or the cover of this design, can be replaced freely like a figure 78 below, and such as replaced with another cover which has different color.

Figure 73 alternative 3

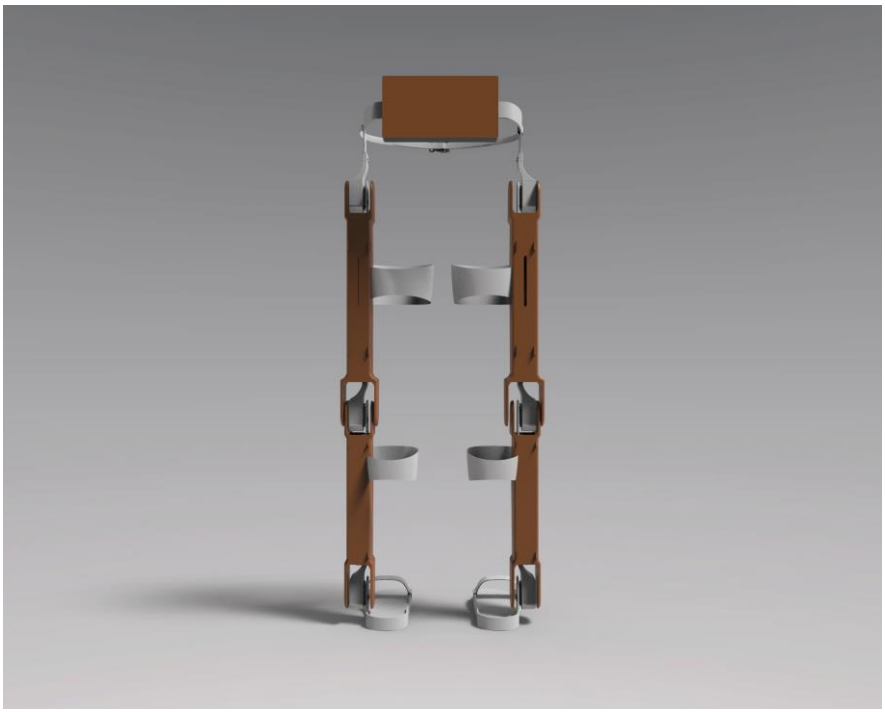


Figure 74 alternative 3

Figure 75 alternative 3

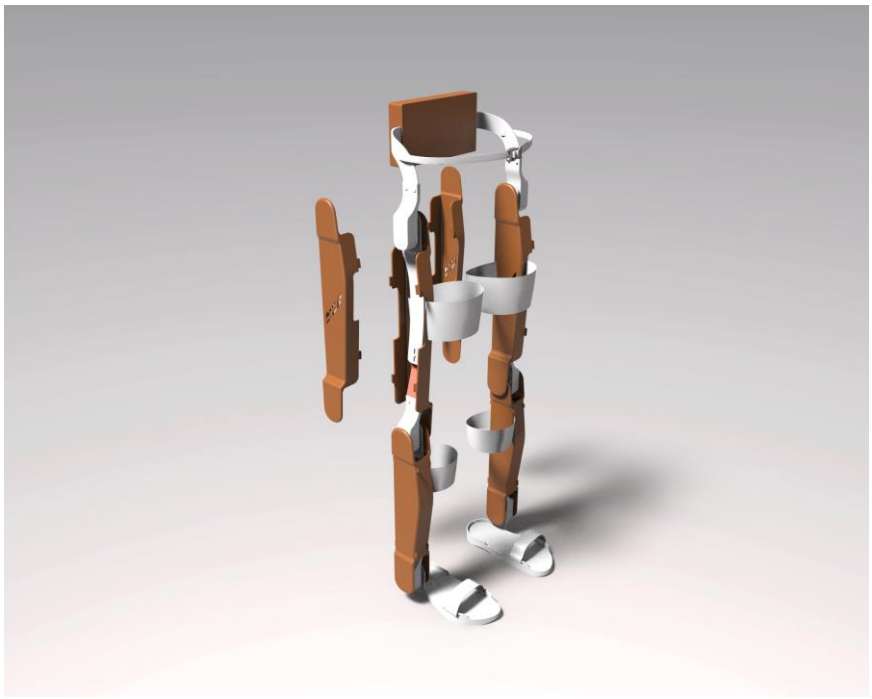


Figure 76 alternative 3

5.3 Ansys Simulation

A static stress simulation is used to identify the possibility of stress, displacement and strain of part of the exoskeleton. The simulation is proceed through a simulation tools on the Fusion 360. The main part which is used in this simulation is the outer and sol part as its part is frequently have contact with the external force from the body and other external factors.

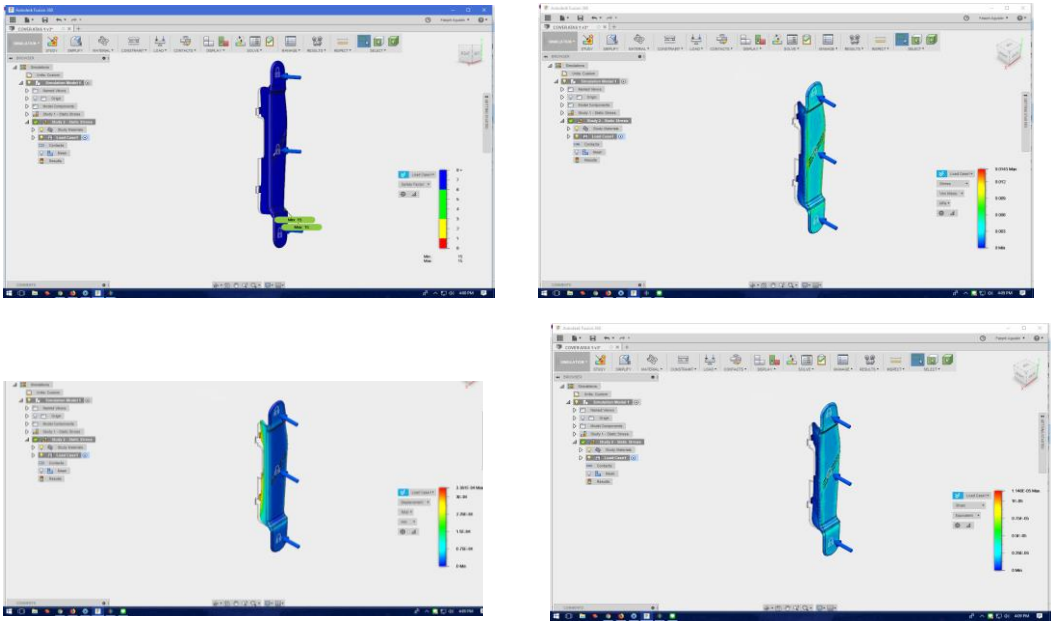


Figure 77 simulation

The result of the 1st simulation is shown as above:

Table 18 simulation result

Indicator	Simulation 1	Simulation 2	Simulation 3	Simulation 4
Scale Factor	8	8	8	8
Stress	0.0143	0.02859	0.04289	0.06627
Displacement	3.391	6.783	0.001017	1.304
Reaction Force	0.6868	1.374	2.06	2.742
Strain	1.148	2.295	3.443	5.019

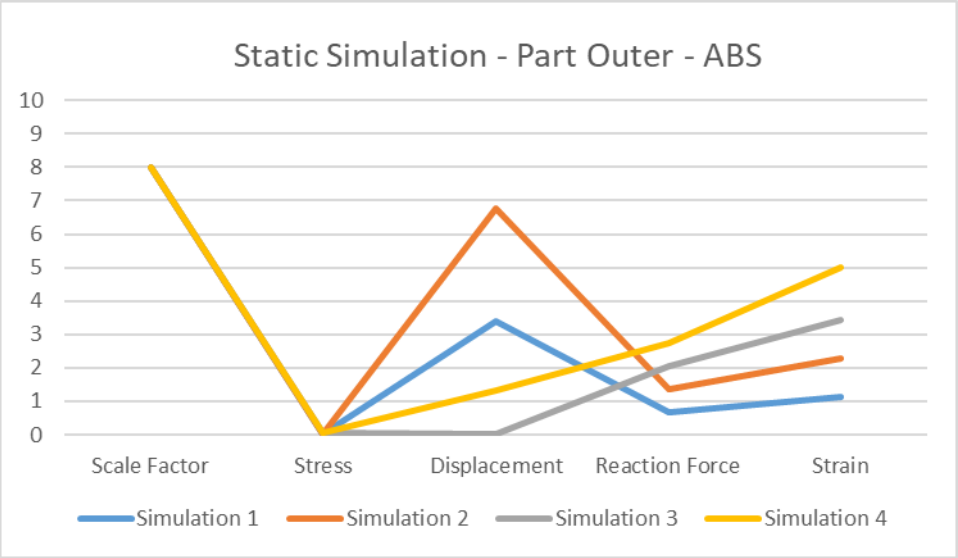


Figure 78 simulation outer part using ABS

The result of the 2st simulation is shown as above:

Table 19 Result of the second simulation

Indicator	Simulation 1	Simulation 2	Simulation 3	Simulation 4
Scale Factor	8	8	8	8
Stress	0.01446	0.02893	0.04339	0.05785
Displacement	2.655	5.31	7.965	0.001062
Reaction Force	0.6889	1.378	2.067	2.756
Strain	9.014	1.803	2.704	3.606

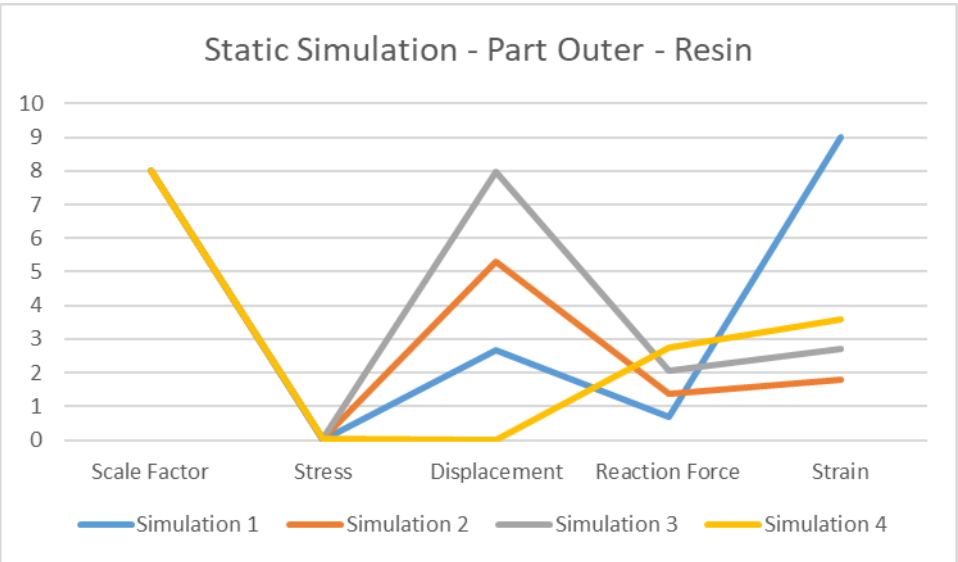


Figure 79 simulation of outer part using resin

5.4 Usability

The usability conducted to check on the ergonomic and comfort of the exoskeleton's prototype. Based on the first prototype the safety and comfort of the exoskeleton only use a single straps. Thus, on the second prototype the user was comforted by having a bigger strapping so it can improve the safety and amenities while using the product.

Figure 80 ergonomic usability

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CHAPTER 6. CONCLUSION

6.1 Conclusion

Based on this project it can be conclude that in designing a exoskeleton there some factors which needed to be considerate by the designer include biomechanical and design factor. As in this project the manufacturing of the exoskeleton is created locally, so the production cost could be pressured to the lower level so the user from low-middle economical background could afford this.

Herewith the following suggestion which could help the upcoming research or project related to the exosketon especially lower leg exoskeleton:

1. Identifying the current disabilities which will be accommodate with the exoskeleton
2. Choosing the appropriate actuator such as servo or motor to help the movement of the exoskeleton
3. The main frame should be made of typical strong metal, while the other part it is quite good to use materials such as ABS and carbon as based on the static stress simulation

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BIOGRAPHY

Faiqoh Agustin was born at Probolinggo on August 17th 1994. She is the first daughter of Mr Yusup and Mrs Umiyati. She spent her life to get a higher education from one to another city. She was an alumni of SMP N 1 Probolinggo and SMAN 10 Malang Sampoerna Academy. She started to study Industrial Product Design at Institut Teknologi Sepuluh Nopember since 2012. During the studies, she actively involved in some activities including the student organization, self-development program and also social activities. In addition, she also experienced international exposure by having an exchange program to some countries such as Singapore, Thailand and Japan.

As the final project entitle "**Development of Lower Limb Exoskeleton Design as Proposed Tool to Support Post Stroke Patients** "has been finished, thus the author hope that every single information on this report would be beneficial for the future project and research.

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