DESIGN OF MODULAR SMART PICK & PLACE AUTOMATION SYSTEM

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This report is submitted
in fulfillment of the requirement for the degree of
Bachelor of Mechanical Engineering (Design and Innovation)

Faculty of Mechanical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2017

DECLARATION

I declare that this project report entitled “Design Of Modular Smart Pick And Place Automation System” is the result of my own work except as cited in the references.

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Name	:	Syahirah Binti Mohd Fadzil
Date	:	....

APPROVAL

I hereby declare that I have read this project report and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering (Design & Innovation).

Signature :. ....

Name of Supervisor : Ir. Dr. Tan Chee Fai

Date : ....

ABSTRACT

The main purpose of this project is to design and develop a smart modular pick and place automation system for training students in Vocational Technical School. The project primarily focus on development of the pick and place system within the best design characteristics such as easy to fabricate, cost effective, high performance with great a great grip and safe. The provision of pick and place system is simple design yet very effective that is it can grip a variety of shape and size of object. It is simple enough to be handle by students and easy to maintain. The size and weight of the pick and place system should be suitable for portability so that it can be moved around easily. There are a lot of pick and place system in the market. However, some equipment that is offered has not been completely satisfied. For example, some existing pick and place system are very large and complicated to handle, weighing hundreds of pounds and therefore expensive to purchase and maintained. Pick and place with efficient mechanism will be develop through this project and will meet the best engineering design where it can help in training student's skills.

ABSTRAK

Tujuan utama projek ini adalah untuk mereka cipta sistem automatik memilih dan meletakkan pintar yang inovatif untuk bersaing dengan pihak lain di pasaran. Projek ini terutamanya berfokus kepada pelajar teknik vokasional untuk melatih mereka dalam mengendalikan mesin dan alatan kejuruteraan. Matlamat mereka cipta sistem ini adalah mempunyai kriteria rekebentuk yang mudah namun canggih, mudah untuk difabrikasikan, mempunyai nilai estetik, harga terendah dan lain-lain. Penyediaan sistem automatik memilih dan meletakkan pintar ini sebagaimana disebutkan di atas adalah bersaiz kecil dan cukup sederhana untuk dikendalikan secara manual oleh pelajar pelajar yang belajar di sekolah teknik vokasional. Sebelumnya usaha telah banyak dilakukan untuk menyediakan sistem automatik memilih dan meletakkan ini. Namun, seperti peralatan yang telah dicadangkan masih lagi tidak memenuhi kehendak pengguna. Sebagai contoh, beberapa sistem ini yang ada sangat besar, dengan berat ratusan kilogram dan mahal serta sukar untuk mengendalikan penyelenggaraan. Sistem yang bermekanisme yang efisyen akan dihasilkan melalui projek ini dan akan memenuhi keperluan pelanggan di mana boleh membantu pelajar pelajar menerapkan kemahiran mereka mengendalikan sistem ini dan dalam projek kejuruteraan mereka.

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Last but not least, I owe my loving thanks to both of my parents, Encik Mohd Fadzil Bin Abdul Rahman and Puan Jamaliah Binti Abdul Wahab. Without their encouragement and understanding it would have been impossible for me to finish PSM. My special gratitude is due to my friends Mohamad Azizuddin Bin Mohd Azman, Khairul Aqil Bin Mohd Yusof, Mohd Hanafi, Yuszaili, Nurul Najwa Bt Roslan and many more whom help me in giving an idea and support to finish this thesis.

CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBEREVATIONS

ADTEC	Advanced Technological Training Centre
BMI	British-Malaysian Institute
CAD	Computer Aided Design
CC	Community College
CIAST	The centre for Instructor and Advanced Skill Training
GMI	German-Malaysian Institute
IKM	Institut Kemahiran Mara
ITI	Industrial Training Institute
IKBN	Institute Kemahiran Belia Negara
IKBTN	Institute Kemahiran Belia Tinggi Negara
JMIT	Japan-Malaysian Technical Institute
KKTM	Kolej Kemahiran Tinggi Mara
PDS	Product design specification
Poly	Polytechnic
TVET	Technical and Vocational Education Training
UC	University College
U	University
HOQ	House of Quality

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Modular is the basic term used that involves a module or modules for basic design construction. The most common or important characteristic of a modular is portable which can be used in various system. Meanwhile, the definition of “smart” in an automation system is the ability of a system to work through the process on its own without the guidance of a human. These robots learn from its environment and experience based on the knowledge, often works on highly repetitive task such as precision packing.

The pick and place automation system is a kind of robot that is used in the industrial world. Nowadays, more robots are used to replace human in the industry. This is because robots can give a much better accurate and efficient work outputs. Moreover, they are very helpful and useful in handling dangerous, dirty or even repetitive dull works. In terms of cost, it is much cheaper compare to human labor in a long term. This is because robots can work overnight without even stopping or get tired. Pick and place automation system is widely used in manufacturing, assembly and packing, mass production of consumer and industrial goods.

Meanwhile, automation is termed use for different control system such as numerical control, programmable logic control or other industrial control systems. This is applicable with computer applications or information technology such as Computer Aided Design or Computer Aided Machining to manipulate all the industrial machinery process. Therefore, reducing manpower requirement. Automation is very important especially in rise of technology the in the world economy and daily application. Thus, automation needs to be improved along the way according to customer's requirement.

1.2 PROBLEM STATEMENT

During the Tenth Plan, mainstreaming and broadening access to quality technical and Vocational Education and Training (TVET) were undertaken to address industry needs for skilled workers. Measures were also undertaken to improve public perception towards TVET. These efforts resulted in the percentage of school leavers pursuing TVET after Sijil Peperiksaan Malaysia (SPM), increasing from 25% in 2010 to 38% in 2013. Transforming TVET is one of the game changers in the Eleventh Plan to meet the demand of industry and contribute towards economic growth in view of globalization, knowledge economy, technology advances and global labor mobility. To adapt to TVET, and industrial based training system is needed to train the necessary skills for the TVET student. A modular automation training system that focus on smart pick and place is proposed.

1.3 OBJECTIVE

In the manufacturing industries, smart pick and place automation system is design to help human accomplished difficult task and made the job much easier and decrease the time of production.
The objective of this project is to develop a modular pick and place system that is simple, safe, durable and high effective for training students in the technical college.

1.4 SCOPE OF PROJECT

In order to complete this project, scopes are required to assist and guide the development of this project. The scope should be identified and planned to achieve the objective of the project successfully on time.

The scopes of this project are:

1. Designing the mechanical parts of the pick and place automation system within the criteria of training purpose, easy to fabricate and cost effective.
2. The provision of pick and place automation system is a table size machine and is simple to be handle by students.
3. To apply the design and analysis using engineering software, CATIA V5R19 and ANSYS Structural Analysis.

1.5 GENERAL METHODOLOGY

The actions that need to be carried out to achieve the objectives in this project are listed below.

1. Literature review Journals, articles, or any materials regarding the project will be reviewed.
2. The suitable design for smart modular automation pick and place system will be proposed.
3. If the design process of the pick and place system has passed, the calculation process will take place to determine whether the design has fulfilled the requirement needed in the objective.
4. The simulation of the mechanism will be done using CATIA software. The maximum force and the movement of the pick and place system will be tested in the software.
5. The result that was tested will be recorded and be placed to make comparison to further improve the system.
6. Report writing will be done at the end of the project.

The methodology of this study is summarized in the flow chart as shown in **Figure 1.1**.

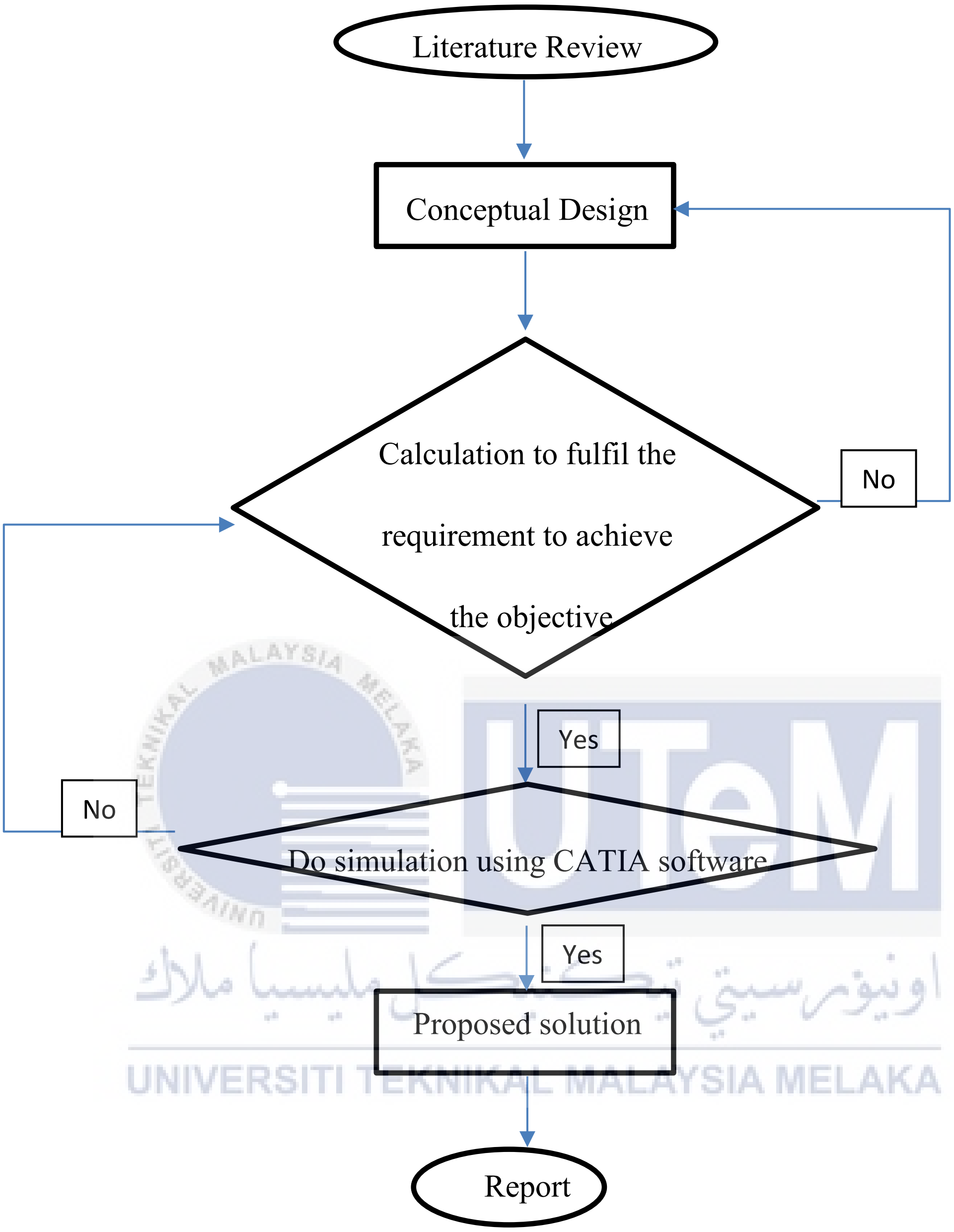


Figure 1.1: Flow chart of General Methodology

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter discusses about the basic type of pick and place automation system together with their advantages and disadvantages. Not to mention, a little explanation on TVET system in Malaysia. Other than that, the type of end effector are also discussed in this chapter. From the basic configuration, there are a few aspects to be taken note so that the type of robot is suitable for the user. Tanya M. Anandan (2013), stated that the bigger size of the robot is not always better because of some reasons. Therefore, some aspects needs to be research first before buying a certain pick and place system. Besides that, the degree of freedom of robots are also discussed to further apply to the next step on developing a pick and place system. Lastly, the existing pick and place system and their cost in the market are also shown in this chapter.

2.2 TVET system in Malaysia

According to Prof. Dr. Jailani et al (2013) the Technical & Vocational Education Training system can be in both private or public institution which provide basic skill training that can be apply through application of mathematics and science. There are five level of qualification which is Certificate, Diploma, Degree, Master and Doctoral. In Malaysia, TVET can be applied by any students at an early age, that is after students have finished their PT3. TVET can gain students by brushing up their basic training skill to a high level mathematics and science. Below are examples of technical and vocation provider in Malaysia for government and private sector.

	Level of study				
	Certificate	**Diploma**	**First Degree**	**Masters**	**PhD**
Government : Ministry of Higher Education	CC, Poly	Poly, UC, U	UC, U	UC, U	UC, U
Ministry of Human Resource	ITI, CIAST, JIMIT, ADTEC				
Ministry of Youth and Sports	IKBN, IKBTN				
Majlis Amanah Rakyat	IKM, IKTM, GMI, BMI, MFI, MSI,				

	MIAT				
Private		UNIKL, KLIUC, MMU, UTP, UNITEN, UNISEL	UNIKL, KLIUC, MMU, UTP, UNITEN, UNISEL		

Table 2.1 : Examples of Technical and Vocational Education and Training Level providers in Malaysia (Source: Prof. Dr. Jailani et al 2013)

2.3 Type of configuration of pick and place system

According to A.Modi and M.Patel (2015), there are three broad class of industrial automation which are fixed automation, programmable automation and flexible automation. For robots, the movement can be divided into two general categories which are arm and body motions, and wrist motions. The term "degree of freedom" is referred when the individual joint motion associate with these two categories. Most of the robot is equipped with 4 to 6 degrees of freedom. The basic structure of robots can be seen in **Figure 2**. There are polar, cylindrical, Cartesian, jointed-arm and SCARA configuration.

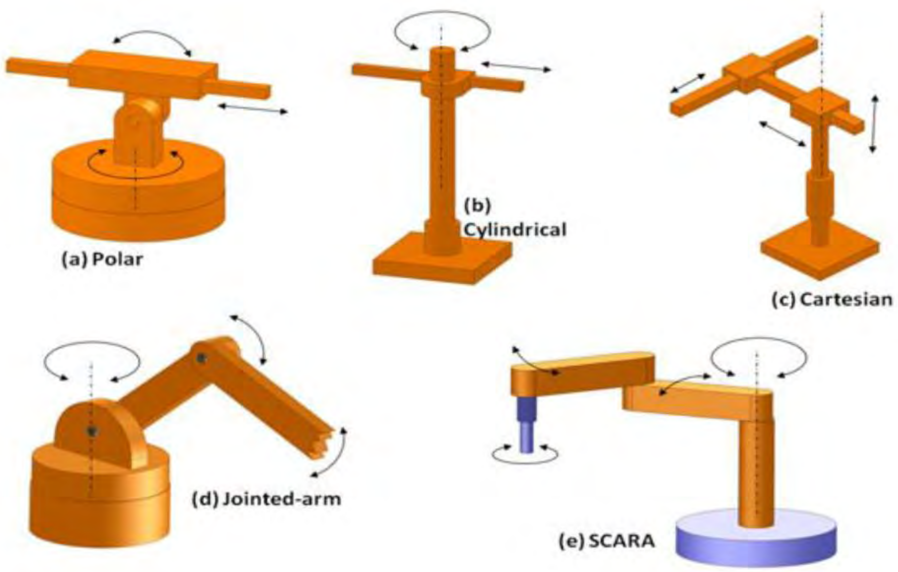


Figure 2.1: The five basic robot anatomies. (Source: A.Modi and M.Patel, 2015)

The robots are connected through many manipulator joints that are rigid called links. In the industrial robot, the joints used often involves in a relative motion of the adjoining links that is either linear or rotational. Linear joints involve sliding or translational motion of the connecting links.

2.3.1 Polar configuration

According to R.Shiilling (2013), the polar configuration which also known as spherical configuration, has a concept design similar to the military tank. The robot will move vertically from a pivot point in the middle and can rotate around the axis perpendicular base. Another rod, as the wrist or gripper, will extend and retract to reach for things. According to The Anatomy of Industrial Robot (2011), the advantage of this design is that it is capable of reaching long extended things horizontally. It can do more job than the Cartesian and the cylindrical configurations. Besides that, this design is very simple despite being able to lift heavy weight. Meanwhile, the disadvantage is that the vertical movement is very low and limited. The most common applications of polar configuration are die casting, injection molding, forging, glass handling, material transfer, stacking and unstacking.

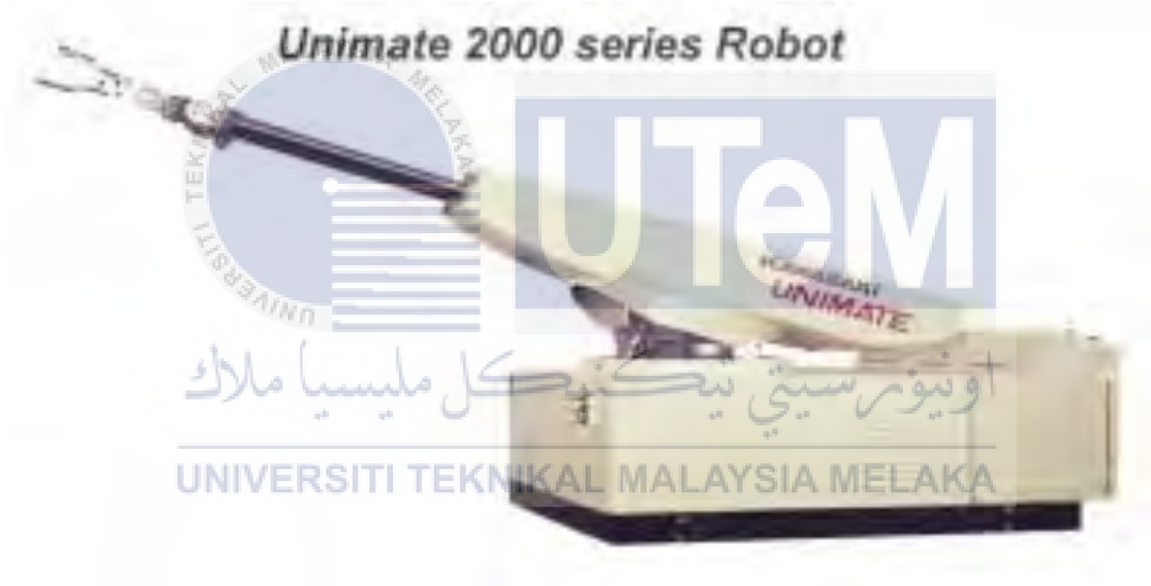


Figure 2.2: UNIMATE Polar configuration robot (Source: Robotics Bible, 2011)

2.3.2 Cylindrical configuration

The cylindrical configuration moves up and down the cylinder and can turn 360 degree along the cylindrical pole that it is attached to. The wrist which is perpendicular to the cylinder can move in and out to reach out the items. According to The Anatomy of Industrial Robot (2011), the advantage of this configuration is can do a larger scope of work than the Cartesian configuration. The disadvantage of this configuration the accuracy and the repeatability of the robot is low due to the inertia of the object when rotating. The cylindrical configuration needs a more complex control system than the Cartesian configuration. According to R. Shilling (2013), the cylindrical configuration are often applied in meat packing, assembly, die casting and general material handling.

Figure 2.3: Example of cylindrical robot (Source: Hazman Azfar Robotics, 2011)

2.3.3 Cartesian configuration

According to Zach Olsen (2009), the cartesian configuration robot has X, Y and Z axes. The robot will process in this three joints movement in a rectangular work space. The advantage of this configuration is that has a simpler control system. The fewer controllers offer less periodic maintenance and training. This configuration works efficiently in many application as it has high speed travel and can carry heavy loads and have a high degree of mechanical rigidity. Besides that, it has high accuracy and repeatability. However, the movement is limited to a small, rectangular work space. Thus, needs a large work envelope.

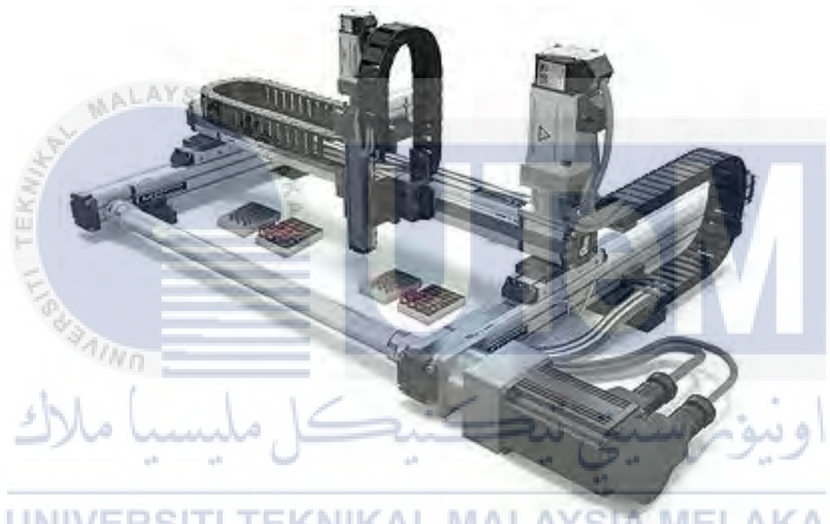


Figure 2.4: Example of Cartesian robot (Source: Zach Olsen, 2009)

2.3.4 Joint-arm configuration

According to R.Shiilling (2013), the joint arm configuration, also known as revolute configuration, is the most common robot used in the industry world and the concept design is similar to a human arm. Just like the human arm, the robot follows the action of the human shoulder, elbow, wrist and a joint called sweep that represent the waist. The advantage of this configuration is that is has the capability to adjust to any work space. It is very flexible and has a quick operation. However, the disadvantage of the configuration is it is very costly and has many components. The operating procedure of this configuration is quite difficult.

Figure 2.5: Example of joint arm robot (Source: Tanya M.Anandan, 2013)

2.3.5 SCARA configuration

The Selective Compliance Assembly Robot Arm (SCARA) configuration was designed by Professor Makino of Yamanashi University, Japan. According to Richard Vaughn and Charlotte (2013), SCARA moves in then X,Y and Z planes like cartesian. It consists of an inner link that rotates at z-axis and connected to an outer link that rotates at z elbow point. It is connected to wrist axis that moves up and down and also rotates about z. SCARA is found to be the most highly used geometries for vertical assembly and small parts pick and place operation. The advantage of this configuration is that is has a high accuracy, reliability and speed. It is also easy to handle with minimum maintenance. However, the programmable movements in 3D is highly complex.

Figure 2.6: Toshiba's SCARA robot (Source: Robotics Bible, 2012)

2.4 Type of end effector

And end effector is the part where the object is gripped and is picked up, also known as the gripper. This is the most important part of the pick and place automation system. Without a great gripper, the object will easily slide or fell down and not reliable to be applied in any industry or work. According to Alvaro Martinez (2015), there are many kinds of gripper that can be classified according to the way of grip which are vacuum gripper, hydraulic gripper, pneumatic gripper, servo-electric gripper and magnetic gripper.

2.4.1 Vacuum gripper

According to Dipen et al (2015), vacuum gripper is the most commonly used in manufacturing industry because if its high flexibility. This type of gripper uses rubber or polyurethane suction cup to pick up items. Some vacuum grippers use a closed-cell foam rubber layer, rather than suction cups to complete the application. This type of gripper is used for electronic components for large objects like car windscreen. It is a very simple astrictive device, but can hold very large loads provided the pretension surface is smooth enough to ensure suction. However, it is not suitable handling objects with pores.

2.4.2 Hydraulic gripper

Hydraulic gripper is the most strong and often used in application that requires a great amount of force. The hydraulic gripper generate their strength from pumps that can provide up to 2000psi. however, it is messier due to the oil used in the pumps. Dipen et al (2015) also stated that the hydraulic gripper are also high maintenance because the gripper being damaged because of the force applied during work.

2.4.3 Pneumatic gripper

Pneumatic gripper is very well known due to its compact size and light weight. It can be easily be used in limited spaces, which is very helpful in the manufacturing industry. Pneumatic robot grippers can either be open or closed.

2.4.4 Servo-electric gripper

Servo-electric gripper is growing rapidly in the industrial settings due to fact that it is easier to control. The electronic motors control the movement of the gripper jaws. These grippers a very flexible and allow for different material tolerances when handling parts. Servo-electric grippers are also cost effective because they are clean and have no air lines.

2.4.5 Magnetic grippers

- electromagnets

electromagnetic grippers include a controller unit and a DC power for handling the materials. Electromagnets is easy to control and very effective in releasing the part at the end of the operation than the permanent magnets. If the work part gripped is to be released, the polarity level is minimized by the controller unit before the electromagnet is turned off. This process will help in removing the magnetism on the work parts. As a result, a best way of releasing the materials is possible in this gripper.

- permanent magnets

permanent magnets does not require any sort of external power like the electromagnets for handling the materials. The advantage of this permanent magnet gripper is that it can be used in hazardous application like explosion-proof apparatus because no electric circuit. Besides that, there is no possibility of spark production as well.

2.5 Degree Of Freedom (DOF) robot

According to R.Shiilling (2013), Degree of Freedom (DOF) is the term used to describe the motion of the robot in three dimensional space. This is the ability of the robot arm to move bend, rotate or translate. Typically, the number of degree of freedom can be identify from the actuators on the robot arm. A joint is required in each degree of freedom. Most robots has 6 degree of freedom which allows them to move freely. However, the movements are not as smooth as the human hand which consist of 22 degrees of freedom as in **Figure 8.**

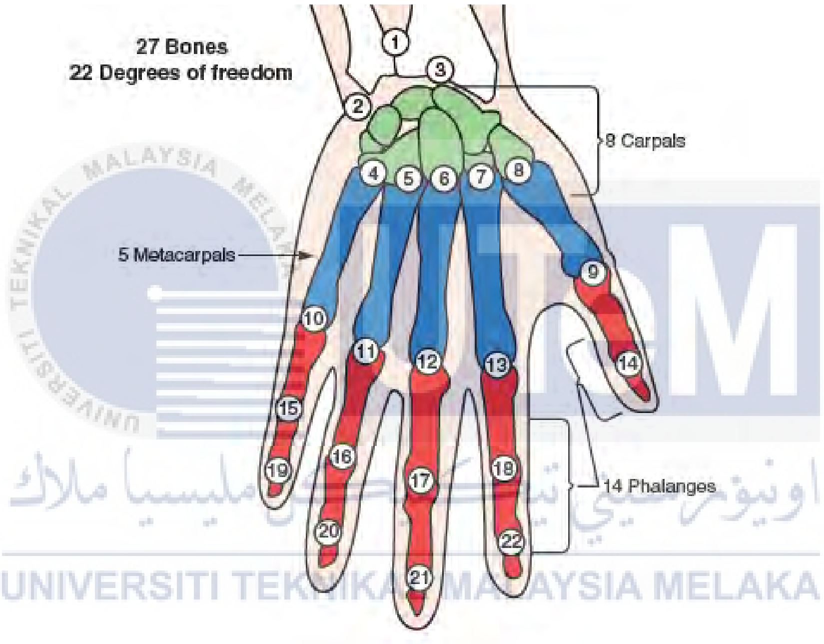


Figure 2.7: Degree of freedom of human hand (Source: R. Shilling, 2013)

According to F. C. Park and K. M. Lynch (2016), every joint connects two links. There are a few type of joints which are revolute joint (hinge joint), prismatic joint (sliding or linear joint), screw joint (helical joint), cylindrical joint, universal joint and spherical joint. These joint have different degrees of freedom. The type of joints and their number of degree of freedom can be seen in **Figure 9** and **Table 2**.

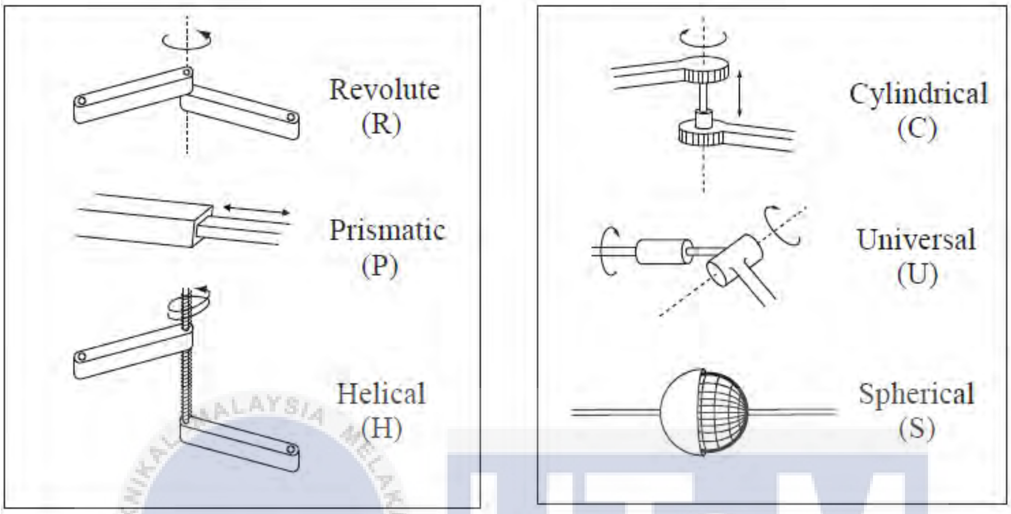


Figure 2.8: Typical robot joints. (Source: F. C. Park and K. M. Lynch, 2016)

Joint type	Degree of freedom
Revolute	1
Prismatic	1
Screw	1
Cylindrical	2
Universal	2
Spherical	3

Table 2.1: Number of degree of freedom by common joints. (Source: F. C. Park and K. M. Lynch, 2016)

The number of degree of freedom of a mechanism can with links and joints be calculated using Grubler's formula.

$$Degree\ of\ freedom = (Sum\ of\ freedoms\ of\ the\ bodies) - (Number\ of\ independent\ constraints)$$

2.6 Specification of best type

2.6.1 Size

Choosing the right pick and place automation system can optimize the use and worth of the robot for the user. This is because each type of robot is specialized for different application and each of them has its own advantage and disadvantage. According to Mathieu Beelanger Barrette, 2014, choosing the suitable pick and place automation system refers to a few aspects. The first aspect is the size needed and space acquired. SCARA robot is suitable for limited workspace as it is compact. Meanwhile, Cartesian robot uses a large workspace but with high efficient work scope. According to Tanya M. Anandan (2013), bigger robot is not always better. This is because bigger robot tend to have larger inertia and low speed because of the large area movements.

2.6.2 Mission

Each robot has its own mission or job scope to do. Selecting the right robot and the most suitable can speed up the work and make it easier for human, either in maintaining or handling the programme. According to Tanya M.Anandan (2013), for a table top pick and place system, SCARA robot is the most suitable. However, in handling a flat conveyor tracking application, Cartesian or Delta style robot is more suitable.

2.6.3 Speed

The speed is also an important aspect towards an efficient process. As Tanya M. Anandan (2013), mentioned earlier, a bigger size of robot will move slower because of bigger area and longer joint arm to be move. Minimizing the Z height can decrease a bit of time because the arm does not have to move so much from one point to another. Some robots can move so fast that the movements can hardly be seen by human. Most companies uses two type of speed which are program and monitor speed. Program speed is when a robot is set and command first to move each motion to a specific speed. Meanwhile, monitor speed allows user to change the speed of the entire application while still maintaining the proportional ratio of individual speeds.

2.6.4 Simulation

Simulation software is a software that can help to test the robot in a virtual world to verify the effectiveness of the robot. According to Tanya M. Anandan (2013), the simulation takes into consideration the actual mechanical characteristics of the robot and actual mechanical inertia, speed, reach and payload capacity. The simulation is very close to the actual performance of the robot. From the simulation, the best location for the robot to convey the object, conveyor or delivery system can be recommended in order to get the best cycle time. A programmer can test the robot without physically applied at the robot itself.

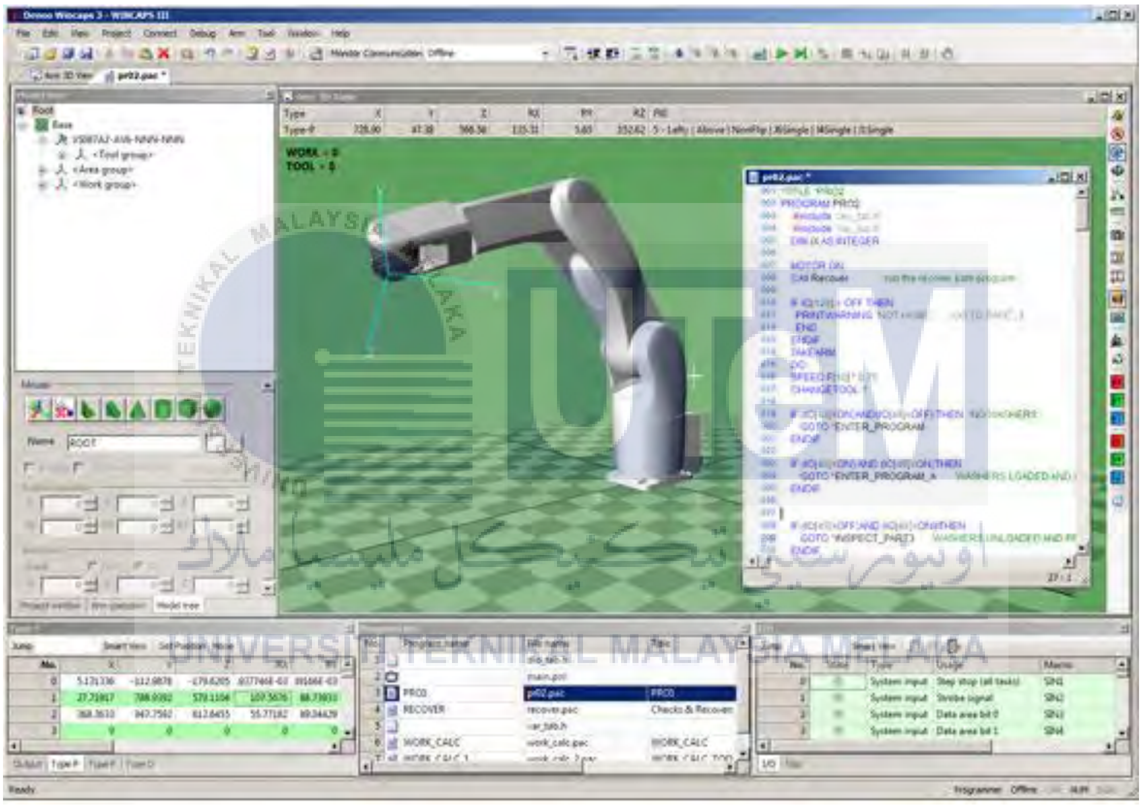


Figure 2.9: Example of simulation programming software, courtesy of DENSO Robotics. (Source: Tanya M. Anandan, 2013)

2.7 Cost in market

Pick and place system comes in a variety of shape and sizes. The shape depends on the type of configuration of pick and place system, whether its SCARA, Cartesian, cylindrical, polar, revolute or delta. Meanwhile, size comes in many ways depend on the work envelop. The bigger the size of the machine, the higher the cost. Not to mention brands, whether its local or international. Some of the most highly demand brands are from TOSHIBA, BOSCH, YAMAHA, SEIKO and MITSUBISHI. Therefore, the cost in the market can be high or low depending on the requirements of what customer wants.

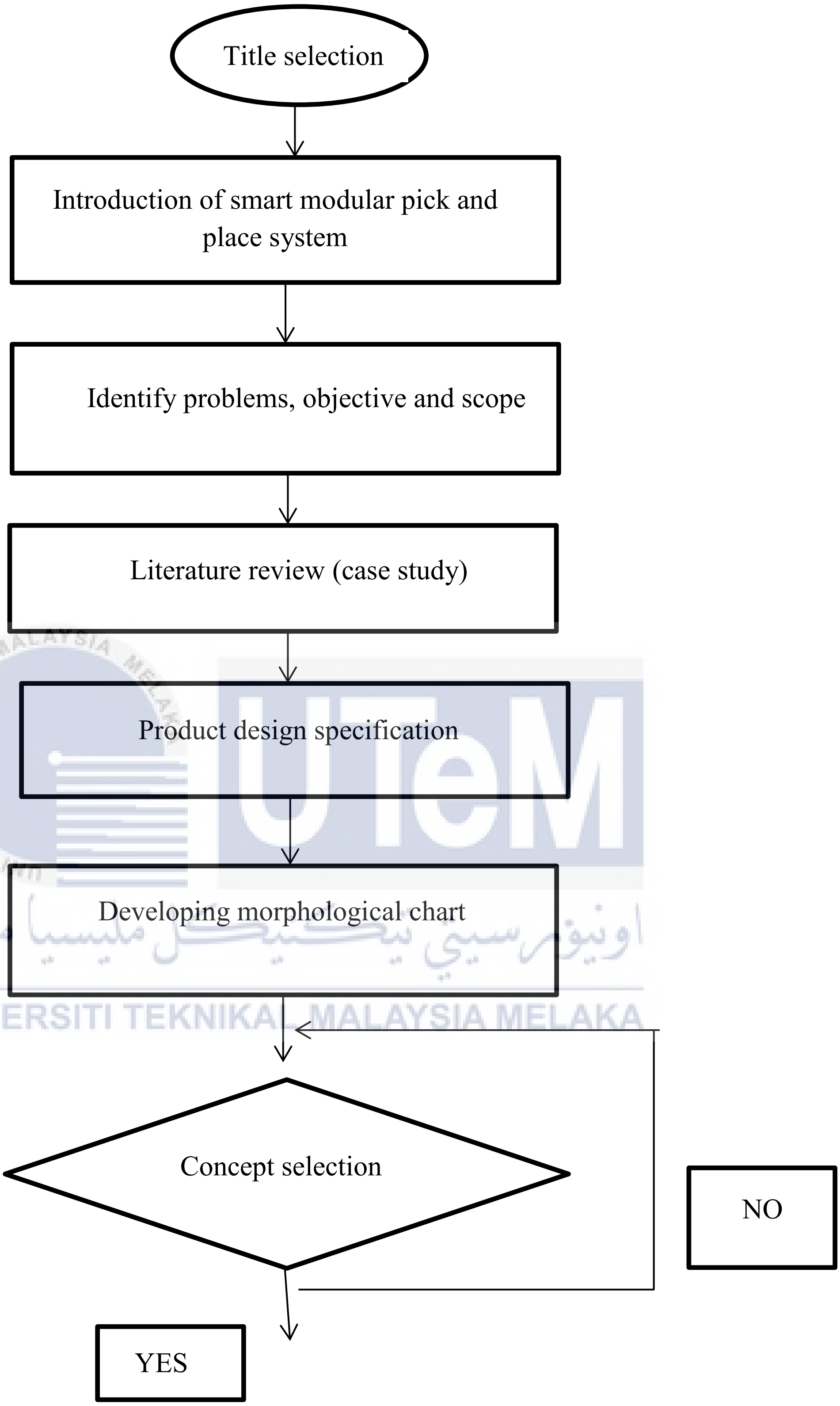
A new industrial robot can cost from $50,000 to $80,000. Meanwhile, a reconditioned robots can cost from $25,000 to $40,000 which is less expensive. The cost is very high because it is an industrial robot, which is very big, mostly used in a big scope of work. A much cheaper price can be obtain from a smaller size of robot. A table size SCARA robot can be from $1,000 to $5,000 only. It is cheaper because it is smaller and is reconditioned. Never the less, a Cartesian robot can go as low as $500 only.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter describes the methodology used in this project to develop the pick and place automation system. A more detailed procedure is explained on how to obtain all the data needed. Figure 3.1 shows the flowchart on the process to develop the pick and place automation system. The process of the flowchart is followed as a guideline to complete the project successfully from the beginning till the final stage. By implementing the each of the process in the flowchart, missing part of the project can be prevent. The flowchart will show the whole idea of the project, current work and further work. This is easier to monitor so that all process will go as flow.


Title selection
Introduction of smart modular pick and place system
Identify problems, objective and scope
Literature review (case study)
Product design specification
Developing morphological chart
Concept selection
NO
YES

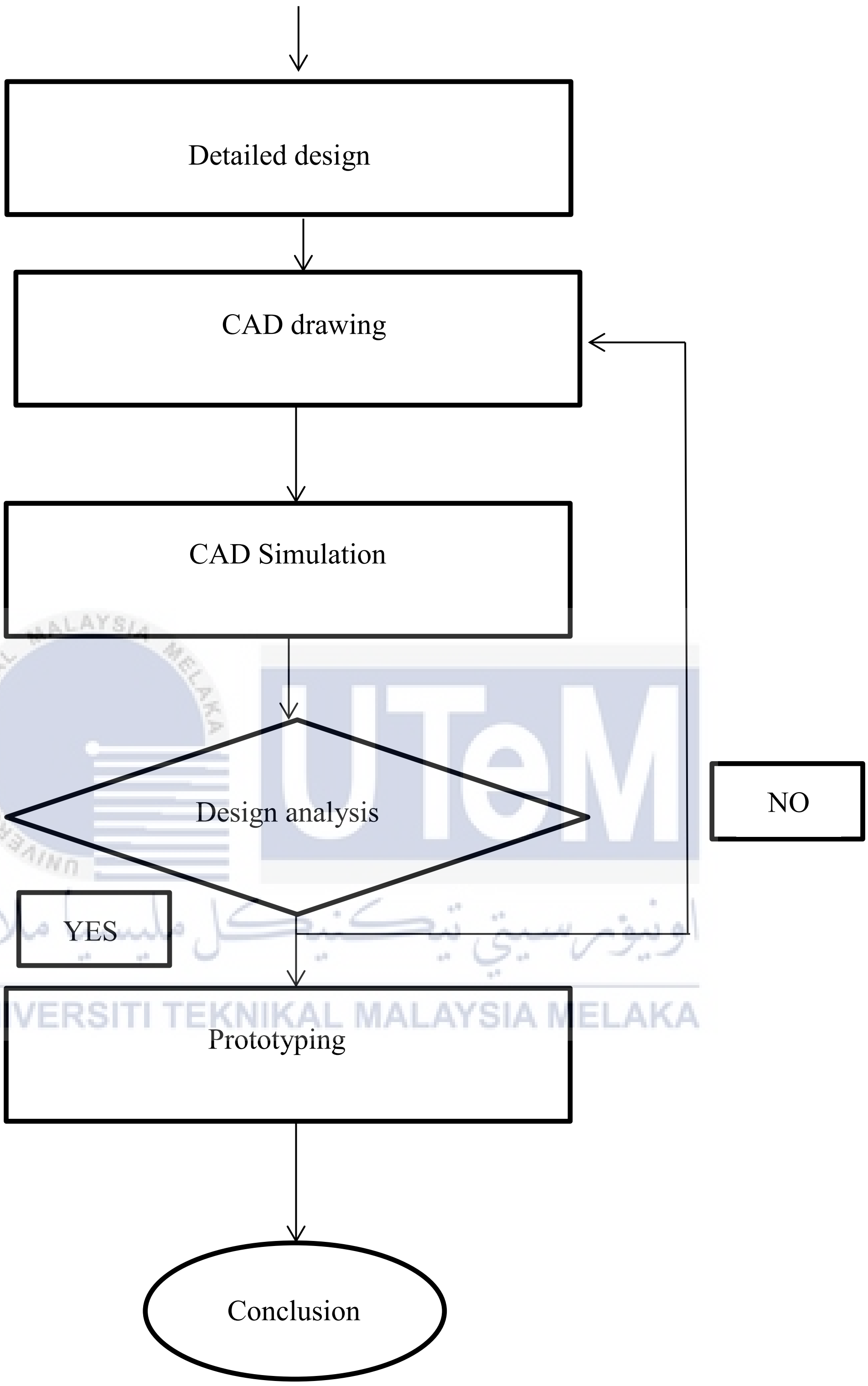


Figure 3.1: Project flowchart

3.2 Product Design Specification

Before designing a product, a design specification of a product needs to be applied and discover first. It is as a reference when designing a new product. This is to achieve the best idea and to be in a certain scope or area of function. Product design specification (PDS) shows the details of requirement that must be applied in the product. A product design specification can include the following information:

- Expected size and weight
- Expected product performance; speed, service life, shelf life, power requirements, etc
- Expected product service environment; indoors or outdoors, exposure to the surrounding, temperature range of the product, etc
- Expected safety requirements; manufacturing and assembly hazards
- Expected product aesthetics; based on customer requirements
- Material requirement; strength and rigidity
- Manufacturing requirements and limitation
- Targeted price

Product design specification needs to be fixed and must not be change furthermore because that can effect the design later on. This is because the product design specification represents the design of the product. When writing the product specification design, it should be straight forward and listed accordingly. The target goals should be entered too. For example, when applying the expected weight, it should not be written as "light weight" only. Rather, it should be more specific like "the weight is to be less than 5 kilograms". Therefore, a more detailed out view can be imagine when designing the product. (Addison Wesly, 1991)

3.3 Developing morphological chart

Morphological chart is a graphical method to generate different ideas in each part and combining them into one whole product. This method can help designers to be more systematic one designing their product. This is because instead of designing for a whole product, the product is divided into a few parts. Therefore, the design can be made even more detailed and is divided specifically. The parts can be from power source, material, shape, size, number of parts and their design of each part. There are a few steps on generating a morphological chart.

Steps:

1. List all the categories that are needed in the product. It can be power source, shape design, material and parts to be divided. These categories are listed in different rows.
2. In each row, there are different design and ideas. The ideas are in different columns respectively.
3. From all the categories in each row, choose only one design. It helps to circle or tick the wanted design.
4. All the circled design are then combined. The final solution is drawn.

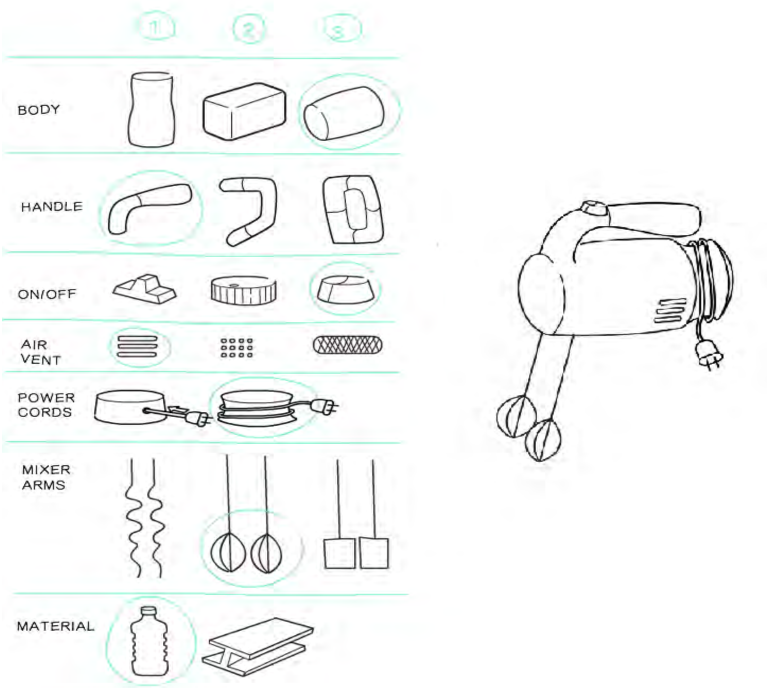


Figure 3.2: Sample of a simple morphological chart and the chosen design (Source: The design section, 2014)

3.4 Concept selection

Concept selection is the step after product design specification. This stage acquires the understanding of the customer requirements and the product design specification. To have a good process, a lot of concept has to be generated. From concept selection, pugh concept selection method is used. Pugh concept selection method is a method to rank each and evaluate each criteria of all design. This method is written in a table with scores and total scores. This Pugh method is one way to locate the best design. The Pugh evaluation process can be seen in the **Figure 3.3** below.

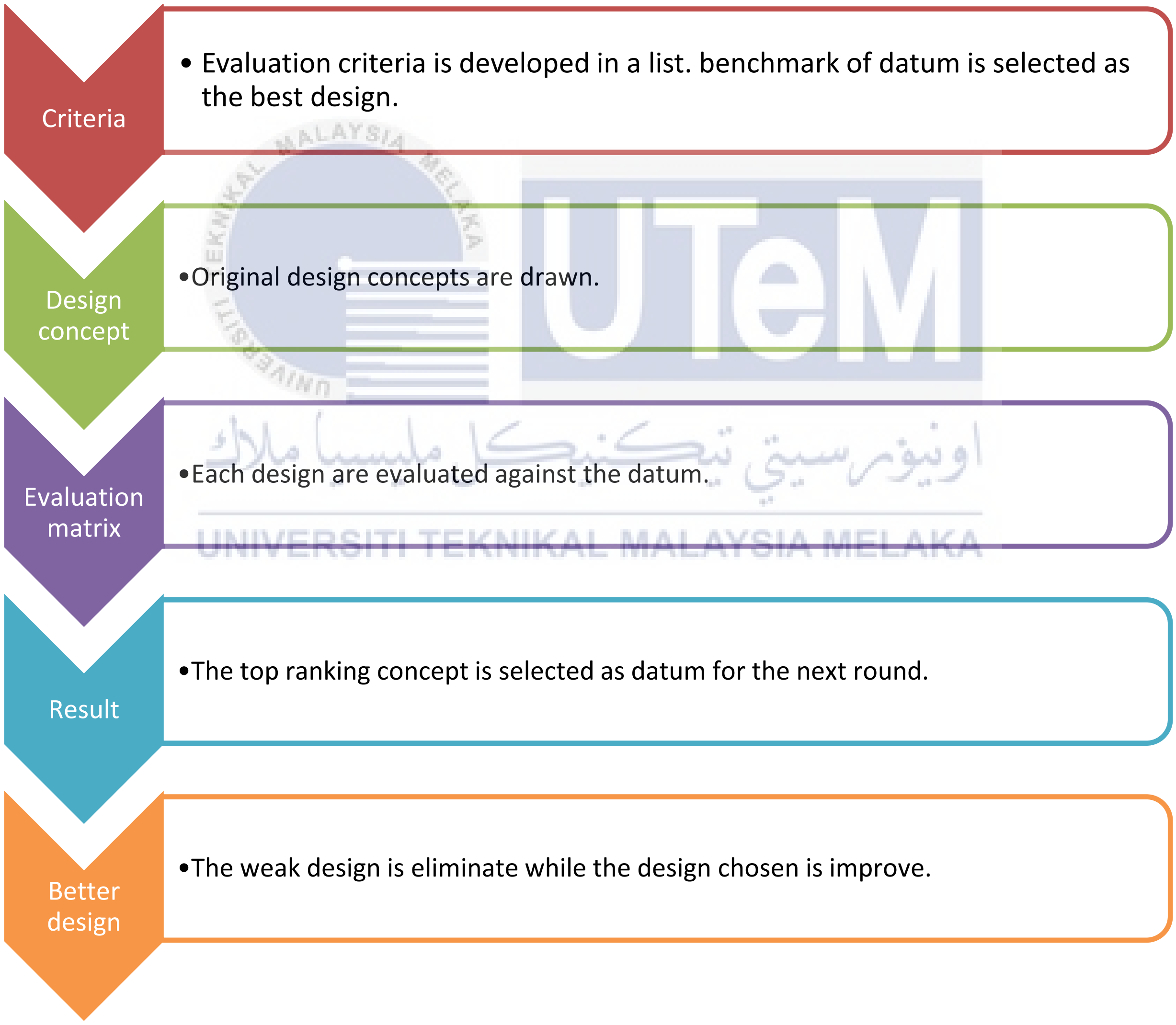


Figure 3.3: Process of Pugh method.

ROW	Selection criteria	Design concept			
			B	C	E
1	Temperature in the hand		DATUM	+	+
2	Temperature outside the cup			-	-
3	Environmental impact			+	+
4	Indenting force of cup wall			+	-
5	Porosity of cup wall			+	+
6	Manufacturing complexity			+	+
7	Easy of stacking the cup			+	+
8	Ease of use by customer			+	-
9	Temperature loss of coffee over time			-	-
10	Manufacturing cost			+	+
		Pluses		8	6
		Minuses		2	4

Figure 3.4: Example of Pugh method. (Source: Aztech Engineering, 2013)

3.5 Design tools

There are varieties of design tools that can be used for drawings of product. From sketch ideas to detailed drawing to a full-real-time simulation on computer and to full-size models or prototype of products. Below are design tools that are used from the beginning till the final stage of project.

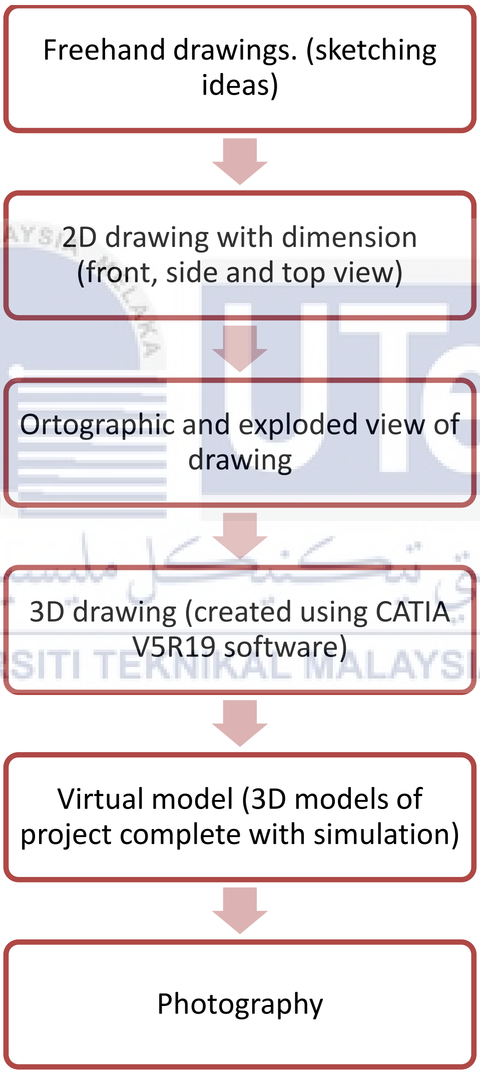


Figure 3.5: Steps on design tools

3.5.1 CAD drawing

Computer Aided Design (CAD) is a software used to create a computer-based models during design process. According to Nicos Bilalis (2000), the role of CAD is by providing:

- Accurate and easy modified graphical model of the product.
- Perform complex design analysis in a short time by implementing Finite Elements Analysis methods.
- Can perform a few analysis methods which are Static, Dynamic and Natural Frequency analysis, Heat Transfer analysis, Plastic analysis, Fluid Flow analysis, Motion analysis, Tolerance analysis and Design optimisation.
- Has a consistency and speed when record and recall information.

For mechanical design, CAD software uses either vector based graphics to depict the objects of traditional drafting, or may also produce raster graphics showing the overall appearance of designed objects. However, it involves more than just shapes. As in the manual drafting of technical and engineering drawings, the output of CAD must convey information, such as materials, process, dimensions and tolerance, according to application-specific conventions. CAD systems can shorten the design time of a product.

3.6 Design analysis tools

3.6.1 ANSYS Structural Analysis

ANSYS Structural Analysis is a design analysis tool that is used to analyse each part of the pick and place system. ANSYS Structural Analysis is based on a numerical technique called Finite Analysis of FEA. ANSYS Structural Analysis belongs to the family of engineering analysis software products.

CHAPTER 4

RESULT AND DISCUSSION

4.1 INTRODUCTION

In this chapter, the whole result and analysis will be discussed. From the preliminary result obtained, detailed design was drawn in CATIA software and the mechanism will be simulated. Analysis will be implemented using ANSYS Software, analysing the stress, total deformation and Von-Misses stress. The result will be verified from the software along with the screenshot of the result. Along the way, discussion will be made at point.

4.1.1 HOUSE OF QUALITY

Figure 1 shows the house of quality (HOQ) that was constructed for the design of pick and place automation system which can be used as reference and guide for this project. The most important factor in development of the inspection robot are easy handling, small size, portable, accurate and smooth movement.

		ENGINEERING CHARACTERISTICS						
Improvement direction		↑	↑	↑	○	↓	↑	↓
Units		n/a	m/s	%	n/a	n/a	n/a	Kg
CUSTOMER REQUIREMENTS	Importance weight factor	Safety	Speed	Efficiency	Material selection	Size and shape	Stability	Total mass
Simple design	4				■	■		
Easy to handle	5	◎					■	
Cost effective	3				■	★		
Lightweight	4							★
Accuracy	3		★	◎			■	
Performance	3		■	★				
Space	2					★		■
Easy access for maintenance	1	◎					■	
Raw score		10	36	30	21	57	27	42
Relative weight %		5.76	16.78	13.32	12.33	22.53	15.30	13.99
Rank order		7	3	4	6	1	5	2

Table 4.1 : House of quality of pick and place system

Priority = Customer assigned value from 1 to 5 used to weight relationship value

Correlation shown the degree of independence among engineering characteristic		
★	Strong	9
■	Medium	3
◎	Weak	1

Table 4.2 : Symbol of correlation

4.1.2 PRODUCT DESIGN SPECIFICATION (PDS)

Product Identification

- Product name: Smart Pick and Place Automation System
- Basic function: For picking and placing object
- Special features: Portable and easy to handle
- Key performance targets: Efficiency and cost
- Service environment: Training student's skill

Product Characteristics

No.	Criteria	Characteristic
1	Performance	➢ The robot arm can pick up curvature object securely. ➢ The movement of the robot arm is smooth without shaking. ➢ The pickup point and placing point is accurate.
2	Installation	➢ Easy to handle and easy for maintenance
3	Material	➢ Light ➢ Strong ➢ Low cost ➢ Easy to fabricate
4	Ergonomics	➢ User-friendly ➢ Ergonomic design

Table 4.3 : Product characteristics of design

Market Identification

- Target market: Technical College and Universities
- Competing products: SCARA YAMAHA and TOSHIBA robot arm

Physical Description

- External dimensions (Length x Width x Height): 50cm x 50cm x 50cm (min height)
  56cm x 56cm x 100cm (max height)

4.1.3 MORPHOLOGICAL CHART

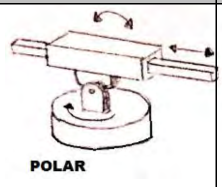
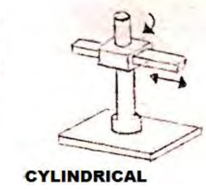
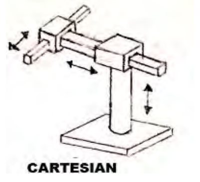
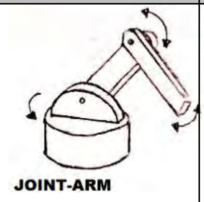
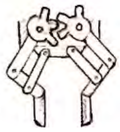
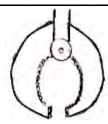
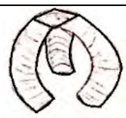
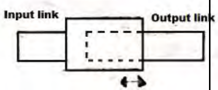
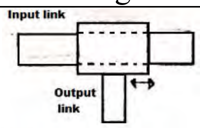
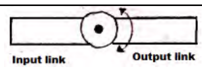
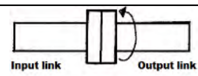
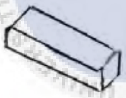
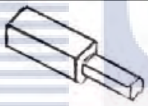
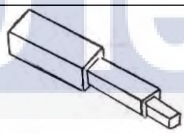
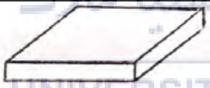
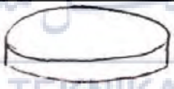
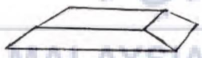
Specification	Design				
	1	2	3	4	5
Type of Configuration					
Type of Gripper	 4 linkage	 2 parallel linkage	 2 curved linkage	 Soft Rubber pneumatic	 Flexible Fin Ray concept
Type of Joint movement at End Effector	 Linear joint	 Orthogonal joint	 Rotational joint	 Twisting joint	
Adhesive Gripper Material	Rubber	Rough fabric	Silicone		
Length Optimization	 Single-rod	 Double- rod	 Triple-rod		
Base Support	 Rectangular	 Circular			

Table 4.4 : Morphological chart of pick and place

4.1.4 CONCEPTUAL DESIGN

4.1.4.1 Concept design 1

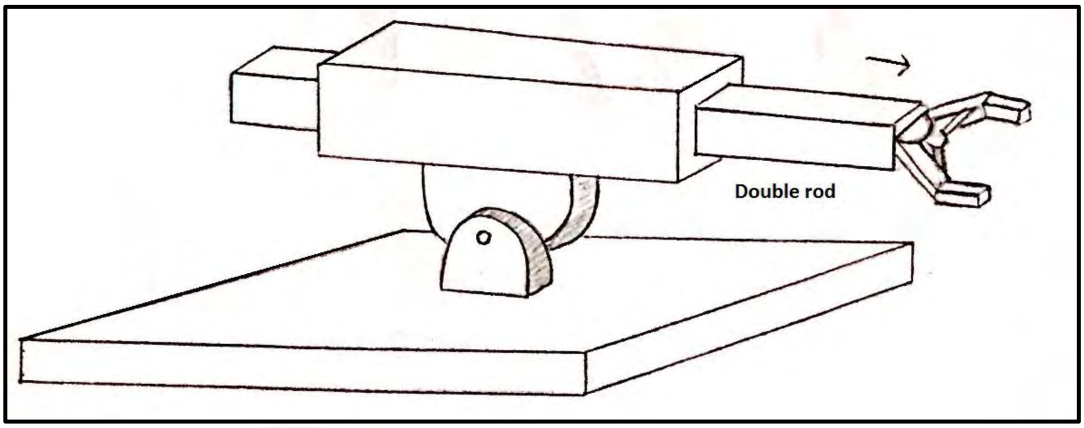


Figure 4.1: Concept design 1

The first concept is a combining of Polar configuration with a 2-joint linkage gripper with a total of 4 degree of freedom. The type of join movement at the end effector is linear to move the wrist of the robot arm. The adhesive gripper material is rubber with a double rod for length optimization. The base support is a rectangular shape. This design is used in many conventional purpose as its job scope is small and the movement is limited. This design is useful for stacking unstacking.

4.1.4.2 Concept design 2

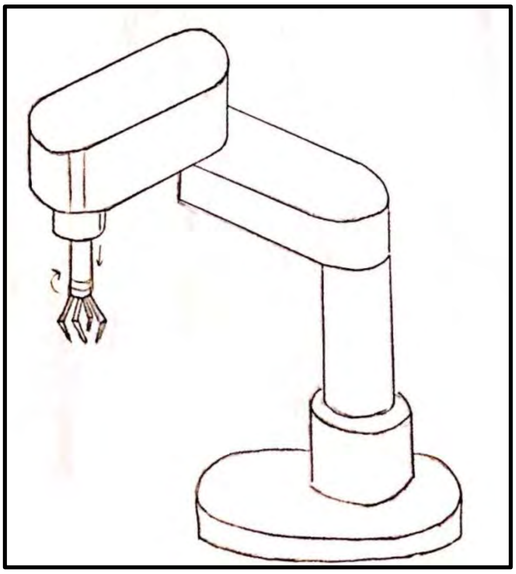


Figure 4.2: Concept design 2

Concept design 2 is a combination of SCARA configuration with a 4-joint linkage gripper. The total degree of freedom of this robot arm is 4. The type of joint movement at the end effector is by twisting and the adhesive gripper material is rough fabric. The length optimization is double rod. It has a circular base support. This type of design is useful for small parts pick and place.

4.1.4.3 Concept design 3

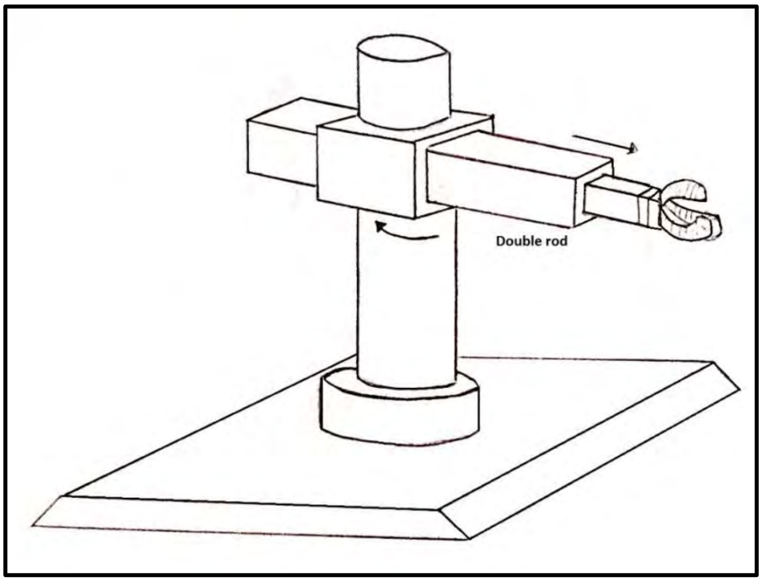


Figure 4.3: Concept design 3

Concept design 3 is a combination of cylindrical configuration with a soft pneumatic gripper. The total degree of freedom of this robot arm is 4. The type of joint movement at the end effector is by rotary and it can be up to the use of triple rod for length optimization.

4.1.4.4 Concept design 4

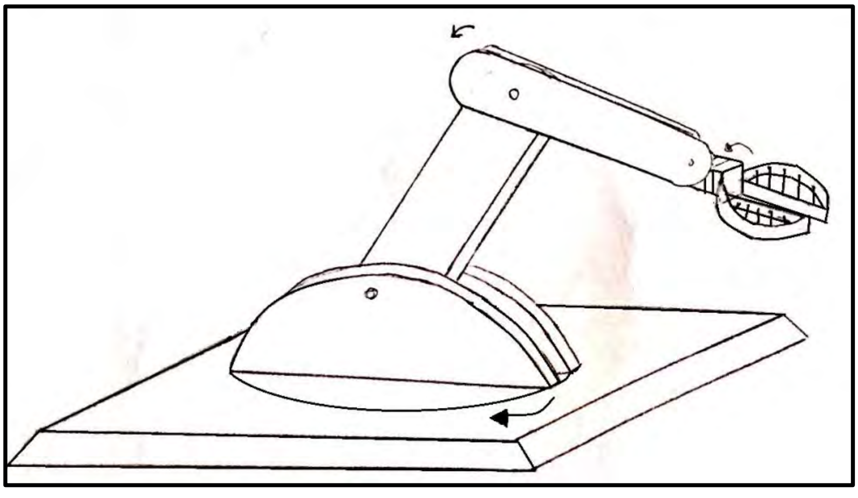


Figure 4.4: Concept design 4

Concept design 4 is a combination of joint-arm or revolute configuration with a 2 joint linkage which is in a shape of a fin ray. The total degree of freedom of this robot is 6 with single rod for length optimization. The adhesive gripper material is silicone and the type of movement at the end effector is twisting. The joint arm can increase its stability with a trapezium shape base support.

4.1.5 Concept evaluation

Selection criteria	**Concept**			
	1	**2**	**3**	**4**
Ease of handling	+	+	+	+
Safety	0	0	+	+
Reliability	+	+	+	+
Speed	-	+	-	+
Performance	-	0	+	+
Ease of manufacturer	+	-	+	0
Sum +'s	3	3	5	5
Sum 0's	1	2	0	1
Sum –'s	2	1	1	0
Net Score	1	2	4	5
Rank	4	3	2	1
Recommended Concept	x	x	x	√

Table 4.5 : Pugh table for concept selection

4.1.5 Best concept

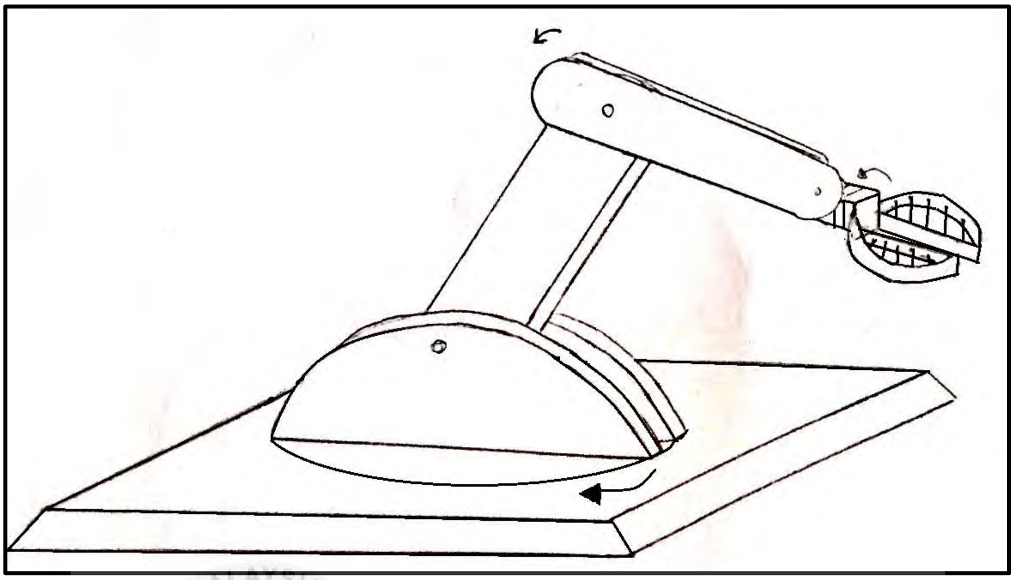


Figure 4.5: Best concept

4.2 STRUCTURE MODELING

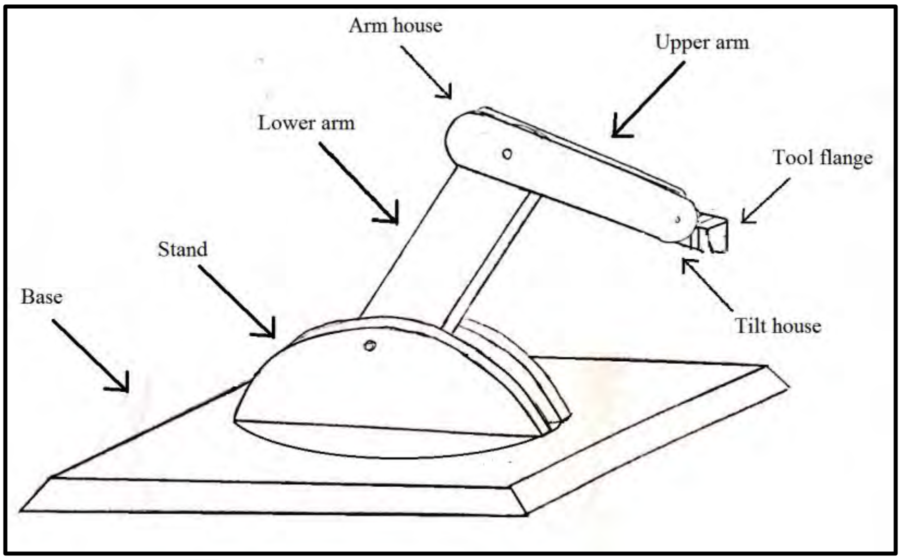


Figure 4.6: Structure of body

This specific shape of pick and place system consist of five rotational joints which have a total of five degree of freedom. The first joint is between the base and stand. The second joint is between the stand and lower arm. The third joint is between lower arm and the upper arm. The fourth joint is between the upper arm and the tilt house. And lastly, the fifth joint is between the tilt house and the tool flange which is where the gripper is connected.

The most common performance of measurements of pick and place system are ;

- Reach and shape of workspace
- Payload handling capacity
- Axis speed and acceleration
- Position and path accuracy
- Number of degree freedom

4.2.1 SYSTEM DESCRIPTION FOR BODY

The pick and place arm has five basic parts. The five parts are the end effector, the wrist, the shoulder, the elbow and the base. The table below are the description of each part and its function.

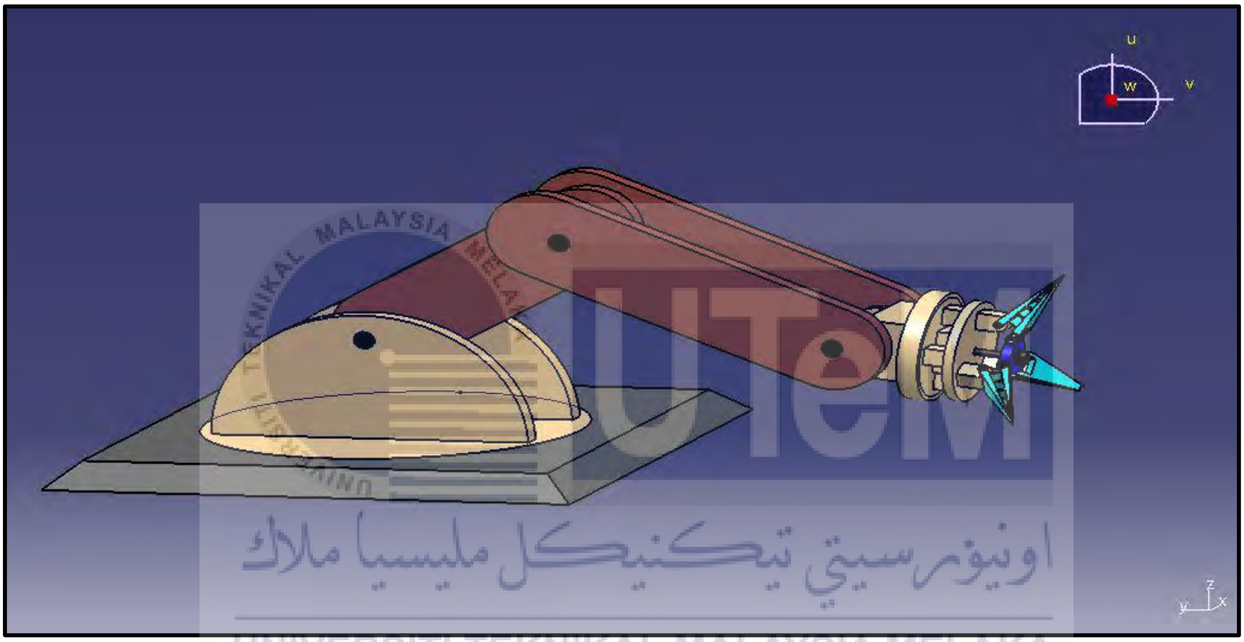


Figure 4.7: Pick and place system 3d drawing

Parts	Description
1. End effector	To grip and outgrip the objects to be lifted or moved. Connected horizontally to the servo motor.
2. Wrist	The joint that links to the end effector. It has one degree of freedom which is actuated by a servo motor. It can rotate about 180^0 about the horizontal axis.
3. Elbow	The joint that is between lower arm and upper arm and has one degree of freedom actuated by a RC servo motor. It can rotate about 180^0 by link of the upper arm. The motion about the elbow is actuated by a set of gear brains connected to the links and DC motor.
4. Shoulder	The joint between the links of the lower arm and the base. Has one degree of freedom
5. Base	The joint is connected to the shoulder and is fixed to the ground. It has one degree of freedom which is actuated by a DC motor connected to the gear in the link of the lower arm. The DC motor is similar to that used in the shoulder but a different gearing arrangement. It rotates at 360^0. The base is the platform on which the arm stands and it carries the weight of the arm which in turns determine the maximum load the robotic arm can lift. The circuit board wiring and other attachments are fixed to the base.

Table 4.6: Description of each parts

4.2.2 SYSTEM DESCRIPTION FOR GRIPPER

Fin Ray Concept

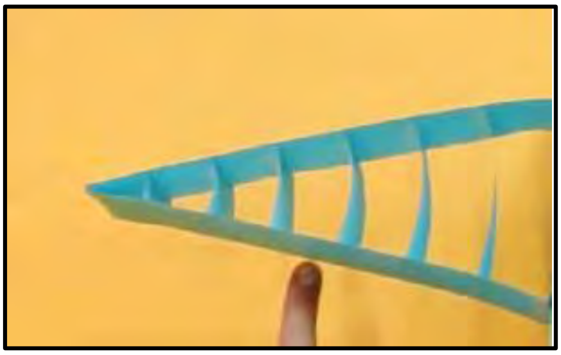


Figure 4.8: Unload Structure

Figure 4.9: Loaded Structure

The fin ray concept is a structural concept base on a fin ray. The unique design makes the structure flexible but very stable. It allows the gripper to bend according to the shape that it is grip. The purpose of modelling the fingers was to analyse the comfort and secure by determine how far each finger moved towards an object for an applied force. The grip strength was to be measured which allow to know the capable of gripping an object and picking it up. The chosen material of the base gripper is Acrylonitrile Butadiene Styrene (ABS) which is a thermoplastic polymer. ABS was chosen as the base gripper as it can be easily fabricated using injection molding and very stable. Meanwhile, the finger of the gripper is made of silicone rubber. Silicone rubber was chosen because it has a high anti-slip characteristic and very flexible.

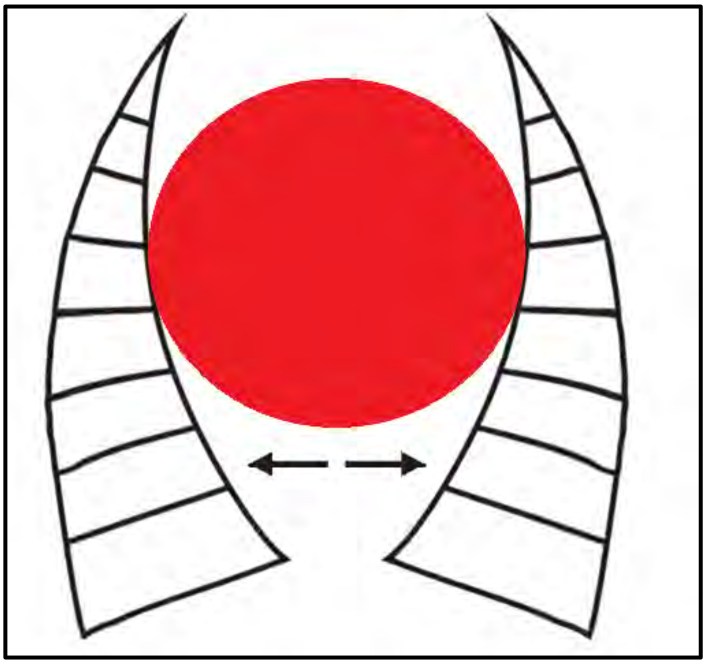


Figure 4.10 : Condition of gripper when holding a curvature object

The curvature bend of the gripper can increase the surface contact of the object with the surface of gripper. Thus, it can increase the stability of the grip and decrease the chances of the object to be dropped. The shape of the finger gripper that follows the shape of the object can allow the gripper to grip any soft and fragile object so that the shape will not change or is compressed which is safer to use.

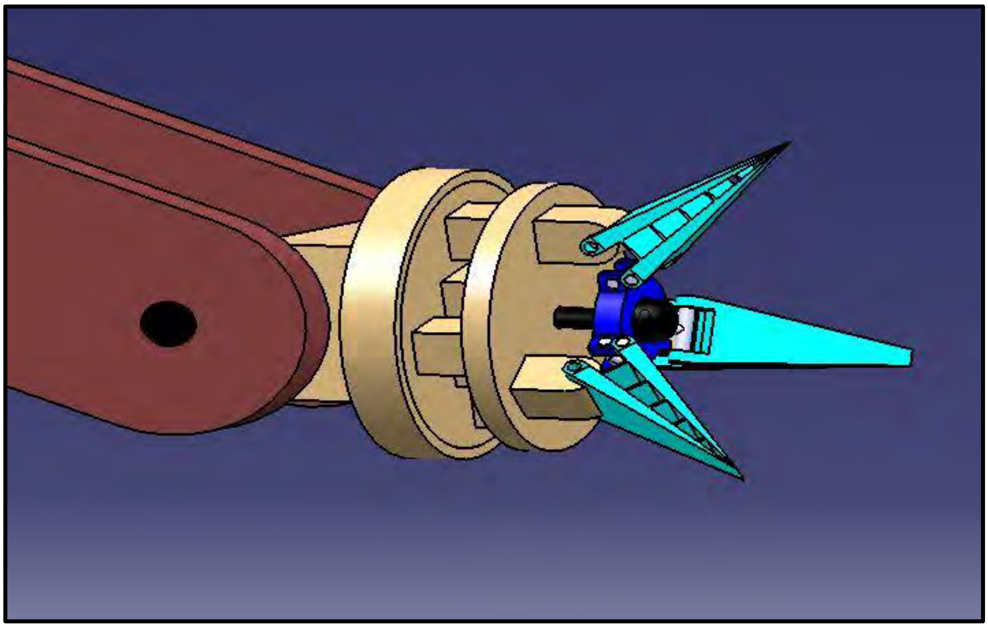


Figure 4.11: Opened gripper

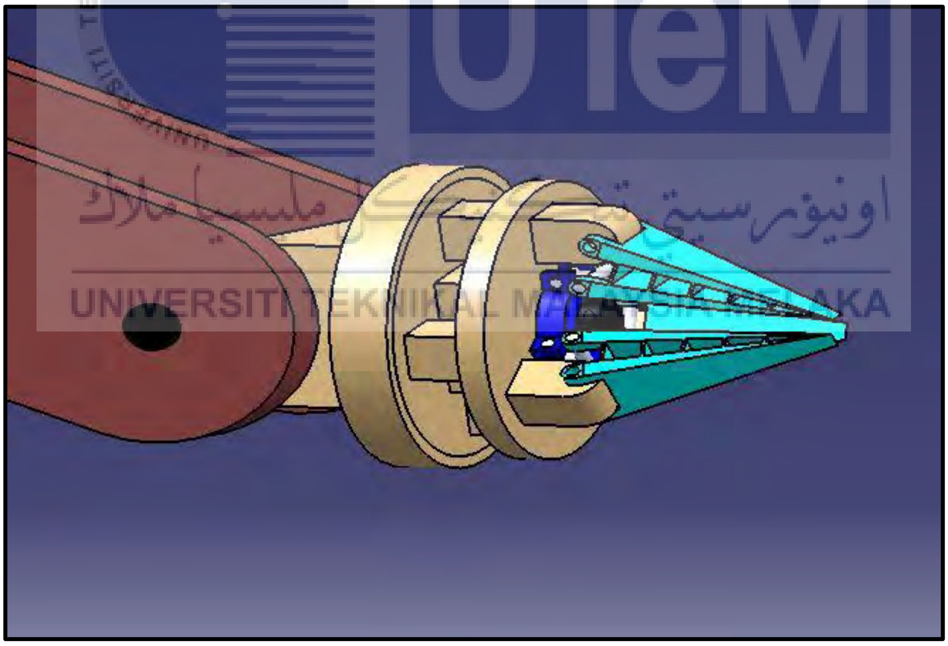


Figure 4.12: Closed gripper

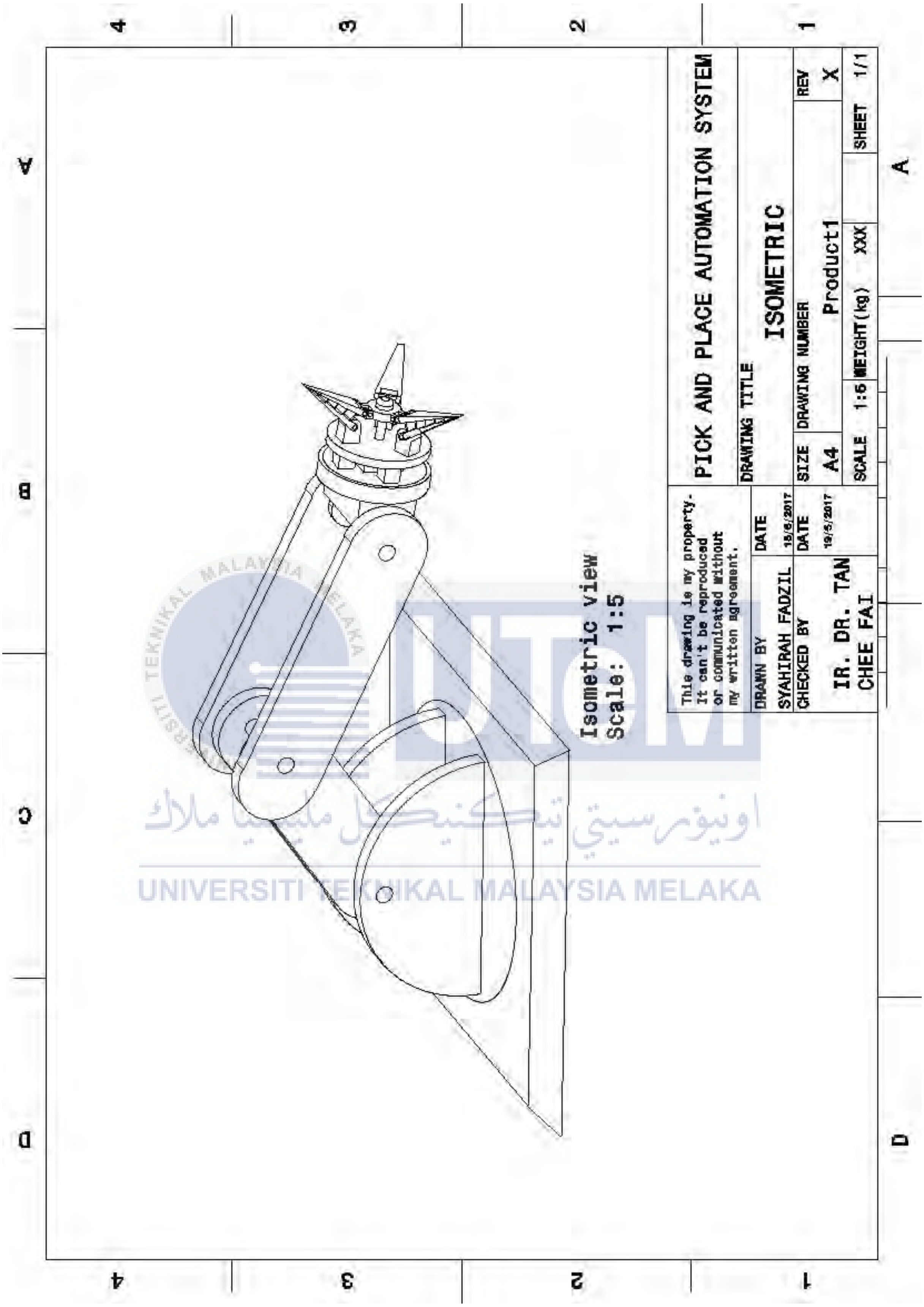


Figure 4.13: Isometric view

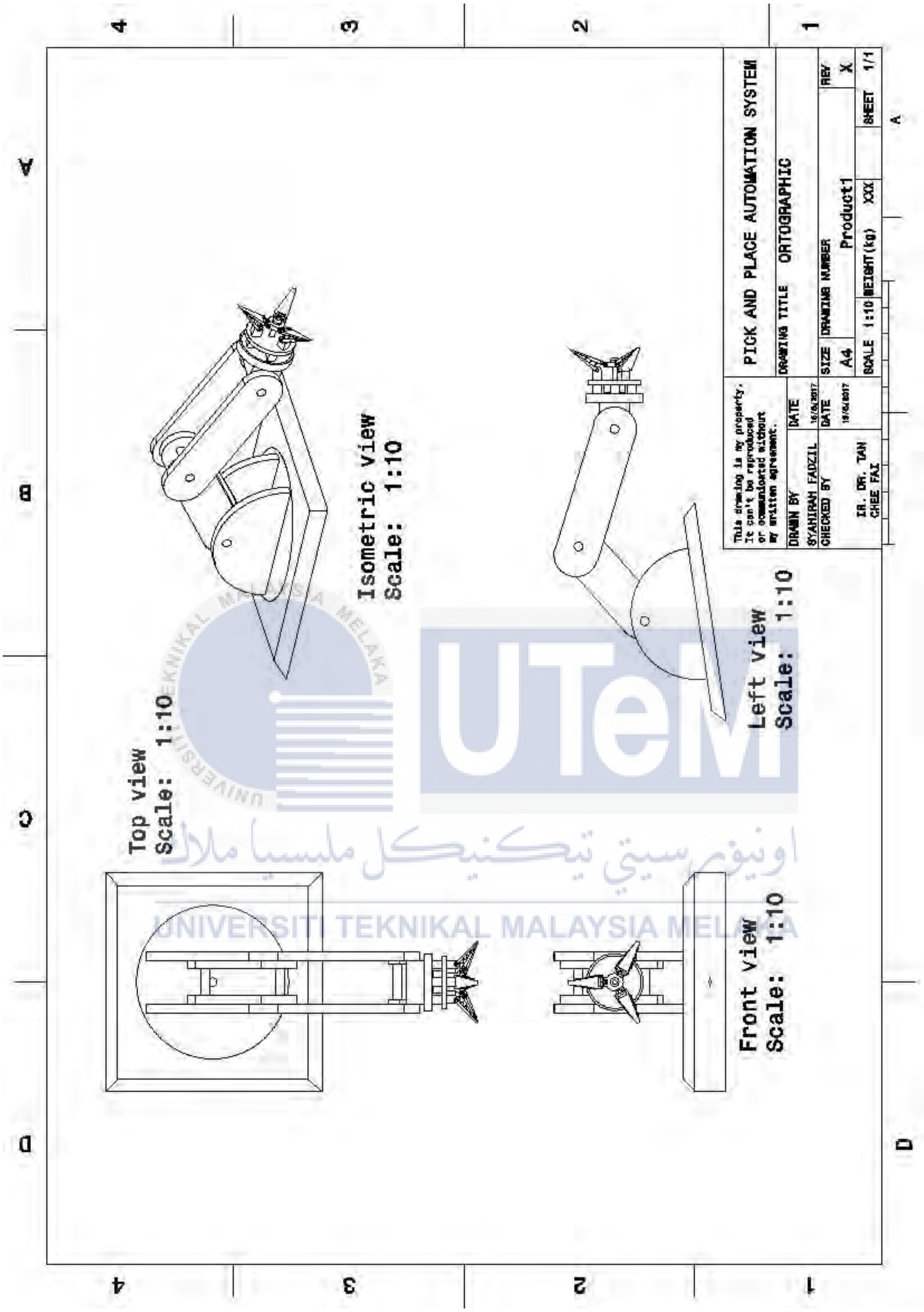


Figure 4.14: Ortographic view

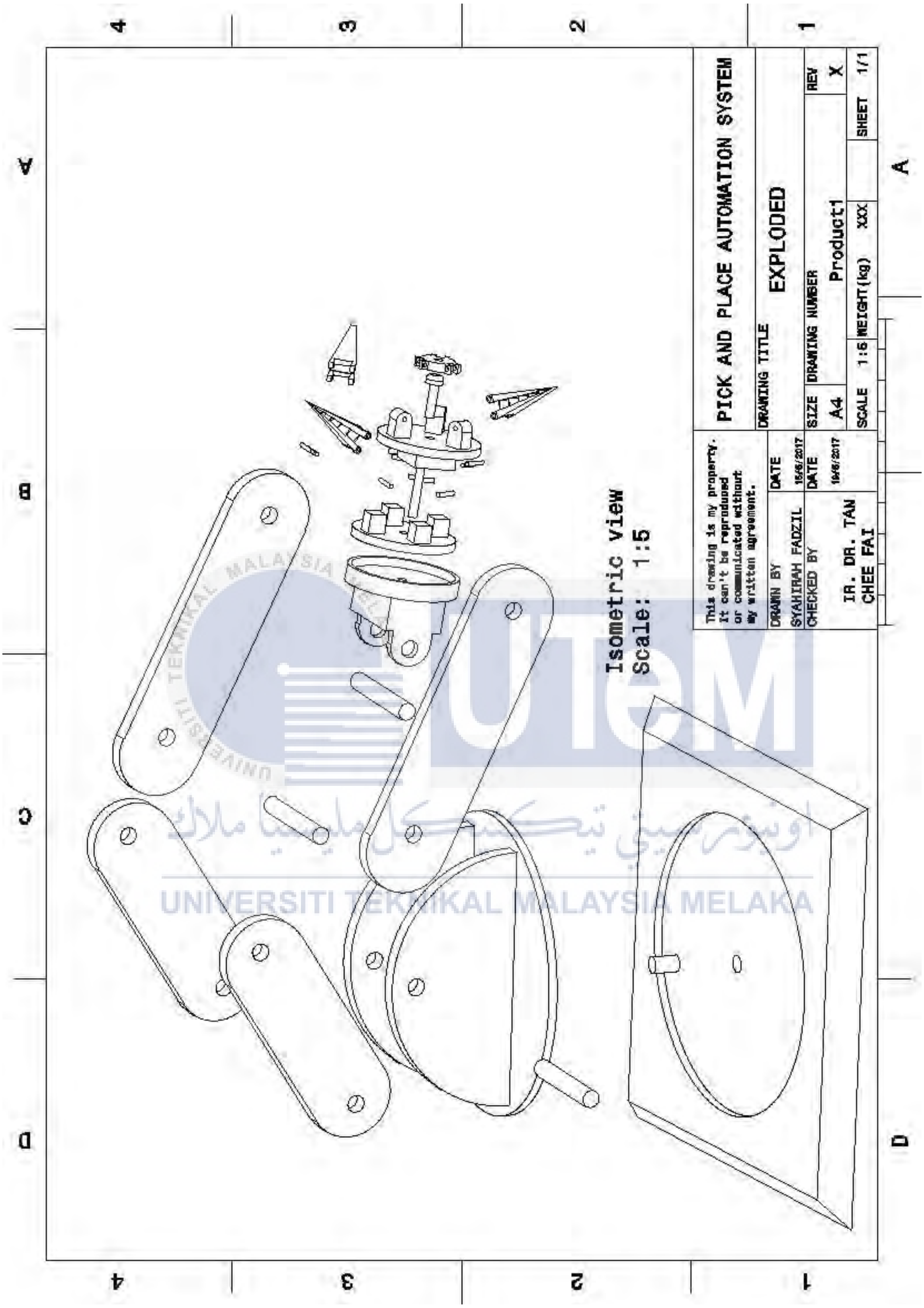


Figure 4.15: Exploded

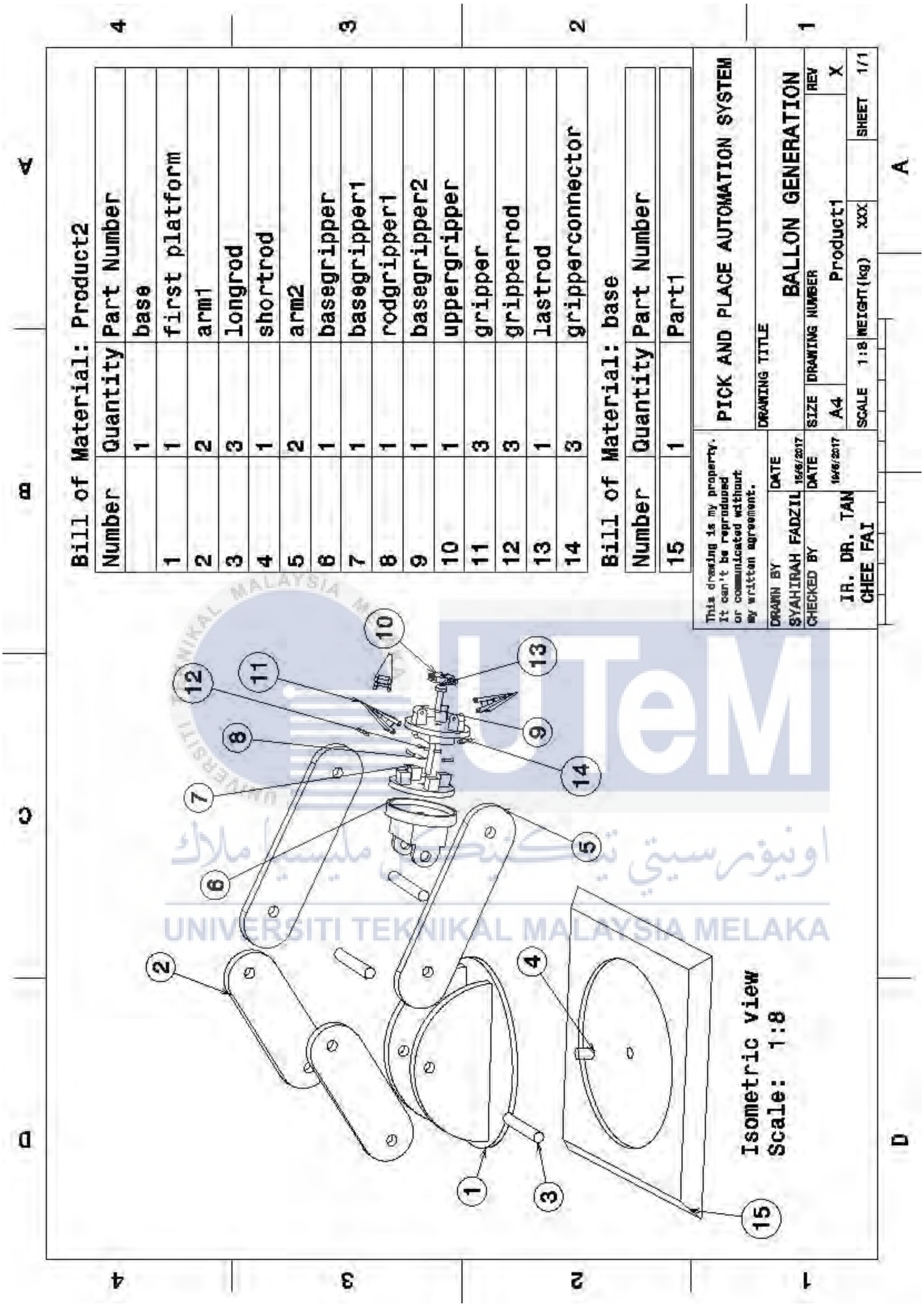


Figure 4.16: Ballon generation

4.3 ANALYSIS

CALCULATION OF STATIC TORQUE

Specification	Value
Maximum horizontal reach	500 mm
Maximum vertical reach	500 mm
Configuration	a) All axes completely independent b) All axes can be controlled simultaneously
Number of servo motor	4

Table 4.7: Specification of the system

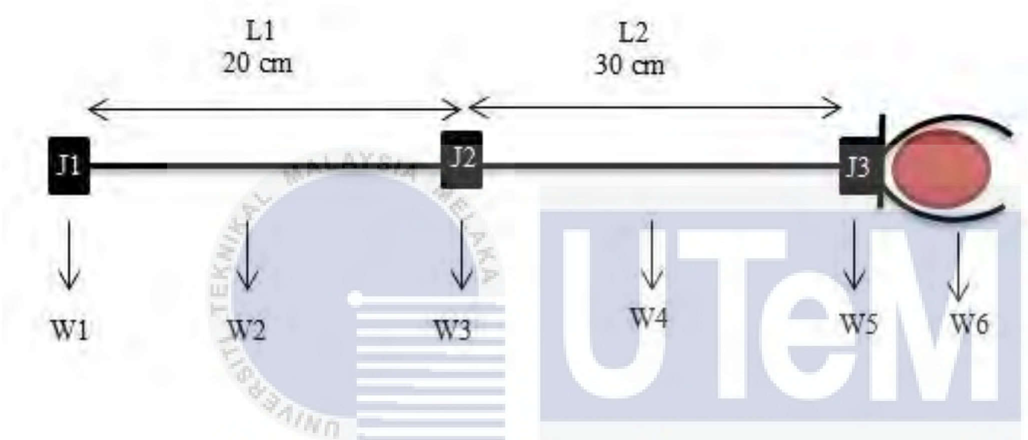


Figure 4.17 : Free Body Diagram of the system

W1: Weight of the Base servo 1 = 0.98 N

W2: Weight of the joint = 0.98 N

W3: Weight of the Joint servo = 0.49 N

W4: Weight of the joint = 0.98 N

W5: Weight of the Gripper servos (Rotating & Gripping) = 0.98 N

W6: Weight of the object lifted + Gripper = (4+.49) N

L1: Length of the joint 1 = 20 cm

L2: Length of the joint 2 = 30 cm

J1: Base servo

J2: Joint servo

J3: Gripper servos (Rotating & Gripping)

Joint 1 : M1 (Tracking arm)

= (L1/2 * W2) + (L1 * W3) + (L1 + L2/3 * W4) + (L1+L2 * W4+W5)

= (10cm)(0.1kg) + (20cm)(0.05kg) + (35cm)(0.1kg) + (50cm)(0.557kg)

= 33.35 kg.cm

Joint 2 : M2

= (L2/2 * W4) + (L2 * W5+W5)

= (15cm)(0.1kg) + (30cm)(0.557kg)

= 18.21 kg.cm

Joint 3 : M3

= 0 kg.cm (distance is 0)

Therefore in this case, different servos are needed at each joint of the arm, which are, two similar servos for both the arms at each joint. The gripper would need the lightest servo only depending on weight of the object the arm would lift. However, when it comes to the second joint from the gripper, it should be powerful enough to carry everything above it including the object, gripper and the weight of the material above it. Thus, in order to achieve this, that joint would require a stronger servo motor compared to the one used at the gripper. Same goes for the rest of the joints below. The base servo would have to be the strongest in the entire arm, while the gripper has the lightest.

STRUCTURE ANALYSIS USING ANSYS SOFTWARE

The process was first started with a 3D model by using CATIA Software. Each part was drawn with the exact dimension for the model. Each part was assembled. Then it was save in igs format so that the drawing can be open in the ANSYS Software. The pick and place system was divided into two parts which is the body and the gripper. The analysis will focus on the body because the upper arm is consider to be the main focus point of the movement. The load was put at the upper arm with load going downwards to at the x-axis. The joint between the upper arm and the lower arm was fixed. Thus, we will analyse the stress at the upper arm.

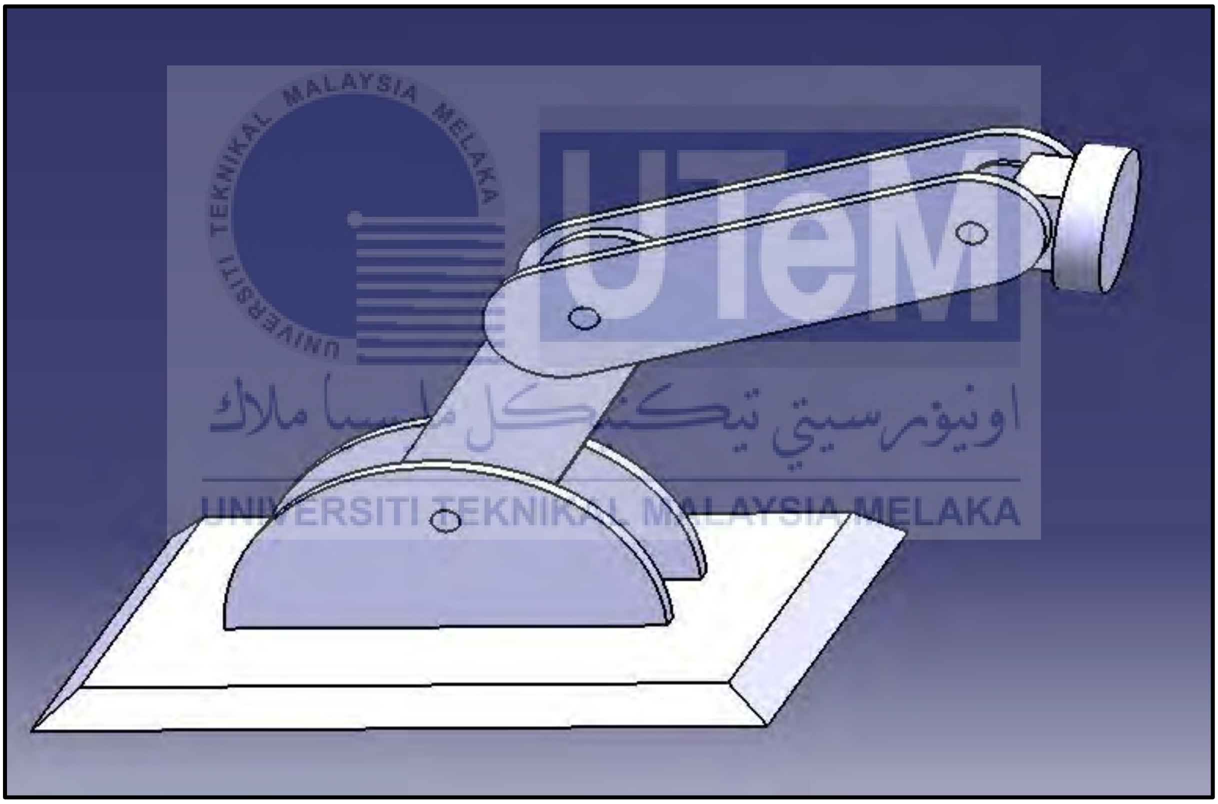


Figure 4.18 : Body of pick and place system

A few details such as von misses, maximum stress and safety factor of the design were taken in this analysis. The raw material selected for the pick and place system is Aluminium alloy 6061 series which is one of the most commonly used aluminium alloy for all purpose. The alloying elements that used in this series of aluminium alloy are magnesium and silicon.

Alloys of this series are moderate in strength (200 – 350 MPa) which is enough to support the body of the pick and place system. The strength of this alloy is achieved through the heat treatment processing or forming. The property of the aluminium alloy is presented in Table below.

Table 4.8 : Properties of aluminium alloy 6061 series

Density	2770 kg/m^3
Ultimate Tensile strength	310 MPa
Tensile Yield strength	276 MPa
Modulus Of Elasticity	68.9 GPa
Fatigue strength	96.5 MPa
Shear strength	207 MPa

The load that was applied in the analysis is 100kg. This is because it is assumed to withstand a load of 100kg without any maximum damages. This part body of pick and place system contains 9 body parts and the total mass of the body part is 31.8 kg with the total volume of 1.148e+003 m^3.

4.3.1 TOTAL DEFORMATION

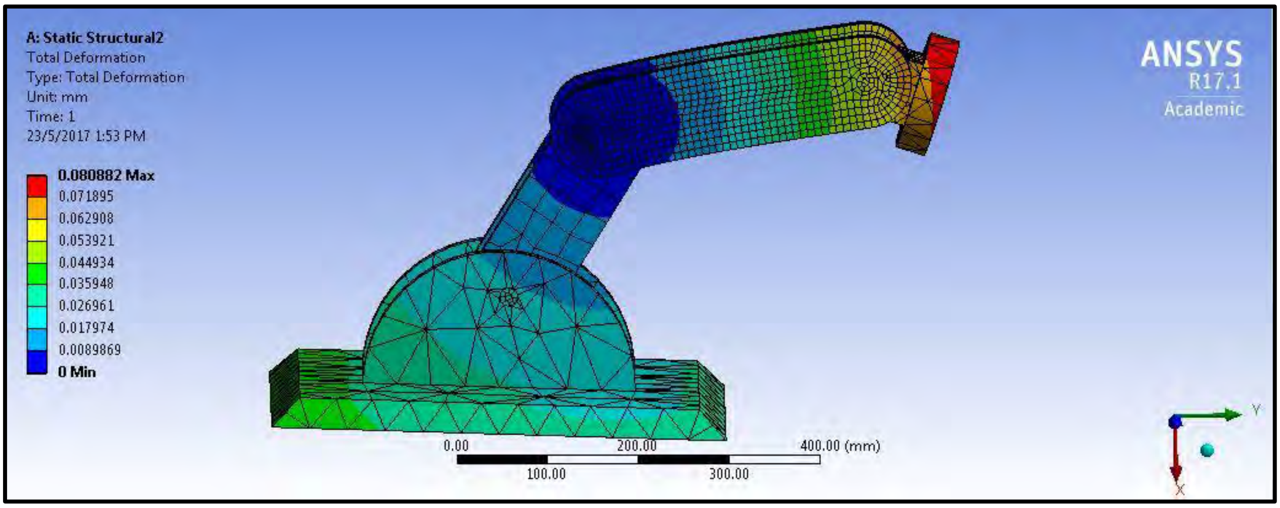


Figure 4.19: Total deformation of design

Deformation analysis is the study of the changes in the shape of a body in time when a force is applied. From the figure above, the maximum total deformation of the body of pick and place system is 0.080882 mm which is very low occurs at the wrist (front side) of the pick and place system. **Figure 4.19** shows that a force of 100kg was applied to the front part of the body which indicates the maximum deformation where the red area is. The deformation is caused by thickness of the rod that holds the two plates of upper arm. From the drawing, the diameter of the rod is 2cm. However, the load will not be placed exactly on that part of the body. A base gripper and a gripper will hold the load and pick up the object. The minimum deformation of this body is zero which is at the fixed part. In this case, it is placed at the joint between the upper arm and the lower arm. This part that is remains fixed in ANSYS analysis because it is easier to analyse the upper arm of the pick and place. This is why it has the minimum value of deformation which is the blue part. The base will be fixed at the ground. The highest deflection occurs at 0.017974 which is the sky blue area.

Manual calculation for deformation

$$\boldsymbol{\delta} = \frac{\boldsymbol{FL}}{\boldsymbol{EA}}$$

Where $\boldsymbol{\delta}$ = total deformation of the member carrying the axial load

$\boldsymbol{F}$ = direct axial loading

$\boldsymbol{L}$ = original total length of the member

$\boldsymbol{E}$ = modulus of elasticity of the material

$\boldsymbol{A}$ = cross-sectional of the member

Note that $\boldsymbol{\sigma = F/A}$, we can also compute the deformation from $\boldsymbol{\delta = \sigma L/E}$

$$\boldsymbol{\delta} = \frac{\boldsymbol{FL}}{\boldsymbol{EA}}$$

$$\boldsymbol{\delta} = \frac{(\boldsymbol{980\ N})(\boldsymbol{0.3\ m})}{(\boldsymbol{68.9\ Gpa})(\boldsymbol{3\ m^2})}$$

$$\boldsymbol{\delta = 1.42235 \times 10^{-9}\ m}$$

4.3.2 MAXIMUM SHEAR STRESS

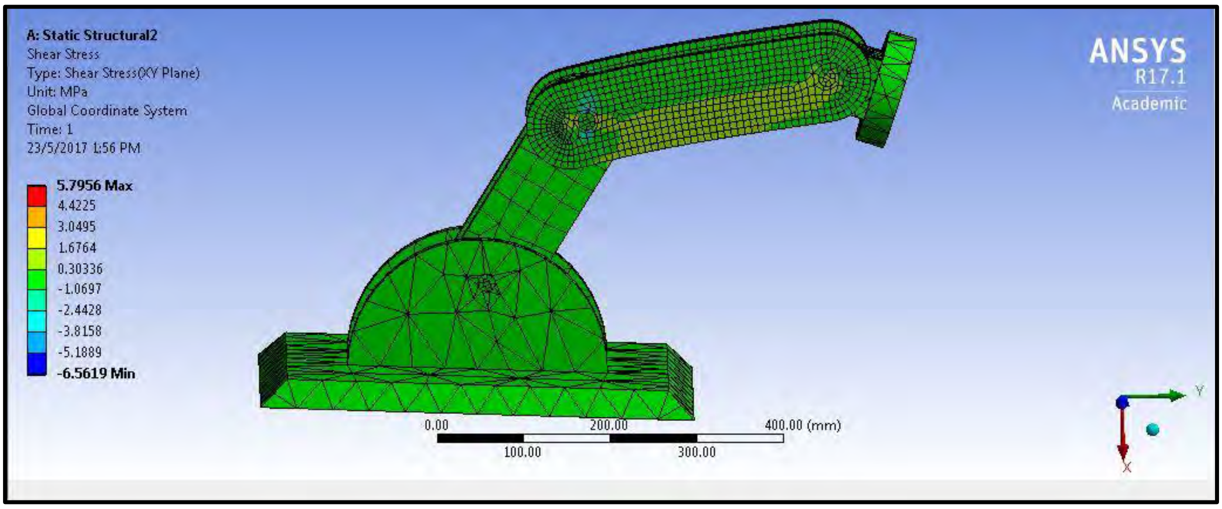


Figure 4.20: Maximum shear stress of design

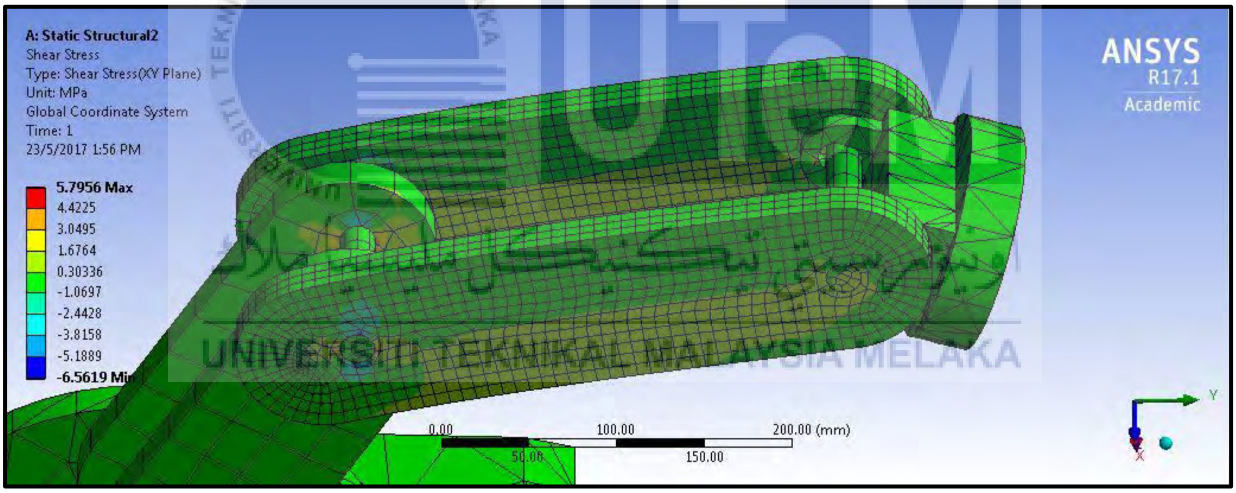


Figure 4.21 : Maximum shear stress of design (close up)

Shear stress is the force tending to cause the deformation of the material. From the **Figure 4.20** and **Figure 4.21** above, the maximum shear stress is 5.7956 Mpa. The maximum value that occurs at the body part is at the range of -1 to 0.3 Mpa. From the close up Figure 35, it is shown that there is a slight deflection occurs at the bottom side of the upper arm. The deflection shows that the stress is higher at that part. The joint between the upper arm and lower arm has the lowest shear value which is at the range of -5.1889 to -2.4428.

4.3.3 EQUIVALENT STRESS (VON-MISSES)

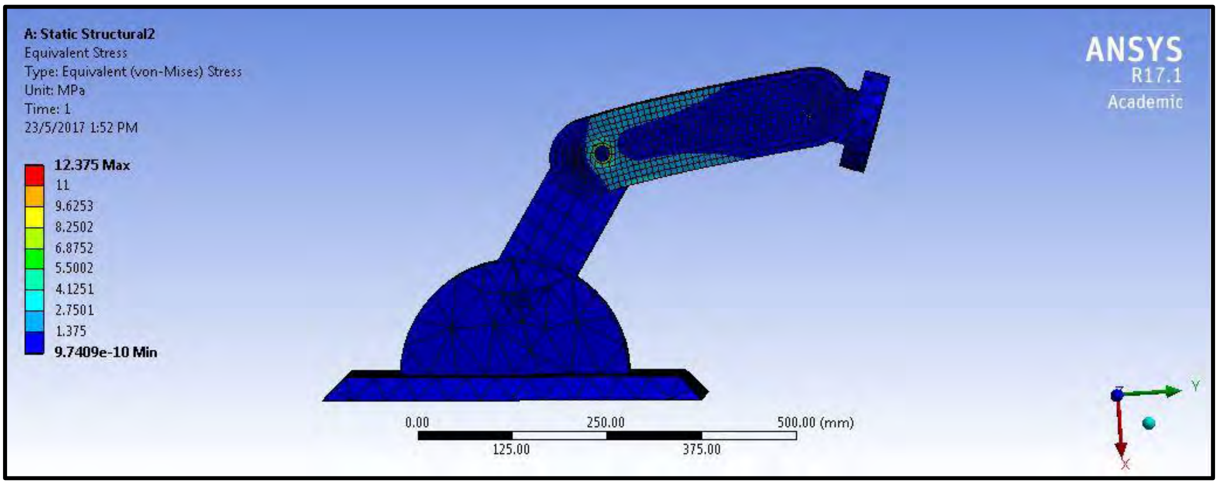


Figure 4.22 : Von misses value of the design

Figure 4.23: Von misses value of the design (close up)

Von Misses Stress is a part of the maximum equivalent stress failure theory used to predict yielding in a ductile material. When the material reaches yield point, the material can be considered as failed. From **Figure 4.22** and **Figure 4.23**, the maximum von misses value of the design is 12.375 Mpa. However, most of the part has a minimum value of von misses which is 9.7409e-10 Mpa. Therefore, the yielding point is far off to reach. Thus, this material isconsideredaspassed.

4.3.4 FACTOR OF SAFETY

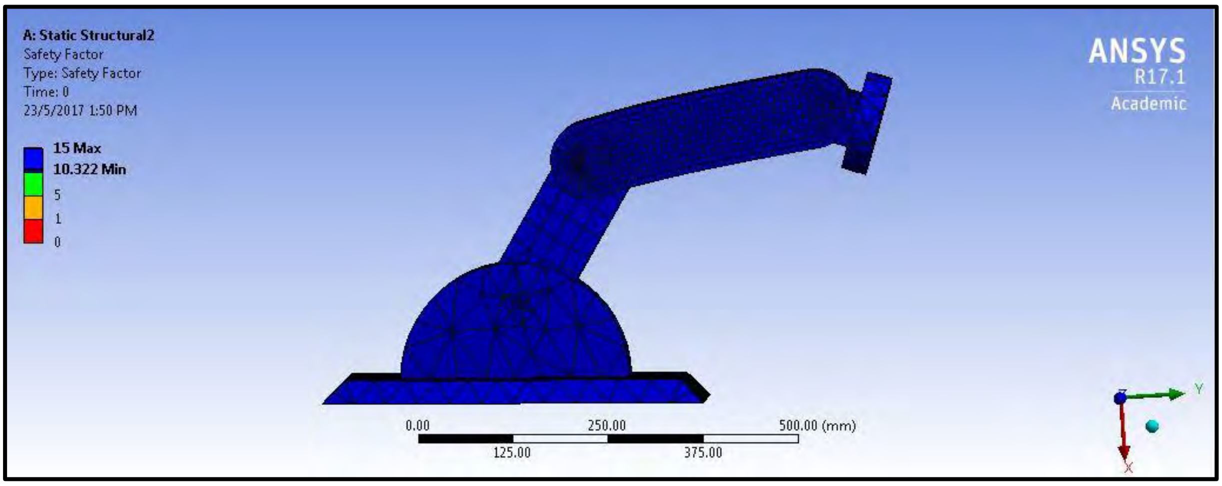


Figure 4.24: Factor of safety at 100kg

Figure 4.24 shows the factor of safety at 100kg load. The figure shows it has a minimum value of 10.375. This shows that the body is very safe and stable. There is no sign of other colour area. The load was upgraded to 400kg, to see the difference of the factor of safety value.

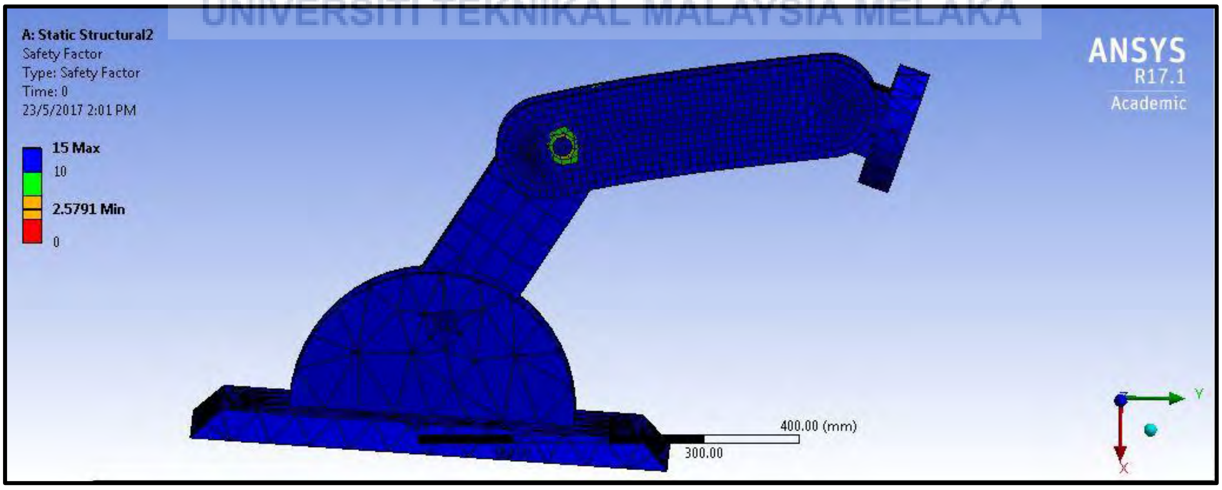


Figure 4.25: Factor of safety at 400kg

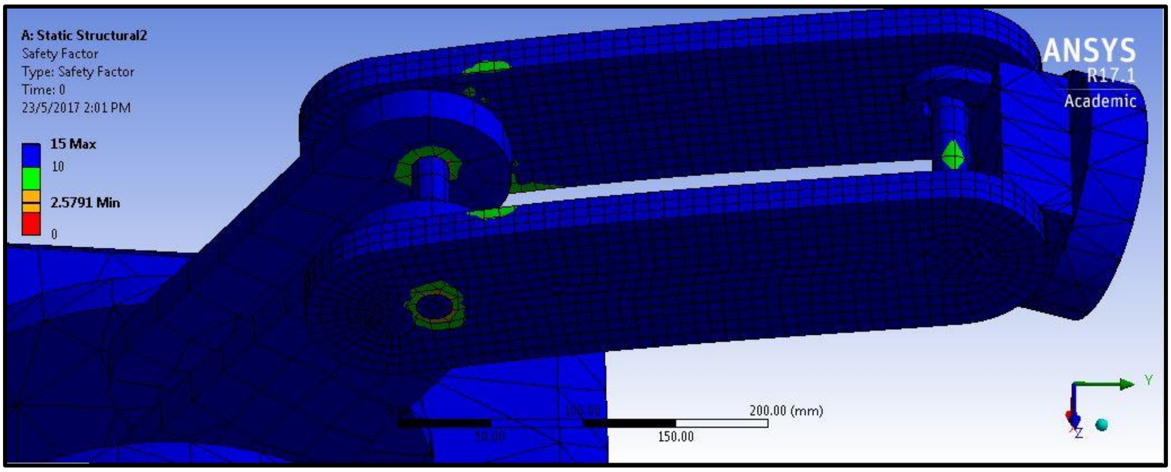


Figure 4.26 : Factor of safety at 400kg (close up)

At 400kg, the minimum factor of safety value is 2.5925. The qualification to achieve the best product is to have a safety of factor with the value of 2.5 and above. Thus, this should be the maximum load that the body part can resist. There is a slight deflection in the green area as in **Figure 4.26**. This shows that 400kg is the maximum load that the system can lift for the part to be safe without any damage.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 INTRODUCTION

In this chapter, conclusion is made to answer if the objective is achieved or not. Overall conclusion is made for the overall report. If any mistaken or flaws happen when achieving the result of the report, recommendation is made.

5.2 CONCLUSION

As a conclusion, it is concluded that the objective of the thesis is achieved. The main focus of this thesis is to develop a smart modular pick and place system for training student's skill in Vocational Technical School. Therefore, the objective of the system is to provide a pick and place system that is simple, safe, durable and high effective. From the design of the pick and place system, is it considered as simple as it can be assembled and disassembled easily so that it is easy for students to understand the structure and function of the system. The total weight of the system is 32 kg. The material of the body part is aluminium alloy as it is lighter and cost effective compare to structural steel. Therefore, it can be easier to be lift and the portability of the design can be increase. The maintenance of the cost can also be reduced by using aluminium alloy because they do not need to repaint or coating to avoid rust. The safety and durability of the structure is achieved as the system shows a positive reaction in the shear stress, total deformation, von misses and safety of factor analysis. From the data, it shows that the total deformation of the design is very small which is 0.080882 mm. The maximum value for shear stress is 5.7956 Mpa. For the von misses stress, which also known as the equivalent stress, the value is 12.375 Mpa. The safety factor for the part at 100kg load is at 10.375 and when the load is increased at 400kg, the safety of factor is 2.5791. Therefore, it is very helpful for students to use it and easy to maintained. The gripper of the system uses the fin ray adapter gripper concept which can bend following the curvature of the object to pick. Therefore, the system is high effective as it can lift up a variety object of different shape without damaging or distorting the shape of the object. A full grip of the object can contribute towards a more secure grip to lift it up. The gripper is also made of silicone so that it is not slippery. Thus, the object will not slip and falls.

5.3 RECOMMENDATION

This thesis is not perfect and a lot of improvements can be made to make it better. Thus, recommendations are needed for further consideration to improve this report. First, it is recommended that the product need to be tested first in order to achieve a more accurate result so that the product function ability can be valid. Therefore, it is better to make a prototype at the early process to adjust any possible mistake or in accurate sizing calculation. Secondly, it is recommended that the type of material used is compared with a few different types to have the best and suitable material. Therefore, it is easier to choose the most cost effective, durable and safe. Thirdly, in order to have the best criteria, it is advisable to have a professional or experienced advisor so that they can help in advising and creating the best smart pick and place system. In this case, the person is the design engineer and the technician or lecturer in the vocational technical school so that they can tell the best criteria.

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APPENDIX A

Table A1 Gantt chart for PSM 1

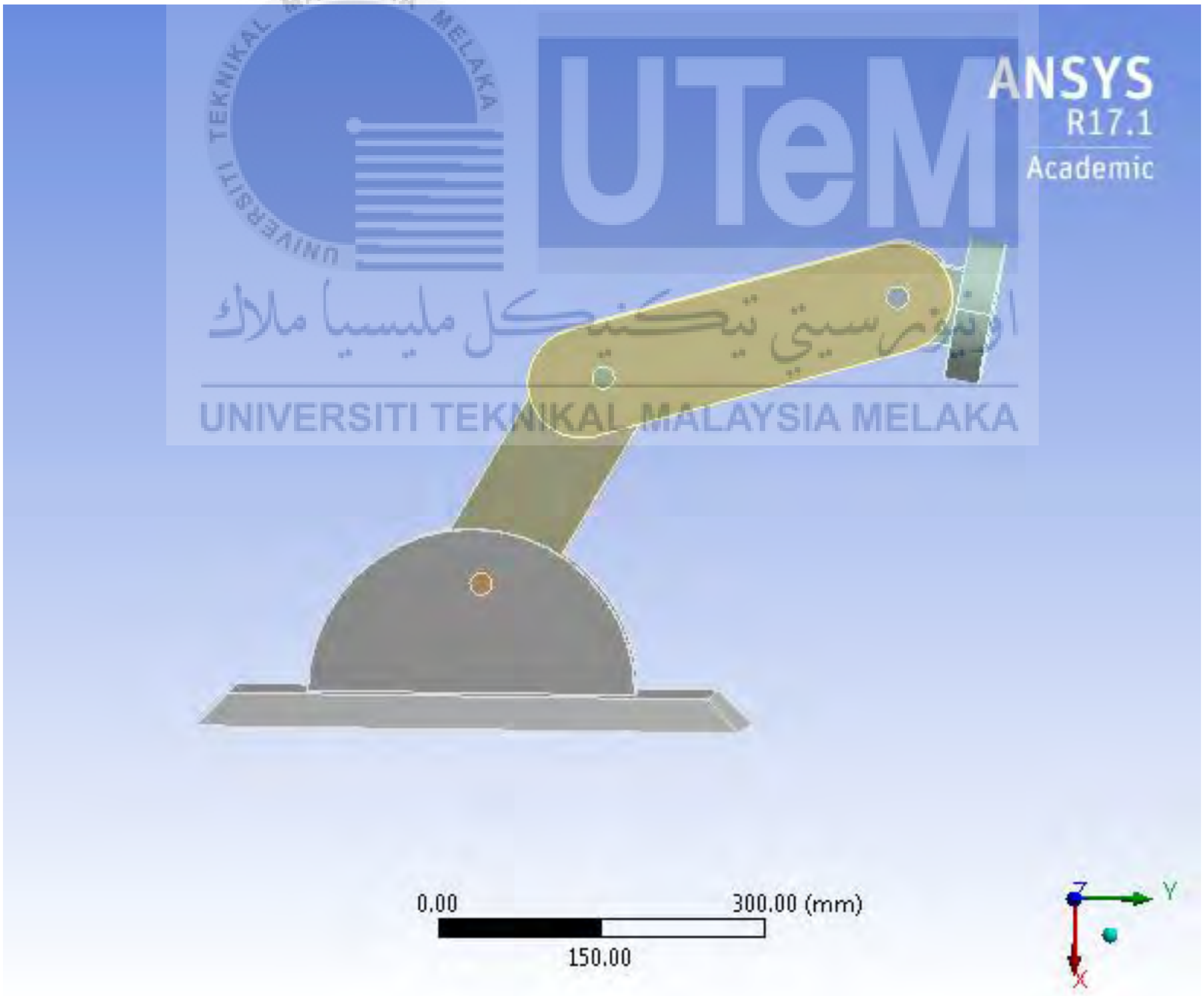
Week Activities	PSM 1													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Problem Statement & Objectives														
Literature review														
Conceptual Design														
Design development														
Design analysis														
Data collection														
Draft of report writing														
Report writing submission														
Seminar 1 presentation														

Table A2 Gantt chart for PSM 2

Week Activities	PSM 2													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Concept Selection	■	■												
Detail design		■	■	■										
CAD drawing				■	■	■	■	■						
ANSYS analysis									■	■	■			
Data collection											■			
Report writing	■	■	■	■	■	■	■	■	■	■	■	■	■	
Report submission														■
Presentation														■

Project

First Saved	Monday, May 15, 2017
Last Saved	Monday, May 15, 2017
Product Version	17.1 Release
Save Project Before Solution	No
Save Project After Solution	No



Contents

Units

TABLE 1

Unit System	Metric (mm, kg, N, s, mV, mA) Degrees rad/s Celsius
Angle	Degrees
Rotational Velocity	rad/s
Temperature	Celsius

Model (A4)

Length Unit	Meters
Element Control	Program Controlled
Display Style	Body Color
Bounding Box	
Length X	452.61 mm
Length Y	733.18 mm
Length Z	500. mm

<table>
<tr><th colspan="10">Properties</th></tr>
<tr><td>Volume</td><td colspan="9">1.148e+007 mm³</td></tr>
<tr><td>Mass</td><td colspan="9">31.8 kg</td></tr>
<tr><td>Scale Factor Value</td><td colspan="9">1.</td></tr>
<tr><th colspan="10">Statistics</th></tr>
<tr><td>Bodies</td><td colspan="9">9</td></tr>
<tr><td>Active Bodies</td><td colspan="9">9</td></tr>
<tr><td>Nodes</td><td colspan="9">28338</td></tr>
<tr><td>Elements</td><td colspan="9">6051</td></tr>
<tr><td>Mesh Metric</td><td colspan="9">None</td></tr>
<tr><td>Nonlinear Effects</td><td colspan="9">Yes</td></tr>
<tr><td>Thermal Strain Effects</td><td colspan="9">Yes</td></tr>
<tr><th colspan="10">Bounding Box</th></tr>
<tr><td>Length X</td><td>180. mm</td><td colspan="3">20. mm</td><td>133.58 mm</td><td colspan="2">182.89 mm</td><td colspan="2">273.46 mm</td></tr>
<tr><td>Length Y</td><td>500. mm</td><td colspan="3">20. mm</td><td>121.98 mm</td><td colspan="2">388.32 mm</td><td colspan="2">199.56 mm</td></tr>
<tr><td>Length Z</td><td>500. mm</td><td colspan="3">140. mm</td><td>130. mm</td><td colspan="4">20. mm</td></tr>
<tr><th colspan="10">Properties</th></tr>
<tr><td>Volume</td><td>8.0371e+006 mm³</td><td colspan="3">43978 mm³</td><td>7.3305e+005 mm³</td><td colspan="2">7.445e+005 mm³</td><td colspan="2">5.445e+005 mm³</td></tr>
<tr><td>Mass</td><td>22.263 kg</td><td colspan="3">0.12182 kg</td><td>2.0306 kg</td><td colspan="2">2.0623 kg</td><td colspan="2">1.5083 kg</td></tr>
<tr><td>Centroid X</td><td>183.93 mm</td><td>-186.17 mm</td><td>-108.81 mm</td><td>81.992 mm</td><td>-176.72 mm</td><td colspan="2">-144.68 mm</td><td colspan="2">-13.409 mm</td></tr>
<tr><td>Centroid Y</td><td>-42.176 mm</td><td>344.04 mm</td><td>74.938 mm</td><td>-34.581 mm</td><td>397.59 mm</td><td colspan="2">199.72 mm</td><td colspan="2">20.179 mm</td></tr>
<tr><td>Centroid Z</td><td colspan="5">130. mm</td><td>190. mm</td><td>70. mm</td><td>170. mm</td><td>90. mm</td></tr>
</table>

Moment of Inertia Ip1	7.1723e+005 kg·mm²	201. kg·mm²	3117.9 kg·mm²	24617 kg·mm²		1242.4 kg·mm²	
Moment of Inertia Ip2	3.82e+005 kg·mm²	201. kg·mm²	3603.7 kg·mm²	1722.3 kg·mm²		9761.9 kg·mm²	
Moment of Inertia Ip3	3.898e+005 kg·mm²	6.03 kg·mm²	2645.2 kg·mm²	26201 kg·mm²		10904 kg·mm²	
Statistics							
Nodes	1768	506	1113	11381	11505	550	503
Elements	803	88	557	2139	2166	64	58
Mesh Metric	None						

TABLE 2
Model (A4) > Static Structural (A5) > Solution (A6) > Results

Definition				
Type	Equivalent (von-Mises) Stress	Normal Stress	Total Deformation	Shear Stress
Orientation		X Axis		XY Plane
Coordinate System		Global Coordinate System		Global Coordinate System
Minimum	9.7409e-010 MPa	-5.3669 MPa	0. mm	-6.5619 MPa
Maximum	12.375 MPa	6.0767 MPa	8.0882e-002 mm	5.7956 MPa
Minimum Occurs On	rod2	upperarm2	rod2	upperarm1
Maximum Occurs On	upperarm2		gripper	upperarm1

TABLE 3
Model (A4) > Static Structural (A5) > Solution (A6) > Equivalent Stress

Time [s]	Minimum [MPa]	Maximum [MPa]
1.	9.7409e-010	12.375

TABLE 4
Model (A4) > Static Structural (A5) > Solution (A6) > Normal Stress

Time [s]	Minimum [MPa]	Maximum [MPa]
1.	-5.3669	6.0767

TABLE 5
Model (A4) > Static Structural (A5) > Solution (A6) > Total Deformation

Time [s]	Minimum [mm]	Maximum [mm]
1.	0.	8.0882e-002

TABLE 6
Model (A4) > Static Structural (A5) > Solution (A6) > Shear Stress

Time [s]	Minimum [MPa]	Maximum [MPa]
1.	-6.5619	5.7956

FIGURE 1
Model (A4) > Static Structural (A5) > Solution (A6) > Fatigue Tool

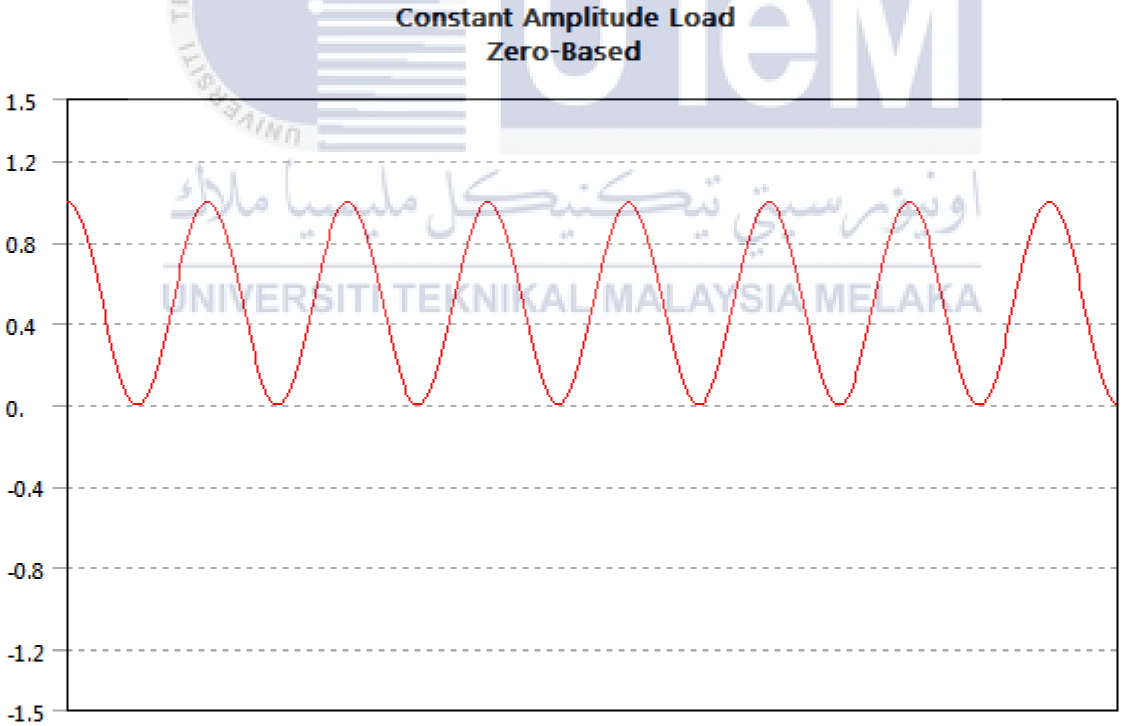
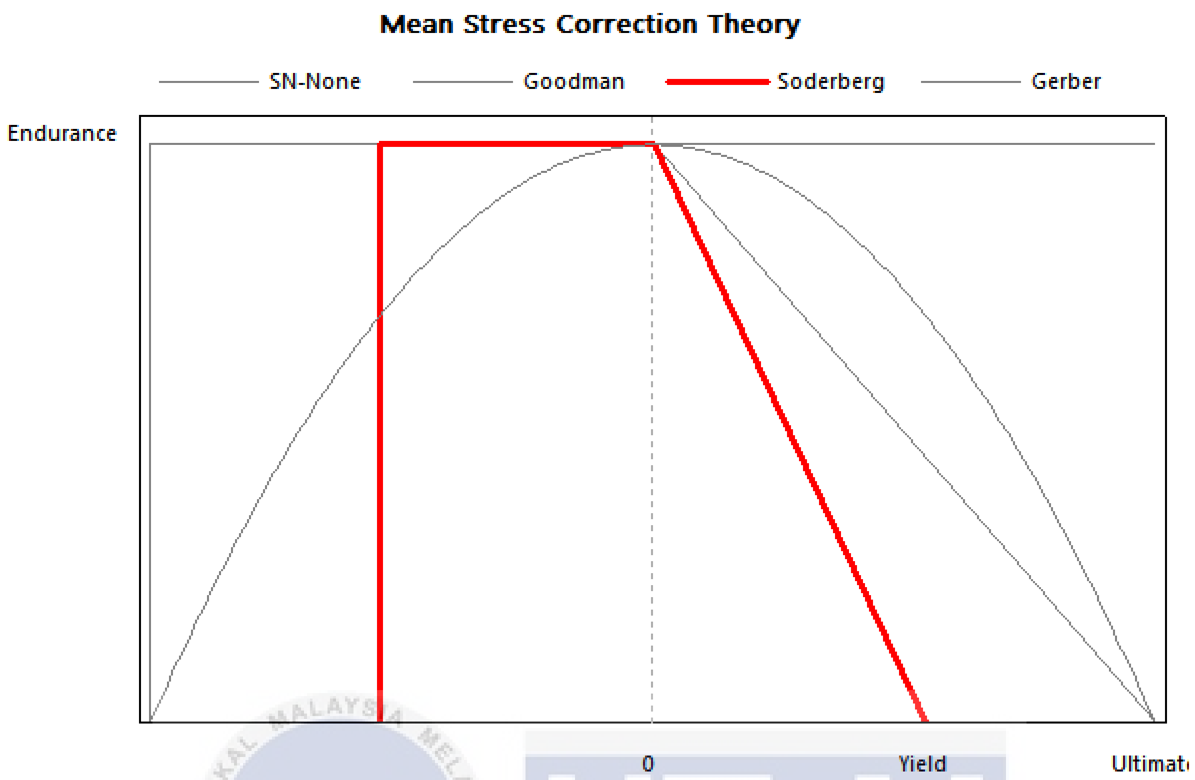


FIGURE 2
Model (A4) > Static Structural (A5) > Solution (A6) > Fatigue Tool



Minimum Occurs On	upperarm2

TABLE 7
Model (A4) > Static Structural (A5) > Solution (A6) > Fatigue Tool > Safety Factor

Time [s]	Minimum	Maximum
1.	10.322	15.

Material Data

Aluminum Alloy

TABLE 8
Aluminum Alloy > Constants

Density	2.77e-006 kg mm^-3
Coefficient of Thermal Expansion	2.3e-005 C^-1
Specific Heat	8.75e+005 mJ kg^-1 C^-1

TABLE 9
Aluminum Alloy > Color

Red	Green	Blue
138	104	46

TABLE 10
Aluminum Alloy > Compressive Ultimate Strength

Compressive Ultimate Strength MPa
0

TABLE 11
Aluminum Alloy > Compressive Yield Strength

Compressive Yield Strength MPa
280

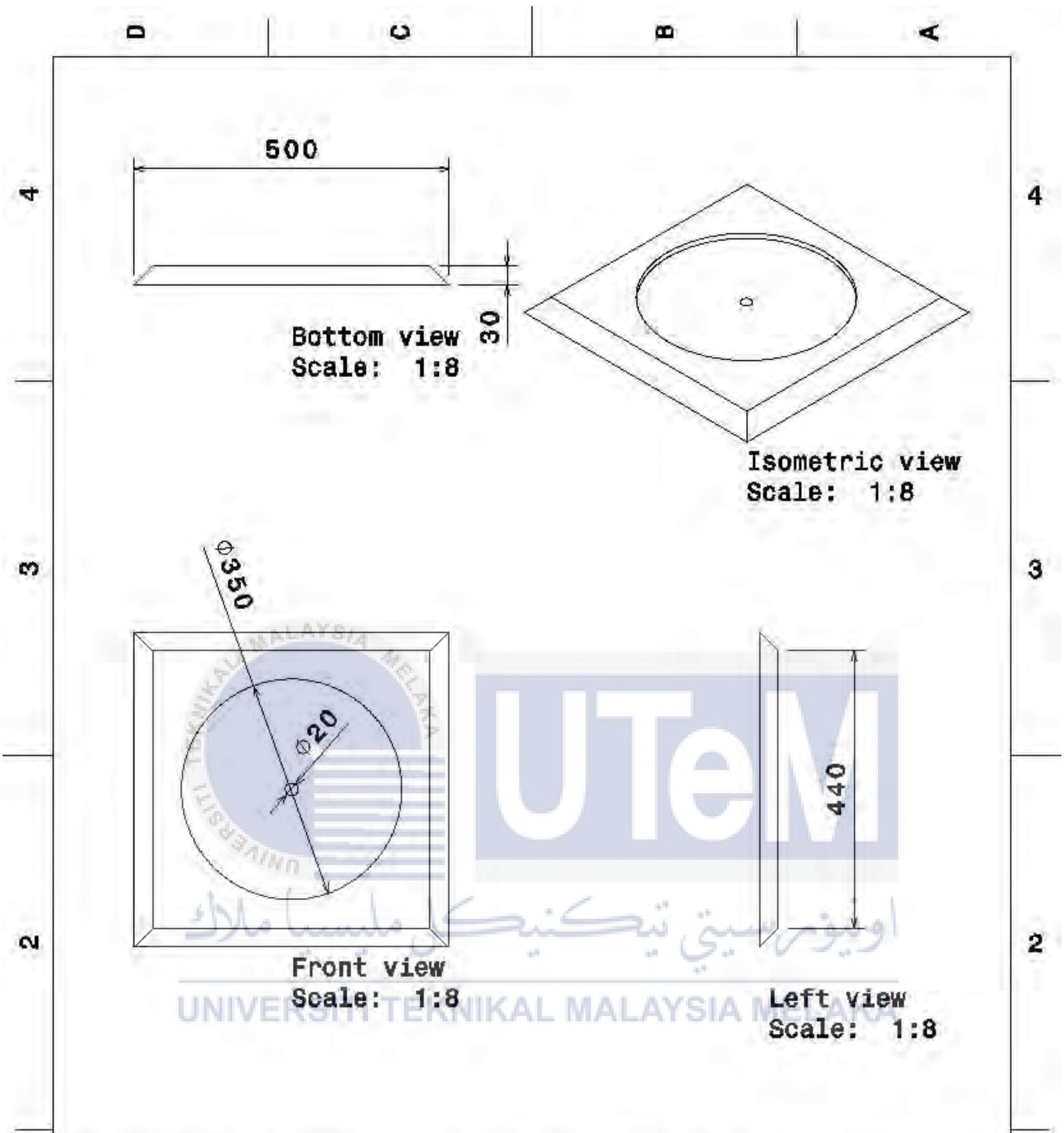
TABLE 12
Aluminum Alloy > Tensile Yield Strength

Tensile Yield Strength MPa
280

TABLE 13
Aluminum Alloy > Tensile Ultimate Strength

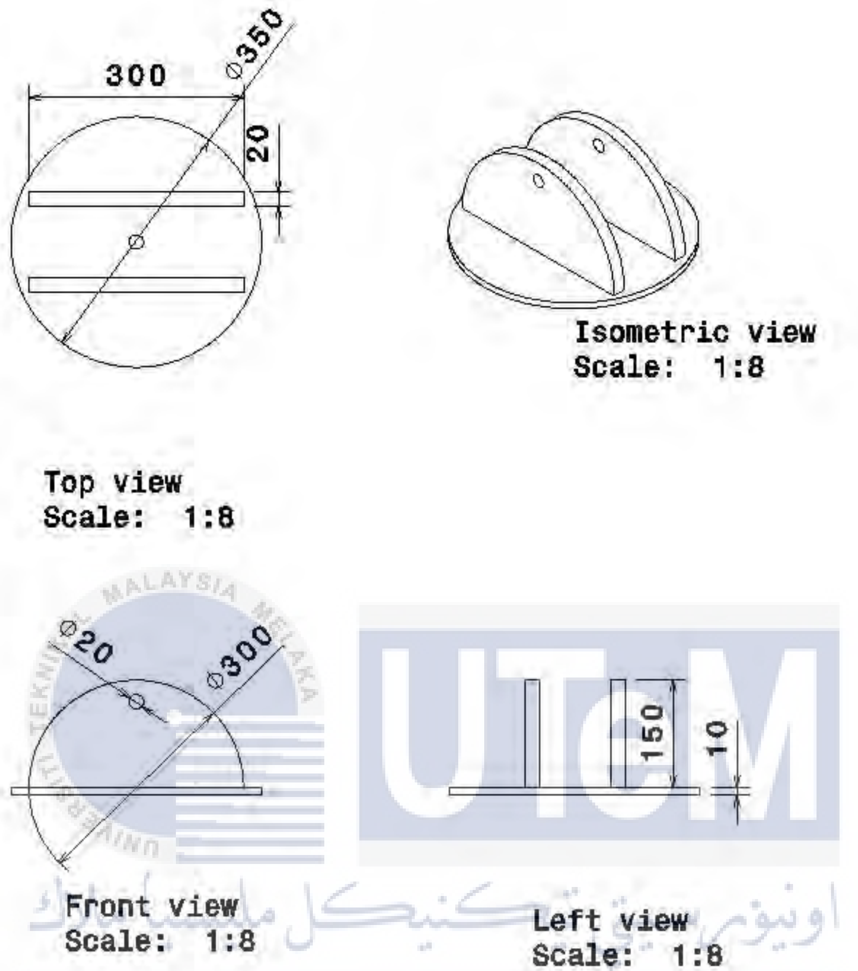
Tensile Ultimate Strength MPa
310

APPENDIX B



This drawing is our property. It can't be reproduced or communicated without our written agreement.		PICK AND PLACE SYSTEM				
DRAWN BY SYAHIRAH	DATE 19/5/2017	DRAWING TITLE BASE				
CHECKED BY DR. TAN	DATE XXX	SIZE A4	DRAWING NUMBER XXX			REV X
DESIGNED BY SYAHIRAH	DATE XXX	SCALE 1:8	WEIGHT(kg) XXX		SHEET 1/1	

D A



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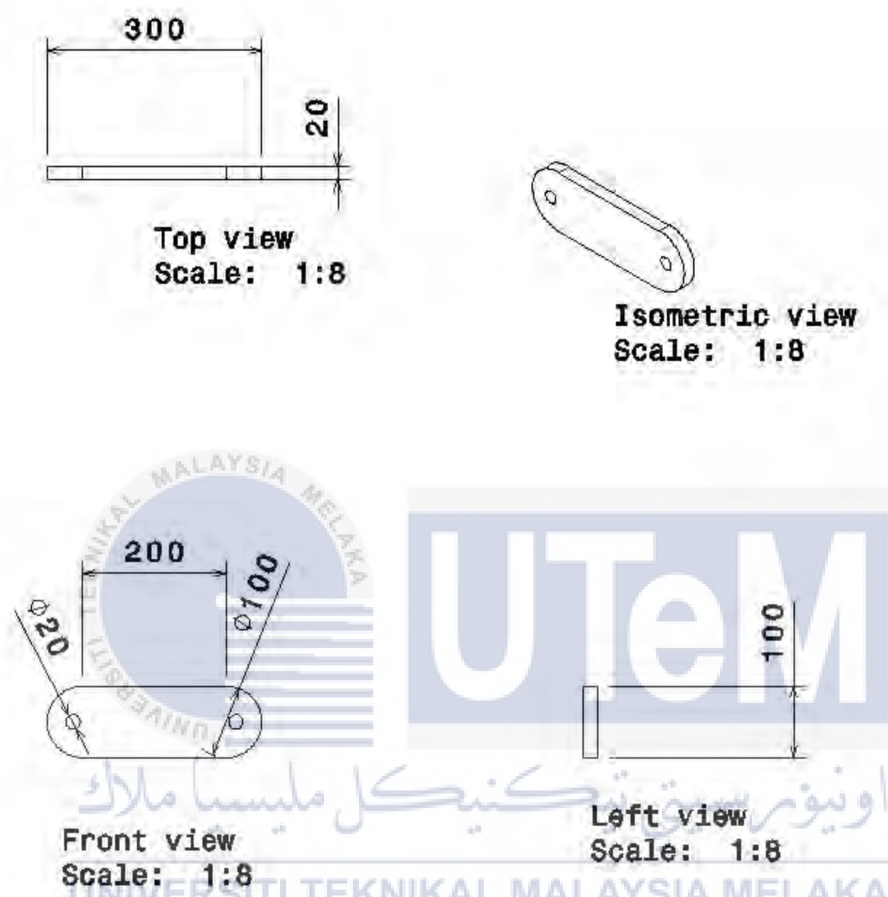
PICK AND PLACE SYSTEM

DRAWN BY: SYAHIRAH	DATE: 19/5/2017	DRAWING TITLE: FIRST PLATFORM		
CHECKED BY: DR. TAN	DATE: XXX	SIZE: A4	DRAWING NUMBER: XXX	REV: X
DESIGNED BY: SYAHIRAH	DATE: XXX	SCALE: 1:8	WEIGHT(kg): XXX	SHEET: 1/1



PICK AND PLACE SYSTEM

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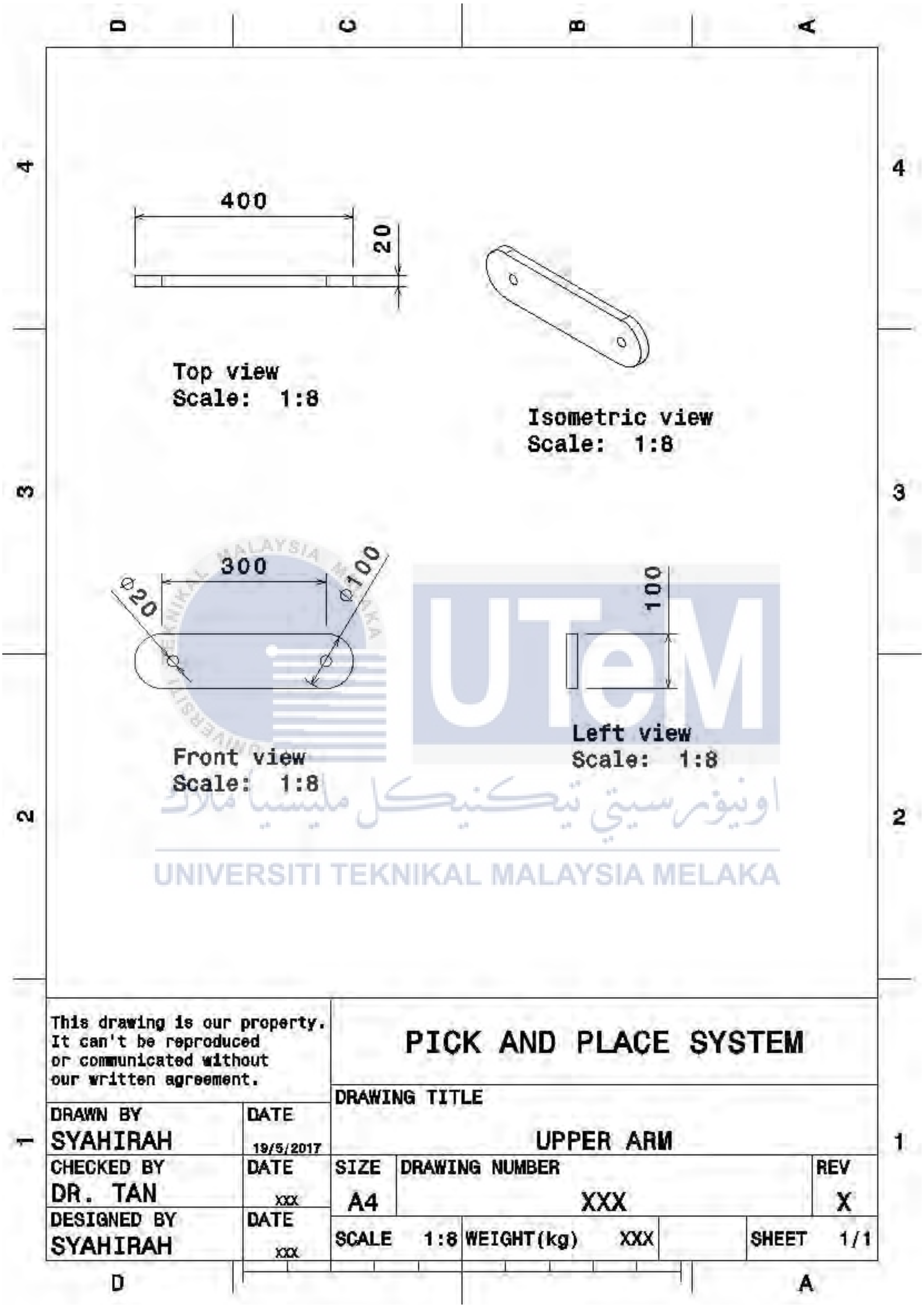
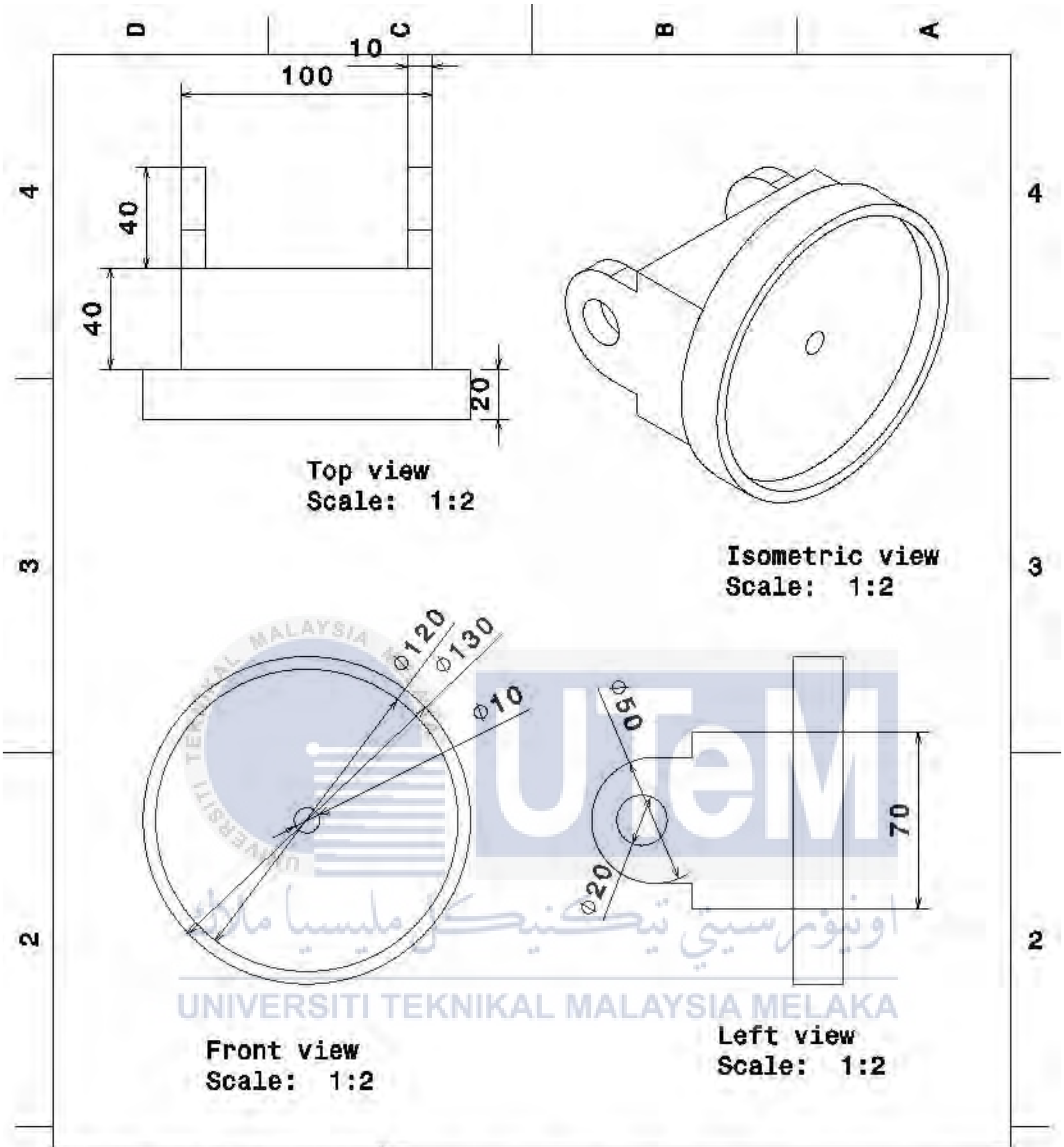
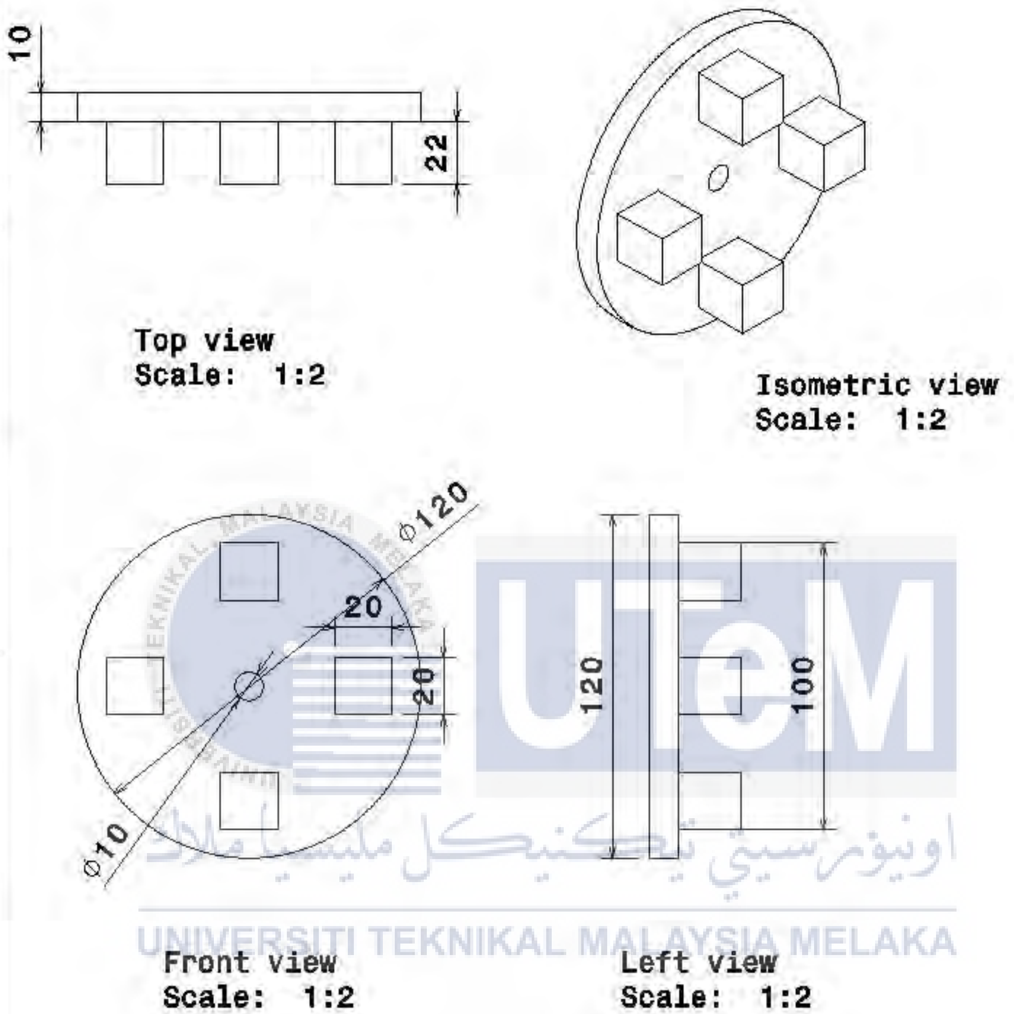
DESIGNED BY SYAHIRAH	DATE XXX	SCALE 1:8	WEIGHT(kg) XXX	SHEET 1/1


400
20
Top view
Scale: 1:8
Isometric view
Scale: 1:8
300
⌀20
⌀100
100
Front view
Scale: 1:8
Left view
Scale: 1:8
This drawing is our property. It can't be reproduced or communicated without our written agreement.
PICK AND PLACE SYSTEM
DRAWING TITLE
UPPER ARM
DRAWN BY
SYAHIRAH
DATE
19/5/2017
CHECKED BY
DR. TAN
DATE
XXX
DESIGNED BY
SYAHIRAH
DATE
XXX
SIZE
A4
DRAWING NUMBER
XXX
REV
X
SCALE 1:8
WEIGHT(kg) XXX
SHEET 1/1



This drawing is our property. It can't be reproduced or communicated without our written agreement.		PICK AND PLACE SYSTEM					
DRAWN BY SYAHIRAH	DATE 19/5/2017	DRAWING TITLE BASE GRIPPER					
CHECKED BY DR. TAN	DATE XXX	SIZE A4	DRAWING NUMBER XXX				REV X
DESIGNED BY SYAHIRAH	DATE XXX	SCALE 1:2		WEIGHT(kg) XXX		SHEET 1/1	

1 D A



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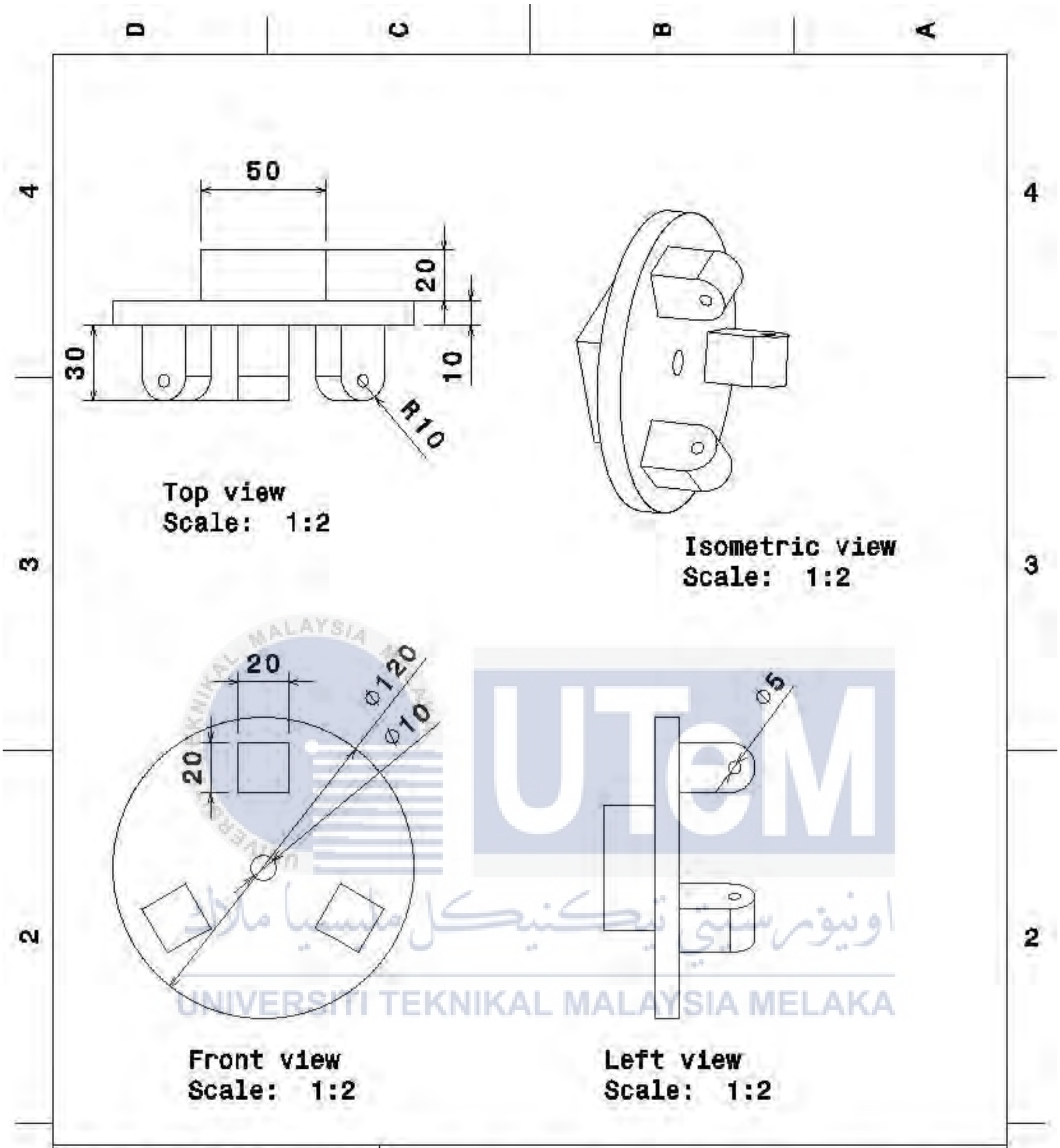
CHECKED BY DR. TAN	DATE XXX	SIZE A4	DRAWING NUMBER XXX			REV X
DESIGNED BY SYAHIRAH	DATE XXX	SCALE 1:2	WEIGHT(kg) XXX		SHEET 1/1	



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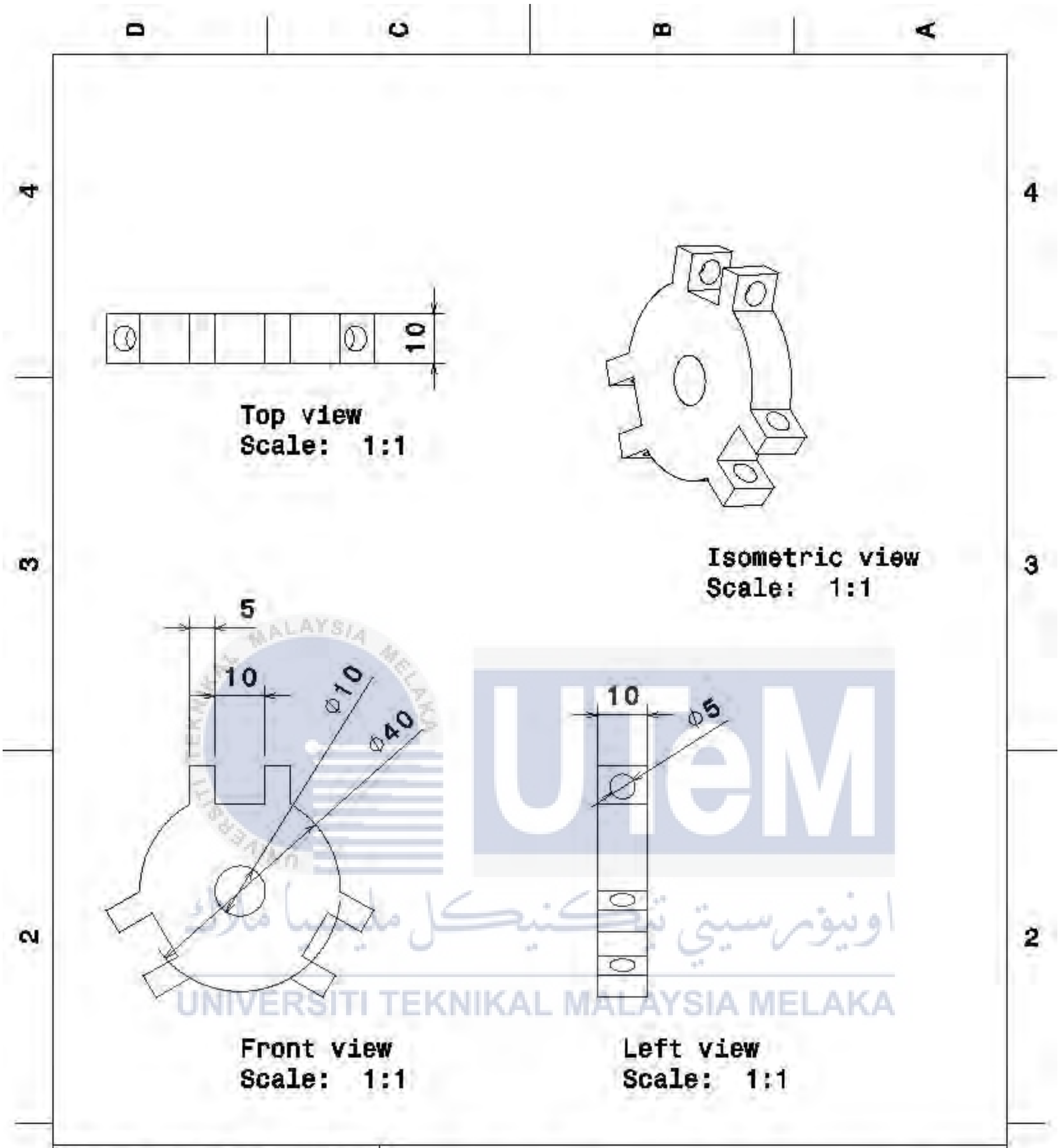
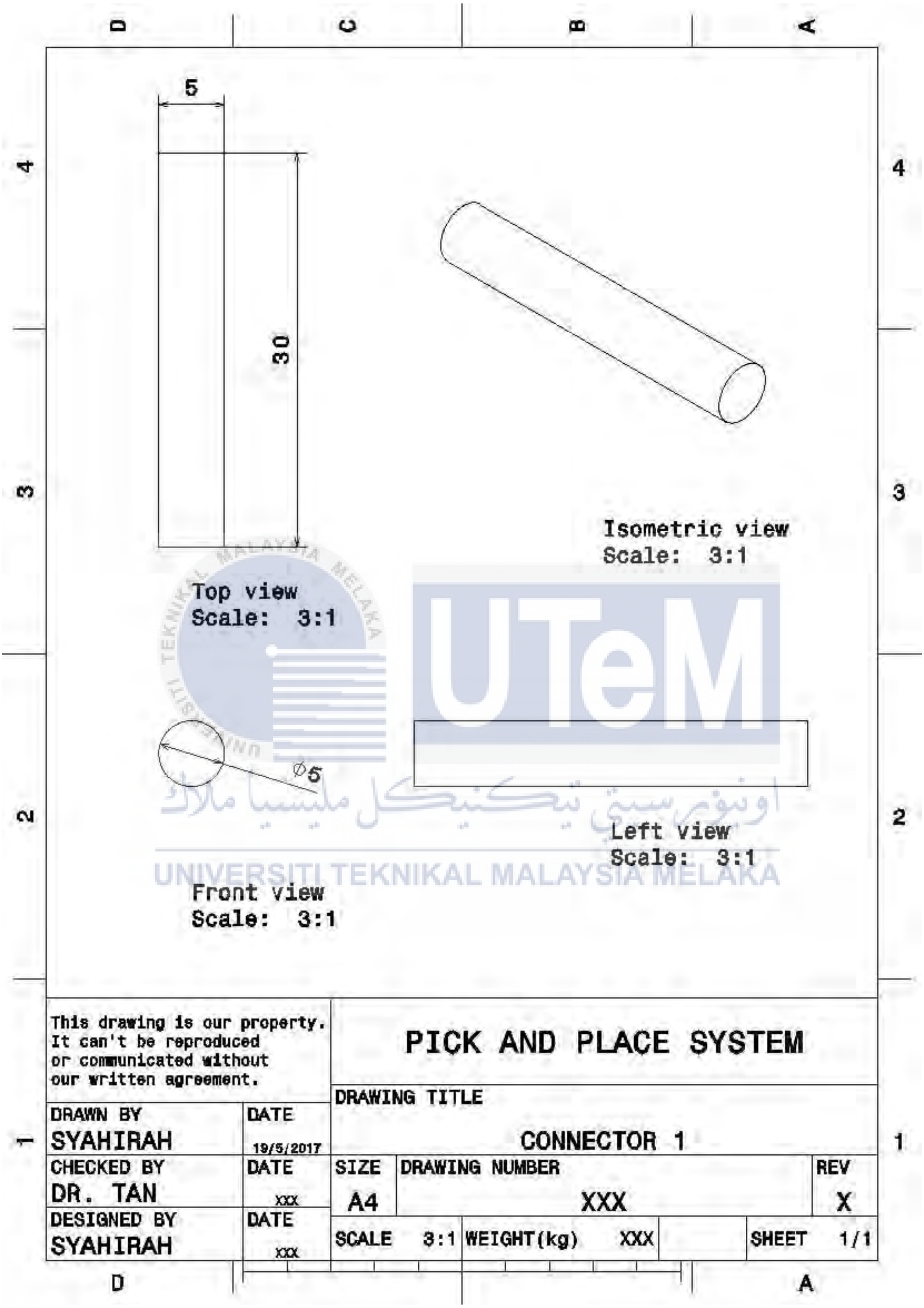
CHECKED BY DR. TAN	DATE XXX	SIZE A4	DRAWING NUMBER XXX		REV X
DESIGNED BY SYAHIRAH	DATE XXX	SCALE 1:2	WEIGHT(kg) XXX		SHEET 1/1

D A



This drawing is our property. It can't be reproduced or communicated without our written agreement.		PICK AND PLACE SYSTEM			
DRAWN BY SYAHIRAH	DATE 19/5/2017	DRAWING TITLE BASE GRIPPER3			
CHECKED BY DR. TAN	DATE XXX	SIZE A4	DRAWING NUMBER XXX		REV X
DESIGNED BY SYAHIRAH	DATE XXX	SCALE 1:1	WEIGHT(kg) XXX		SHEET 1/1


D
C
B
A
4
3
2
1
5
30
Isometric view
Scale: 3:1
Top view
Scale: 3:1
Ø5
Left view
Scale: 3:1
Front view
Scale: 3:1
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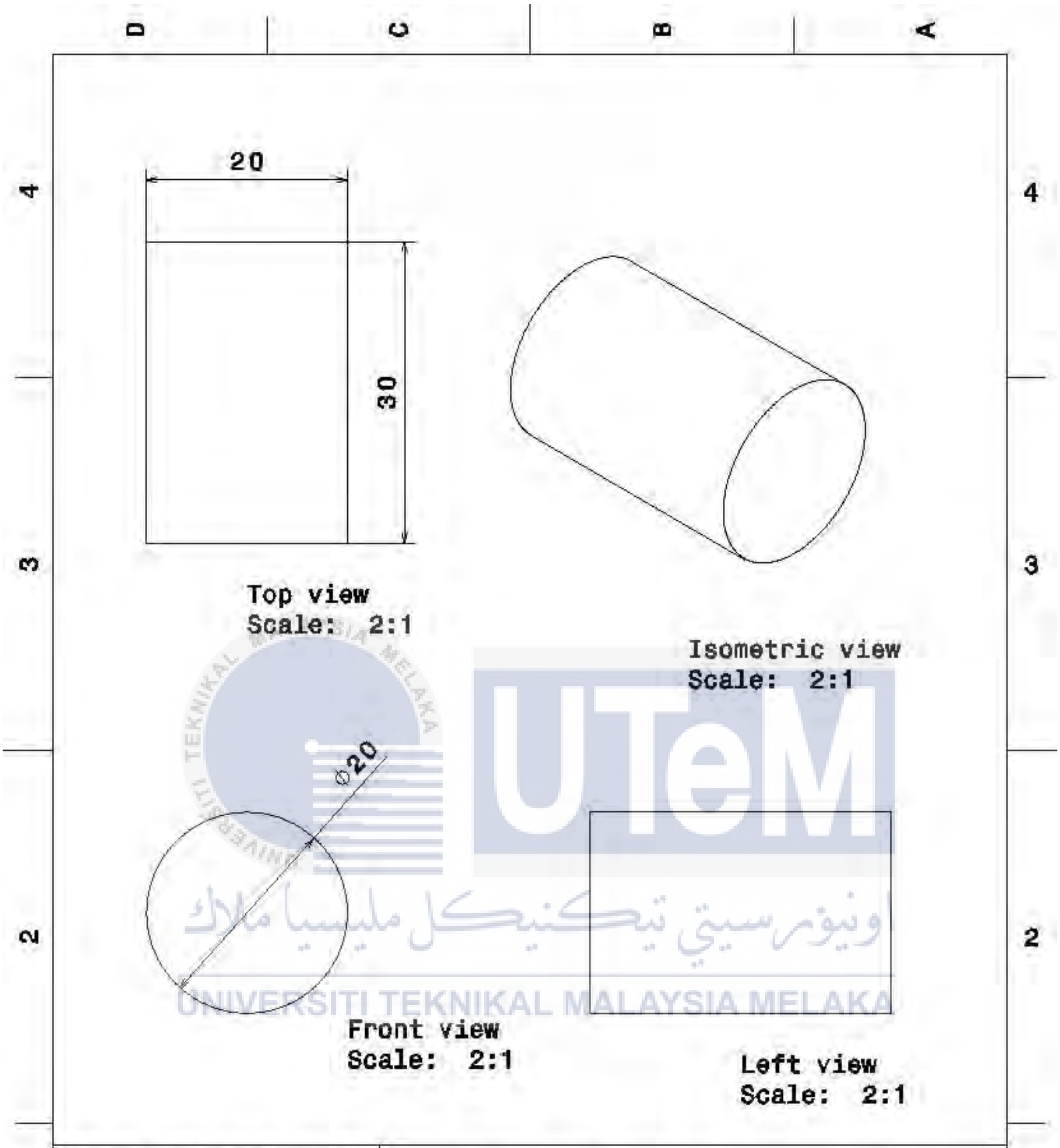
PICK AND PLACE SYSTEM
DRAWING TITLE
CONNECTOR 1
DRAWN BY
SYAHIRAH
DATE
19/5/2017
CHECKED BY
DR. TAN
DATE
XXX
DESIGNED BY
SYAHIRAH
DATE
XXX
SIZE
A4
DRAWING NUMBER
XXX
REV
X
SCALE 3:1
WEIGHT(kg) XXX
SHEET 1/1



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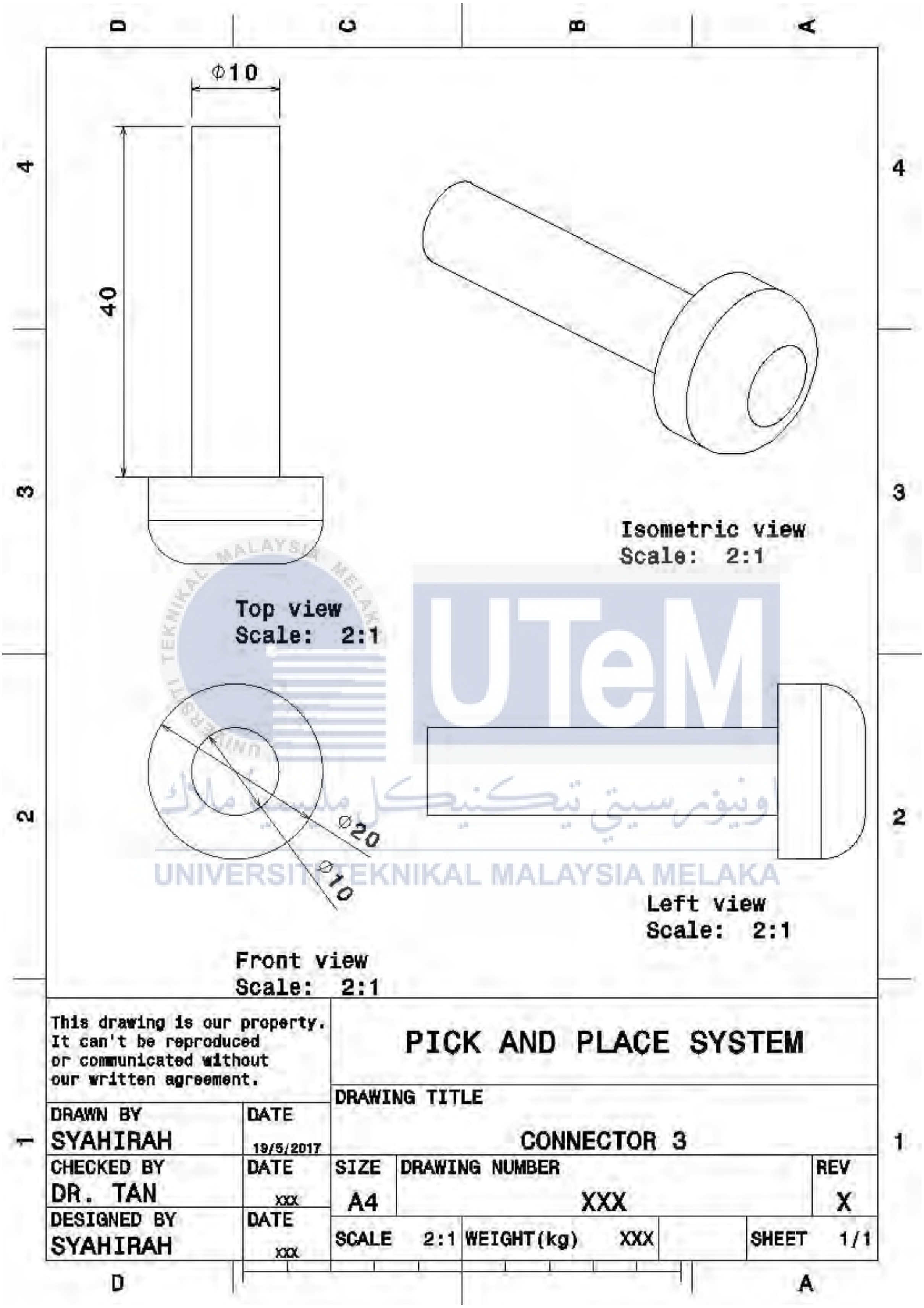
DRAWN BY SYAHIRAH	DATE 19/5/2017	DRAWING TITLE CONNECTOR 2			
CHECKED BY DR. TAN	DATE XXX	SIZE A4	DRAWING NUMBER XXX		REV X
DESIGNED BY SYAHIRAH	DATE XXX	SCALE 2:1	WEIGHT(kg) XXX		SHEET 1/1



D
C
B
A
4
3
2
1
Ø10
40
Top view
Scale: 2:1
Isometric view
Scale: 2:1
Ø20
Ø10
Left view
Scale: 2:1
Front view
Scale: 2:1
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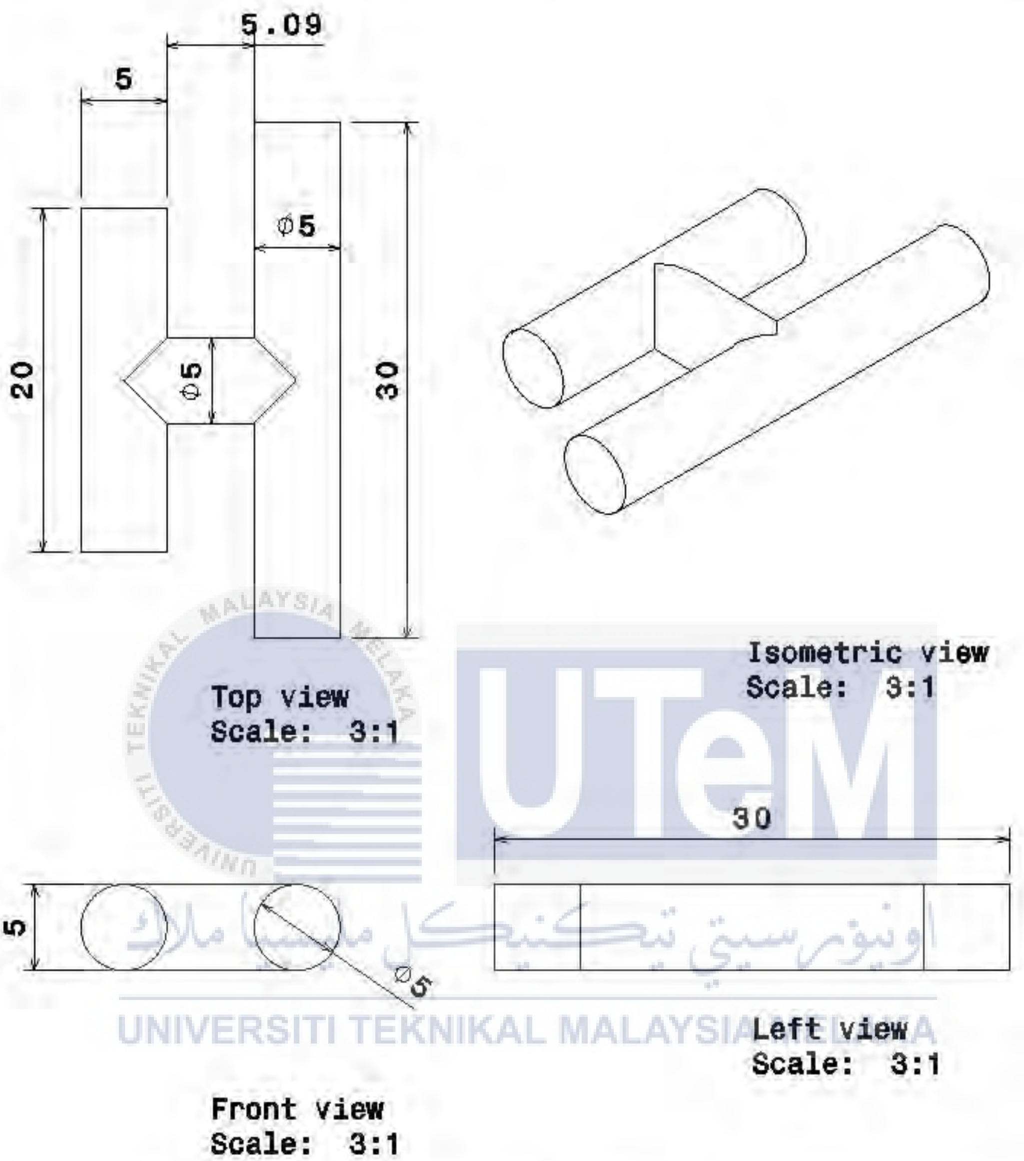
PICK AND PLACE SYSTEM
DRAWING TITLE
CONNECTOR 3
DRAWN BY
SYAHIRAH
DATE
19/5/2017
CHECKED BY
DR. TAN
DATE
XXX
DESIGNED BY
SYAHIRAH
DATE
XXX
SIZE
A4
DRAWING NUMBER
XXX
REV
X
SCALE 2:1
WEIGHT(kg) XXX
SHEET 1/1



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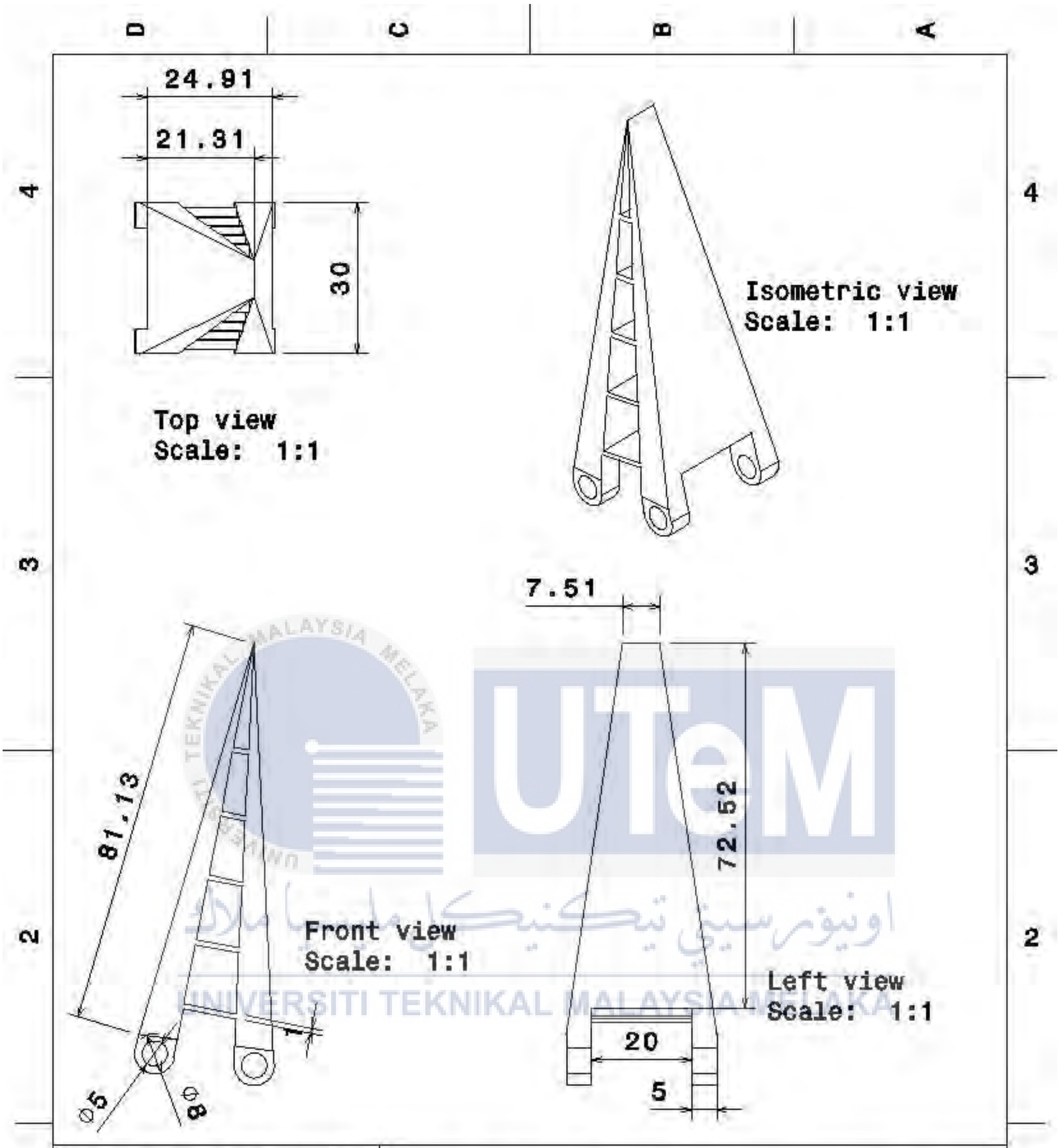
DRAWN BY SYAHIRAH	DATE 19/5/2017	DRAWING TITLE CONNECTOR 4					
CHECKED BY DR. TAN	DATE XXX	SIZE A4	DRAWING NUMBER XXX				REV X
DESIGNED BY SYAHIRAH	DATE XXX	SCALE 3:1	WEIGHT(kg) XXX			SHEET 1/1	



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PICK AND PLACE SYSTEM

DRAWN BY SYAHIRAH	DATE 19/5/2017	DRAWING TITLE GRIPPER			
CHECKED BY DR. TAN	DATE XXX	SIZE A4	DRAWING NUMBER XXX		REV X
DESIGNED BY SYAHIRAH	DATE XXX	SCALE 1:1	WEIGHT(kg) XXX		SHEET 1/1