DESIGN OF MODULAR-BASED UNDERWATER INSPECTION ROBOT

KHAIRUL AQIL BIN MOHD YUSOF

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

DESIGN OF MODULAR-BASED UNDERWATER INSPECTION ROBOT

KHAIRUL AQIL BIN MOHD YUSOF

A report submitted
in fulfillment of the requirements for the degree of
Bachelor of Mechanical Engineering (Design and Innovation)

Faculty of Mechanical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2017

DECLARATION

"i hereby to declare that this project report entitle design of modular-based underwater inspection robot is written by me and is my own effort except the ideas and summaries which i have clarified their sources."

Signature : ....

Author : KHAIRUL AQIL BIN MOHD YUSOF

Date : MAY 2017

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 and Innovation).

Signature :...................................

Name of Supervisor: Ir. Dr. TAN CHEE FAI

Date : ……………………….

DEDICATION

To my lovely parents, Mr. Mohd Yusof bin Abdullah and Mdm. Wan Hasnah Binti Alang Ibrahim, for theirs uncountable supports. To all my friends, and my housemates, for always provide me with ideas to complete this project. Last but not least my beloved lecturer, Ir. Dr. Tan Chee Fai for guiding and endless help during the preparation of this report.

ABSTRACT

The main purpose of this project is to design a modular-based underwater inspection robot. This project primarily focuses on development of underwater inspection robot within the good design characteristics such as modularity, easy to maintenance, with austhetic value, with the lowest price and etc. The research and development activities have been numerous worldwide. Due to the development of new material, electronic component and other high –tech component, the improvement can be achieved. This project target to produce a more modular design to ease the maintenance work, ease the control system and etc. However, such proposed equipment has for one reason or another not been completely satisfactory. For example, some of the existing underwater inspection robots are very large, complex control system, complex of body structure and therefore expensive to purchase and maintain. Underwater inspection robot with efficiently mechanism will develop through this project and will meet customer requirement where can help people easily maintain and operate the robot.

ABSTRAK

Tujuan utama projek ini adalah untuk mereka bentuk berasaskan modular-pemeriksaan air robot. projek ini terutamanya memberi tumpuan kepada pembangunan pemeriksaan air robot dalam ciri-ciri reka bentuk yang baik seperti mudah untuk melakukan penyelenggaraan, dengan nilai austhetic, dengan harga yang murah dan lain-lain. Dimana aktiviti-aktiviti penyelidikan dan pembangunan telah banyak di jalankan seluruh dunia. Disebabkan oleh penciptaan bahan baru, komponen elektronik dan lain-lain komponen berteknologi tinggi, kemajuan dapat dicapai. Sasaran projek ini ialah untuk menghasilkan reka bentuk yang lebih modular bagi memudahkan kerja penyenggaraan, meringkaskan sistem kawalan dan lain-lain. Walau bagaimanapun, produk yang sedia ada mempunyai reka bentuk yang kurang memuaskan. Sebagai contoh, beberapa robot pemeriksaan air sedia ada mempunyai reka bentuk yang sangat besar, system kawalan yang kompleks, kompleks struktur badan dan oleh itu mahal untuk membeli dan melakukan selenggaraan. Pemeriksa robot yang dicipta dengan mekanisme yang mudah dan cekeap akan dibangunkan melalui projek ini dan akan memenuhi keperluan pelanggan di mana boleh membantu pelanggan untuk mudah menyenggarakan dan mengendalikan robot.

ACKNOWLEDGEMENT

Highest praise to Allah Almighty. Grateful to Him with His will I had successfully finished in preparing this ‘Projek Sarjana Muda’ thesis.

Several people played an important role in the accomplishing of this ‘Project Sarjana Muda’ thesis and I would like to acknowledge them here. I owe my most sincere gratitude to Ir Dr. Tan Chee Fai. I would like to thank him for his guidance, support, advices and time during the course of my project.

I would like to thank Dr. Abd. Rahman bin Dullah and Dr. Mohd Nizam bin Sudin as my second examiner and in taking an effort in reading this thesis and provide good suggestion in perfected this thesis.

Special thanks to FKM technicians whom are patient in giving me a lot of advice and useful tips in performing the research.

Last but not least, I owe my loving thanks to both of my parents, Mr. Mohd Yusof bin abdullah and Mdm Wan Hasnah binti Alang Ibrahim. Without their encouragement and understanding it would have been impossible for me to finish PSM.

My special gratitude is due to my course mate, my housemate and my entire friend who participated in this project directly and indirectly who also help me in generating idea and support me to finish this thesis.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Underwater inspection robot are very common technology to use for any underwater piping inspection or moreover. This technology had been improved in many time lapses and the improvement is meant to help human power. Basically robots are designed in such way that they remove human intervention from labour intensive and hazardous work environment, sometimes they are also used to explore inaccessible work places which are generally impossible to access by humans. Human ability is very limited to dive deep under the water can give a very high risk to human health. Therefore this technology is made to exceed human ability and surf to deeper underwater for any work of inspection. The underwater inspection robot has its use such as preventive maintenance in a nuclear power plant, underwater pipeline inspection, visual inspection of nuclear reactor internals, underwater welding technology and many more.

Currently, there are many types of underwater inspection robots. There already lots of amazing design of the underwater robot, for example, design of a bio mimetic lobster that mimic the biology or physical of a lobster there also a design of a bio mimetic of an eel and the movement is physically as an eel. Common underwater robots are design that its movement is only by using propeller, also a common track wheeled robot also one of the robot use in the industry. Each of the design may be different but however, it shares the same objective that is to do underwater inspection. This robot is use in different places and environment. Usually the underwater robot use to dive deep into the deep blue sea, however they also been use in to dive into a lake, drain, reservoir and any space that consist of water.

To design an underwater robot there are several important quality and characteristic that must be take care of such as the design issues like mobility, steer ability, turning radius, size and shape adaptability, online adaptability, flexibility, stability, autonomous operation and obstacle avoidance, efficiency at uneven surface, safe operation, material selection, Type of task to be performed according to its environments, retrieval of robot, user friendly navigation and control system, range of operation, quantitative analysis of defects around the environment. The design of underwater robot is best to achieve its objective and it functionality by achieving the important aspect, the design are already good and can be manufacture.

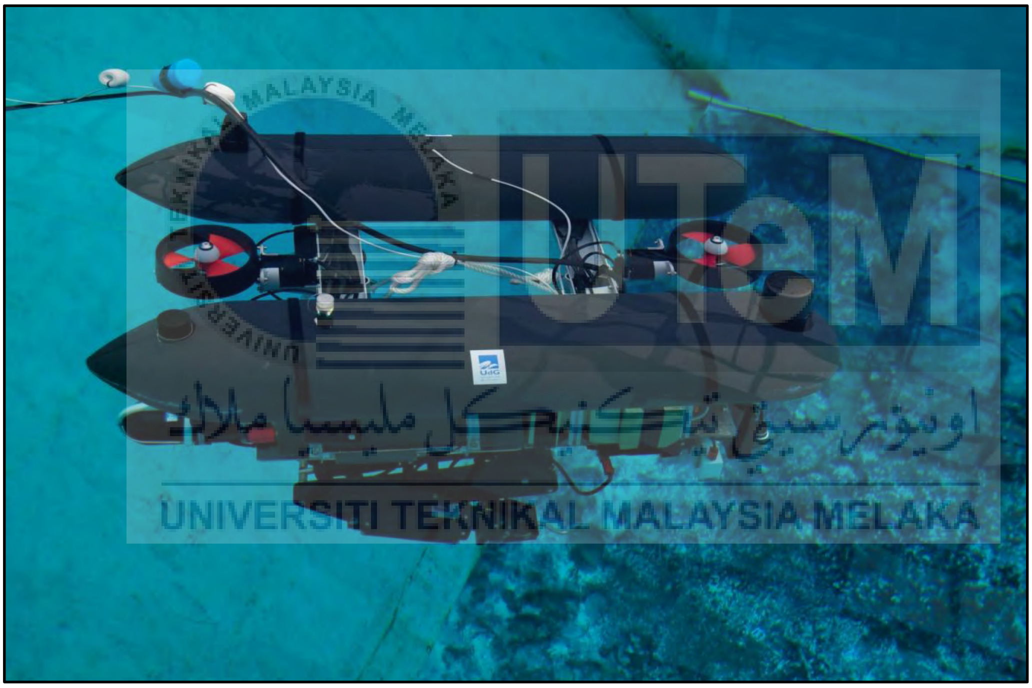


Figure 1.1: Several designs of an underwater inspection robot.

(Source: Success Stories (2014))

1.2 PROBLEM STATEMENT

This present design of underwater robot are commonly design with only one way install and it will has difficulties to maintenance the robot. The work of maintenance is very hard to accomplish because the body design of the robot are very hard to dismantle. The underwater inspection robot had been design with a bigger in size therefore; the mobility of the robot is limited to surf to a smaller region. Control system of underwater vehicles is not easy, mainly due to the non-linear and coupled character of plant equations and also the lack of precise model of underwater vehicles dynamics and parameters, as well as the appearance of environment disturbances.

1.3 OBJECTIVE

The objectives of this project are as follows:

1. To design a modular underwater inspection robot that easy to be operated and manufactured based on the simple design of every important aspect.

1.4 SCOPE OF PROJECT

The scopes of this project are:

1. Focus on designing a modular based underwater inspection robot that are easier to maintenance.
2. To design a more modern and modular inspection robot on the physical appearance.
3. To implement simpler control system based on innovation of existing material and things.

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. Conceptual design.

   Study the important characteristic in designing an underwater inspection robot and applying it into the design to improve the present design.

3. Detail drawing.

   The selective design will be combining into a one final design and will be drawn into CAD software which is CATIA. The design will be valued and can be redesign with greater ideas.

4. Analysis and proposed solution

   Analysis will be presented on how to create more modular design of inspection robot that suitable with the modern design and more flexible.

5. Report writing

   A report on this study will be written at the end of the project.

1.6 REPORT FRAMES

This project entitled "Design Of Modular-Based Underwater Inspection Robot" can be divided into five chapters.

Chapter I which is the introduction explains the general information of the underwater inspection robot. The elements that consist in chapter 1 are background of underwater inspection robot, problem statement of the project, scope of projects, objectives of project and report organization.

Chapter II comprises literature review information which includes research of previous project of underwater inspection robot by others. This chapter also includes existing underwater inspection robot in market.

Chapter III present the methodology of the project. This chapter is discussing the method used throughout the development of underwater inspection robot. It started with the section identifying customer needs using interview method. Concept selection method and software use to generate the design also had been explained in this chapter. The steps involve in the process of develop underwater inspection robot are described in detail in this chapter.

Chapter IV present the conceptual design of underwater inspection robot. This chapter show 4 new concept designs and explanation of each concept. Besides, 3D modelling drawing and part number also include in this chapter. Other element include in this chapter are the design analysis using CATIA Structural Analysis software, ANSYS workbench and manufacturing process flow of the product.

Chapter V The project is concluded with Chapter V which discusses the conclusion and recommendation of the project based on the objective and the relationship with problem statement presented in Chapter I

CHAPTER II

LITERATURE REVIEW

2.1 INTRODUCTION

The purpose of this chapter is to collect the information from the journal, book article and internet web pages that are related to the project. Basically, this chapter has been divided into two sections. Firstly, is the information about the inspection robot and secondly on the modular design of the inspection robot. Usually, inspection robot are build and use for inspecting some area that are human are unable to reach with its own human power because human were designed with its own limitation. For example, human body cannot withstand the high pressure area nor small area such as in pipes and deep sea, therefore inspection robot can overcome the human limitation.

Figure 2.1: Traditional ways in inspecting underwater area.

(Source: Divingms, (2014)

2.2 INSPECTION ROBOT

A great part of existing literature studies by Junichi, Mineo, Takashi and Osamu (1985) state that the main purpose of robot is to carry out underwater inspecting works instead of divers. However, the efficiency and safety of underwater activity are not sufficient because underwater conditions consist of dangerous environment. Increasing risks and lower working efficiency of port construction work at deeper sea area and shortage of divers will make the situation worse. Therefore, to build up robot are necessary to overcome the problem.

Robotic are currently been build and designed in such way so that they can intervention from dangerous and hazardous work environment, they also used to explore inaccessibility area which are hardly impossible to access by human (Ankit Nayak, 2014). Loius (2000) had state that over 1000 robotic uninhabited undersea are presently in regular operation worldwide and most are commercial remotely operated vehicles (ROVs) and inspection robots designed to perform subsea inspection, survey, construction, and repairing operation at modest depths. This robotic creation helps to minimize the human power and help to avoid any dangerous environment that can affect the human health.

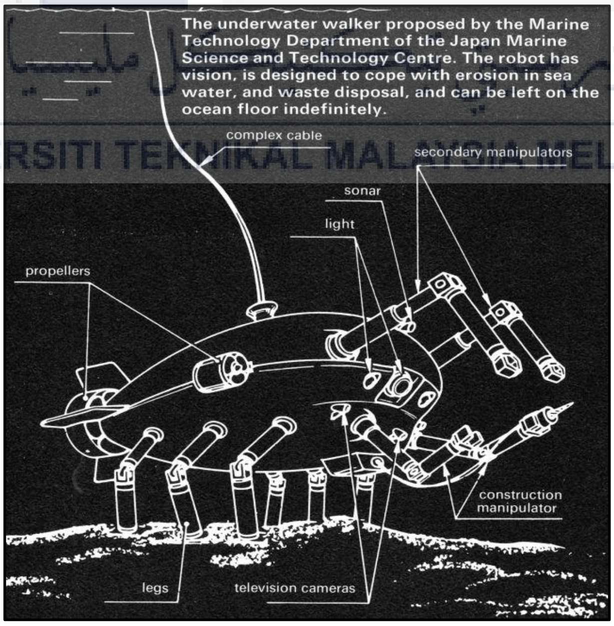


Figure 2.2: An early concept of inspection robot.

(Source: Jasia Riechardt (1978))

2.3 MATERIAL

Braga (2014) stated that most other underwater robot gets their buoyancy from a material called syntactic foam. This composite material filled hollow microscopic glass bubbles. These bubbles lower the material's density and making it buoyant. Putting anything underwater requires a delicate balance between buoyancy and weight. Maintaining that balance become more difficult the deeper its goes. The deeper its goes, the stronger syntactic foam has to be withstanding the increasing pressure, and adding strength also adds size and weight. To increase efficiency is to reduce the weight of buoyant material, the investigation continue to find another material. Ceramics, it turns out are five times stronger than steel when compress, but weigh about third as much. By using small ceramic spheres, it could theoretically enable a robot to carry more weight by using a lighter buoyant material with the same buoyancy as syntactic foam. Though ceramic is cheap and well-understood, its use as a replacement for syntactic foam is not tested yet.

Figure 2.3: Syntactic foam block machined robot's body.

(Source: Braga (2014))

Inspection robot need to dive while maintaining a safety factor of 1.5, and additionally figure out which material would allow it to achieve this goal with the best cost. The different materials will be tested according to the size of the pressure vessel. It is to be noted that this is a simplified version of the actual model, which will be used as a preliminary test in order to understand the effects of hydrostatic pressures on an object under water Martos, Abreu, Gonzalez and Tremante (2013).

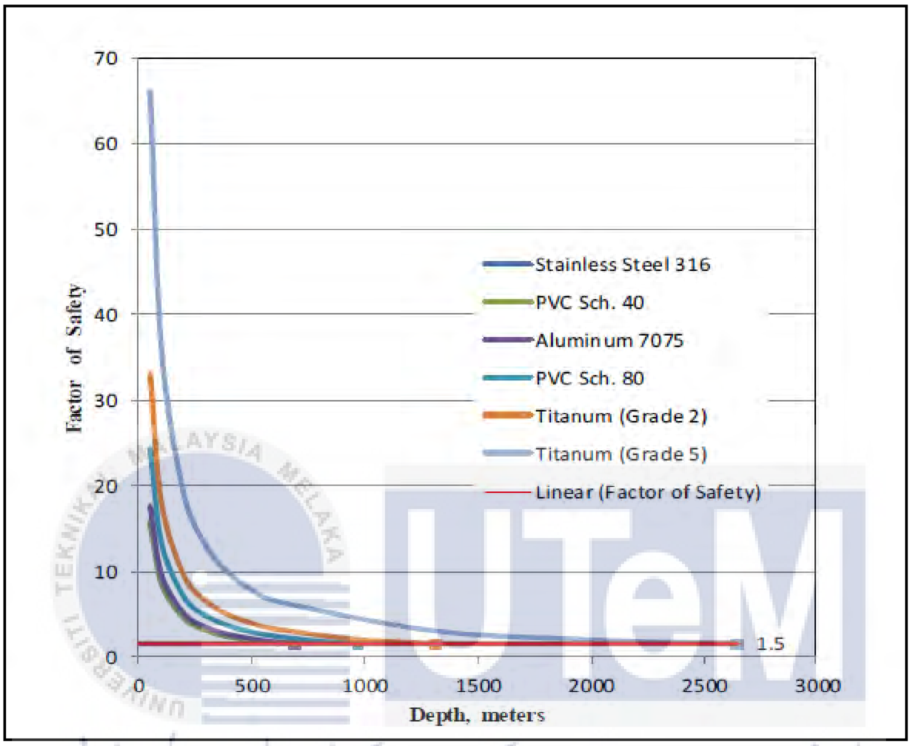


Figure 2.4: Factor of safety graph in comparison to depth.
(Source: Martos, Abreu, Gonzalez and Tremante (2013)).

Table 2.1: Factor of Safety at each Depth.

PVC Sch. 40		Stainless Steel 316		Aluminum 7075		PVC Sch. 80		Titanium (Grade 2)		Titanium (Grade 5)	
Depth	FoS	Depth	FoS	Depth	FoS	Depth	FoS	Depth	FoS	Depth	FoS
50m	15.817	50m	15.887	50m	17.634	50m	24.403	50m	33.093	50m	66.199
100m	8.636	100m	8.675	100m	9.628	100m	13.324	100m	18.069	100m	36.145
200m	4.526	200m	4.546	200m	5.046	200m	6.983	200m	9.47	200m	18.944
300m	3.067	300m	3.08	300m	3.419	300m	4.732	300m	6.416	300m	12.835
400m	2.319	400m	2.329	400m	2.586	400m	3.578	400m	4.852	400m	9.706
500m	1.864	500m	1.873	500m	2.079	500m	2.876	500m	3.901	500m	7.803
600m	1.559	600m	1.565	600m	1.738	600m	2.405	600m	3.261	600m	6.524
610m	1.534	610m	1.541	650m	1.606	770m	1.881	900m	2.186	1300m	3.038
620m	1.509	620m	1.516	690m	1.515	900m	1.612	1100m	1.793	2000m	1.98
624m	1.499	627m	1.499	697m	1.499	969m	1.499	1317m	1.499	2644m	1.499

(Source: Martos, Abreu, Gonzalez and Tremante (2013)).

A typical underwater robot tends to use aluminium, polycarbonate (PC), and polyoxymethylene (POM) for shallow water. While for deep sea underwater robot, high strength steel, titanium and composites material are considered. Steel is commonly used because of its high tensile strength and low cost. The surface steel need to be treat because it had the potential for corrosion and rusting phenomenon. Stainless steel is typically used for hydraulic, pneumatic and fasteners but it is difficult to machine and weld. The aluminium alloy is lightweight and has high strength and reasonable with a non magnetic system. Since it is vulnerable to corrosion, surface treatment also needed. Titanium alloy has very high strength-to-weight ratio, excellent corrosion resistance without any surface treatment, low electric conductivity, and no magnetic field distortion (Siciliano and Khatib, 2016).

2.4 DESIGN CRITERIA

2.4.1 Design

Several design of inspection robot had been evolve from time to time. Pradhan (2014) had stated in his work that comparison of different type in pipe inspection robots on the basis of different design issues have done to find the suitable motion mechanism of robot for same work condition.

Table 2.2: Comparison of different types of robot.

Performance indicator	Wheel type robot			Caterpillar type robot		Without Wheel Type Robot		
	Wheel type robot (Simple structure)	Wheel type (wall pressed type)	Screw drive type robot	Caterpillar Robot (simple structure type)	Caterpillar Robot (wall pressed type)	Leg type robot	Inchworm type robot	Snake type robot
Vertical Mobility	Poor	Very Good	Very Good	Fair	Very Good	Very Good	Fair	Fair
Steerablity	Very Good	Fair	Fair	Fair	Fair	Very Good	Fair	Fair
Size and shape adaptability	Poor	Very Good	Fair	Poor	Very Good	Very Good	Fair	Very Good
Flexibility of body	Rigid	Rigid	Less flexible	Rigid	Rigid	Rigid	Flexible	Flexible
Stability of robot	Poor	Very Good	Very Good	Fair	Fair	Fair	Fair	Fair
Moztion efficiency	Fair	Fair	Very Good	Fair	Very Good	Very Good	Very Good	Fair
Number of actuators	Fair	Fair	Less	Less	Less	More	More	More
Wireless control	Fair	Very Good	Fair	Fair	Fair	Poor	Poor	Poor

(Source: Pradhan (2014))

The robot which carries out the underwater inspection work taking place of divers needs good stability, positioning ability and ability to move on uneven seabed. Compared with free-swimming type, the bottom-reliant type is good for this purpose Junichi, Mineo, Takashi and Osamu (1985).

2.4.2 Control system

From the project article written by Junichi, Mineo, Takashi and Osamu (1985), it stated that the robot which has six-legged called AQUAROBOT was driven by semi-direct DC motors which build inside the leg. Each leg has three articulations. All the motions were controlled by a tiny laptop micro computer, which makes the robot be able to walk on irregular rough terrain. The measurement of the profiles of seabed is possible by recording the motion of the end on the legs while walking. Each of its leg is equipped with a tactile sensor, two inclinometers, a gyrocompass and pressure sensor in the body and the prototype can be operated in 50m deep.

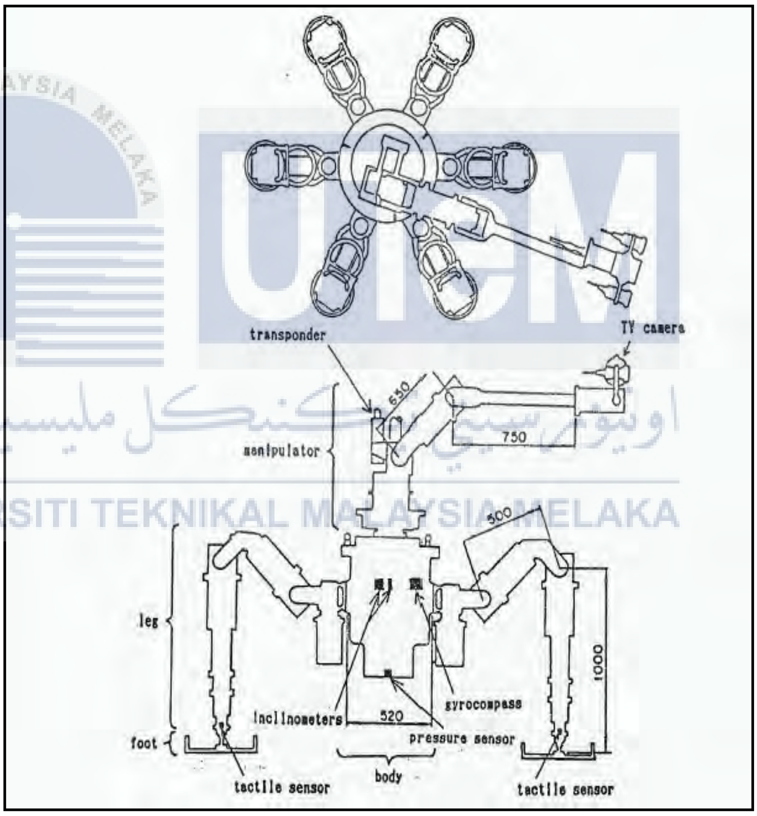


Figure 2.5: AQUAROBOT.

(Source: Junichi, Mineo, Takashi and Osamu (1985)).

Inspection robot requires a high-level controller to sequence the execution of mission task, and to respond effectively to mission needs. Underwater robot requires at least an automatic high level control. Despite over years goes by, researching on high level control, no industry standard has yet evolved for high level control techniques. At present, most underwater robot employ fully custom control system (Whitcomb, 2000). The robot is controlled from a remote console. The console will have a joystick controller for controlling the altitude and movement of the robot. Any sensor data will be relayed to the remote console. A hierarchical structure will be used in communications system, probably using a form of asynchronous transmission mode protocol. Each actuator and sensor has its own processors Bradbeer, Harrold, Nickols and Yeung (1997).

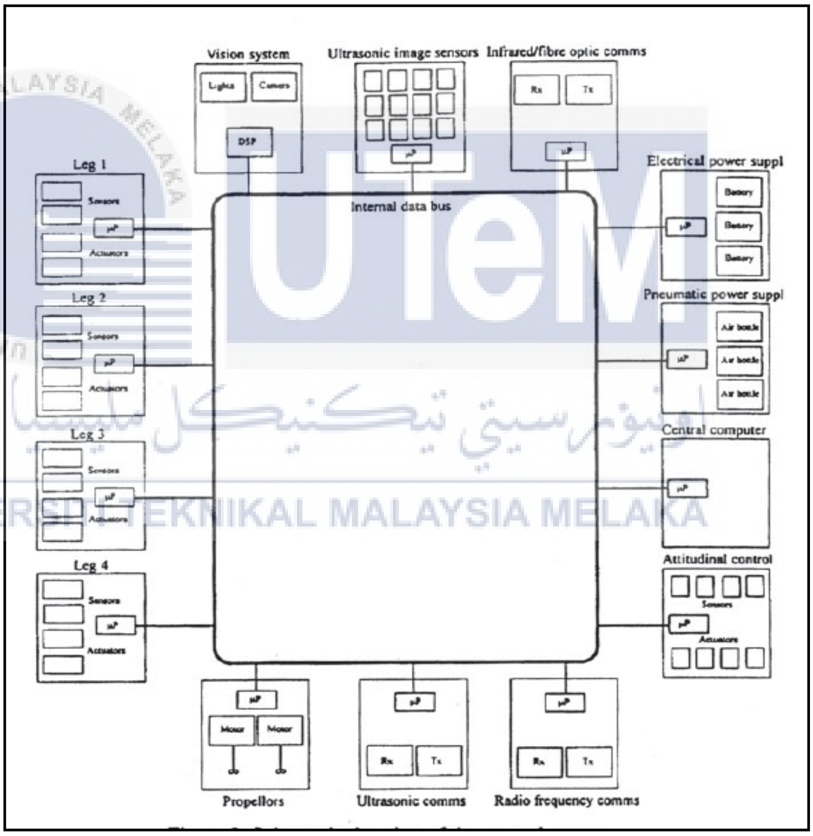


Figure 2.6: Schematic drawing of the control system.

(Source: Bradbeer, Harrold, Nickols and Yeung (1997)).

2.4.3 Subsystem.

The inspection robot consists of several subsystems to complete and operate the robot. Research had been done and the data were collected and tabulated as shown in Table 2.3 and Table 2.4 below:

Table 2.3: Summary of subsystem.

Table 2. Summary of *OTTER* Subsystems.[1]

Subsystem	Component
Structure	Aluminum pressure housings Welded steel frame Free-flooding fiberglass shell Removable 1 DOF manipulator Foam and fiberglassed redwood for flotation
Actuation	8 Ducted, oil-filled thrusters 2 DOF, Pan/tilt device for underwater cameras Arm motor with harmonic drive
Power	Nickel-Cadmium batteries DC-DC power converters Relay bank
Sensing	Stereo CCD cameras Real-time image processing Fluxgate compass Two-axis inclinometer Systron Donner MotionPak (3 linear accelerometers/3 rate gyros) Pressure transducer (depth sensor) Sonic High-Accuracy Ranging and Positioning System (SHARPS) Manipulator torque and acceleration sensors Leak detectors and battery monitors
Computation—Hardware	On-board real-time VME computer On-board ADC and DIO boards Off-board real-time VME computer Off-board UNIX workstations
Computation—Software	VxWorks™ real-time operating system ControlShell™ software framework Virtual-reality user interface X-Window user interface
Communications	Ethernet or serial link through tether NDDS™ communications protocol Serial daisy-chain motor communications network

(Source: Wang, M.Rock, and J. Lee (2000))

Table 2.4: Subsystem of autonomous underwater robots.

Systems	Subsystems	Needs/requirements	Methods/models
Mission	Sensors	Long range information for detecting and inspecting a target of interest	Sonar
	Planner	Plans for the mission goals, unexpected events or system failures	Traditional planner
	World modeling	Set of models for the AUV system and its mission environment	Objective & subjective models
	Data fusion	Meaningful & correct information from massive data of multi-sensors	Analytic methods, AI
Computer	Software	Tools for developing computer codes for vehicle, support and simulation systems, fault-tolerance operation	System software, application software
	Hardware	Integration of electronic modules in a powerful, robust & flexible manner	System architecture, communication network, mass storage
	Fault-tolerance	Accommodation of hardware & software failures	Redundancy design
Platform	Hull	Platform for mission package; depth & power requirements; stability; modularity for different mission parameters; materials; drag reduction	Steel, aluminum, titanium, composite, ceramic
	Propulsion	Navigation/stationkeeping	
	Power	Power for propulsion, mission systems, & payload	
	Workpackage	Tools for cutting, sampling, cleaning, marking, stabilization, docking, retrieval & launch	Manipulators
	Emergency	Initiating appropriate action in response to the abnormal vehicle condition and providing means for locating a disabled AUV	Emergency buoy, drop weight, flame smoke, beacon, water dye
Vehicle sensor	Navigation	AUV position relative to a fixed coordinate system	Acoustic, Doppler, fiber-optic gyro, GPS, inertia system
	Obstacle avoidance system (OAS)	Detecting & avoiding obstacles: order of 50 m & order of 10 degrees	Acoustic, laser
	Self-diagnostic	Monitoring and evaluating the vehicle operational parameters for subsystem status	Sensors for voltage, thruster rpm, speed sensor, leak, & temperature
	Communication	Transferring commands and data between a surface station and vehicles	Fiber-optics, acoustic, radio, laser
Development & support	Logistic support	Organization, equipment, spares, repair & maintenance, documentation, etc.	
	Simulation	Tools for testing the vehicle design and interface mechanism for the analysis of the vehicle operations	Stand-alone simulation, integrated simulation, hybrid simulation in the virtual environment
	User interface	Tools for displaying data, inputting command data	Virtual reality device, joystick, 3D graphics

(Source: J.YUh (2000))

2.4.4 Power

Several studies (J.Yuh, 2000) have reported that the robot can be powered by the mother ship; operating hours of untethered robot are limited by the on-board power system. Most robots depends on batteries supply as their power source. A typical type of battery is lead-acid batteries. However, silver-zinc batteries are expensive. Active research and development in the area of batteries has been in progress, especially with recent attention on electric vehicles that has accelerated the development of more efficient and safer batteries.

Table 2.5: Specific energy comparison of batteries and fuel cells.

System	Energy/weight (Watt-hr/lb.)
Lead-acid	10–18
Ni-Cd	12–20
Ni-Fe	20–25
Ag-Cd	18–45
Ag-Zn	40–48
Hi-H2	80–90
Acid fuel cells	70–460
Alkaline fuel cells	110–430

(Source: J.Yuh, (2000))

Two battery cannisters, each holding six packs of ten D-sized nickel cadmium (NiCad) cells, are mounted on-board robot providing 750 watt hours of power at 160 volts. Each of the 120 D-cells stores 5 amp hrs at 1.33 volts. Mechanical relays are switched on to engage the battery system, and under-voltage and over-temperature sensors built into each battery pack are monitored by the control system. The tether is used to trickle charge the NiCads at 165 volts and 0.25 amps. In the current configuration, the tether is also directly connected to the DC-DC converters powering the main computer cage. The main computer controls the battery relays as well as a bank of solid-state relays that provide power to the rest of the vehicle. When the main computer is booted, the control program can switch on and off individual relays through digital I/O. This configuration provides a large margin of safety during work Wang, M.Rock, and J.Lee, (2000).

Recently there has been work on the power and propulsion of underwater inspection robot by (Bradbeer, Harrold, Nickols and Yeung; 1997). It stated that the robot has two power sources. The first is a compressed air supply from two carbon fibre composite cylinder and NiCad battery on board for powering the electronics and thrust propulsion system. The compressed air used to move the four legs and traverse any blockages. The vehicle can turn over and go to positive buoyancy, where it can walk on top of the pipe.

Usually electrical powers were the source for most underwater robot component. Power source can be as simple as a 12 VDC (Volts Direct Current) car battery or portable power source. In reality, the voltage produced by a fully charged car battery is about 13.5 VDC, but that won't over power your underwater robot equipment. Furthermore, the voltage will drop or decrease as it travels along the wires in your tether. The farther it travels, the greater the drop in voltage, so it will have less thruster power on the bottom, that if it was connected right to the battery. Industrial underwater robot often use much higher voltage than we will use – up to 3000V supplied from the surface, but this high voltage is transformed to 48V, 24V or 12 V DC onboard the ROV for use by the motors, pumps, lights and cameras. . There is at least one positive (+) and one negative (-) wire carrying the power inside the tether for an industrial ROV.

2.5 SAFETY.

One of the important issues that need to be install in the underwater robot is the safety system. The design of underwater robot should not consist of any composite gas mixture that can react or effect the environment. This is important so that the robot does not produce pollution to the water or its surrounding. Therefore the design does not need to consist exhaust fumes or anything else. Usually the natural gas or any composite gases are relevant for the power source. If the robots are out of range of its operator, it is important that it does not interfere with existing control, measurement and safety system in the robot.(Dertien, 2014).

Underwater robot also needs to imply some of safety system such as in the jet fighter. Jet fighter consists of emergency ejected seat. This is to ensure that the pilot can move out of the jet with a single click of a button. Therefore this safety system can avoid the pilot to include in an air explosion. To imply this in the underwater robot, the safety system needs to have an emergency bouy so that the robot can float back on the water surface in a naked time. If this safety system can be applied, the underwater inspection robot can be save from any serious scenario.

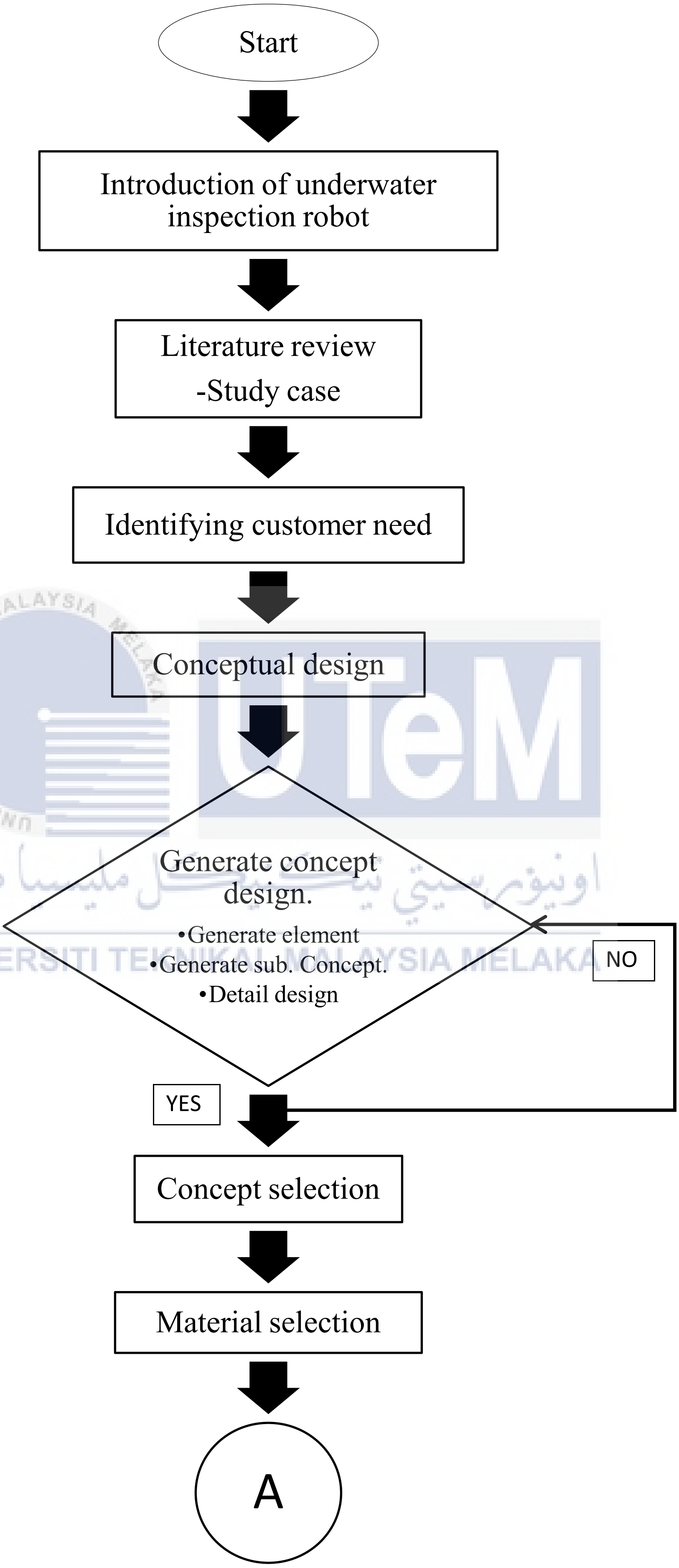
CHAPTER III

METHODOLOGY

3.1 INTRODUCTION

This chapter explain the methods used in product design development for modular underwater-based robot. Flowchart is applied in order to guide the project from beginning phase until final phase. By implementing the flowchart, further chapter for project will be complete systematic. This is to avoid any mistake of the project. The flowchart showed the whole idea about this project, the beginning, currently and further work. It will be much easier to guide the project development process by referring to flowchart.

Figure 3.1 show the flowchart that manner the process on develops test tube washer machine to achieve the objectives of this project. The methods used in product design development for test tubes washer machine are identify customer requirements, product design specifications, and bill of materials, morphology chart, concept generation, concept selection, detail design and design analysis.


Start
Introduction of underwater inspection robot
Literature review
-Study case
Identifying customer need
Conceptual design
Generate concept design.
•Generate element
•Generate sub. Concept.
•Detail design
NO
YES
Concept selection
Material selection
A

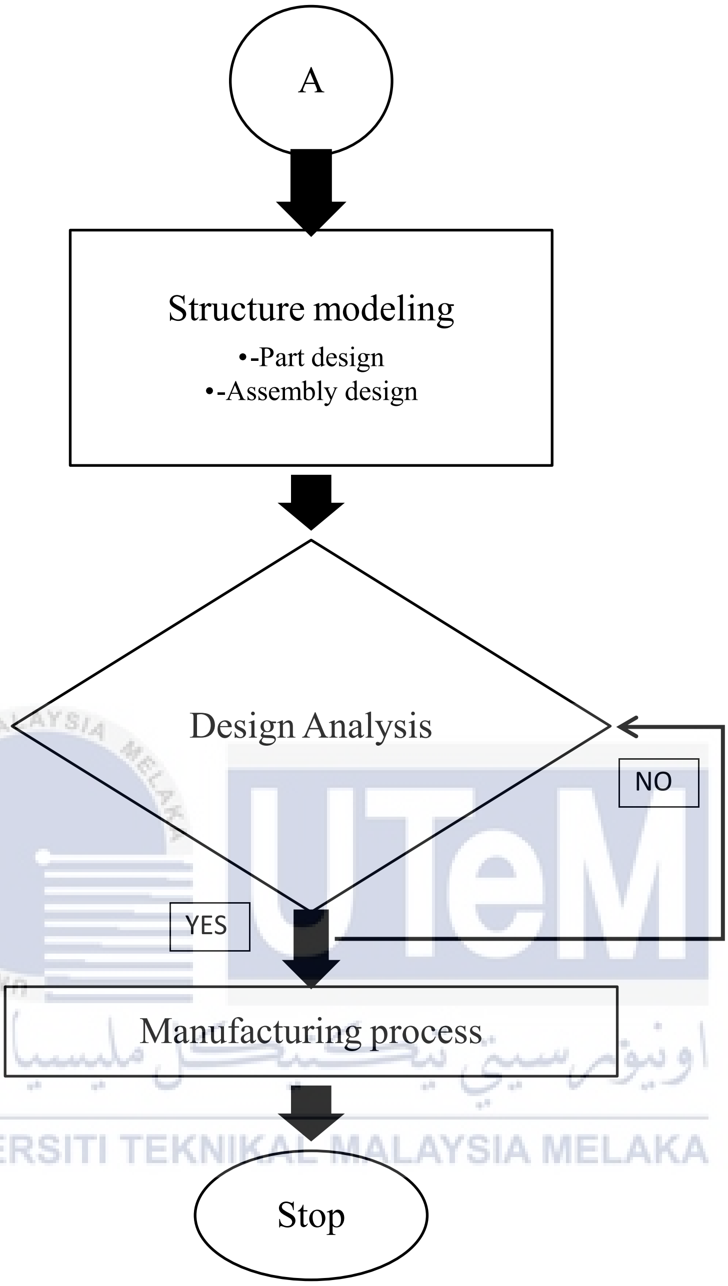


Figure 3.1: Project Flowchart.

3.2 IDENTIFYING CUSTOMER NEED

Customer requirements are the main information collected from customers to carry out research about the product as the customer needs. Therefore, identify customer requirements is an important method contribute to creating a ranked list of customer needs. The aim of this method is to:

i) Identify needs of customer.

ii) Make sure the product is focused on customer needs.

iii) Provide information to justify the specifications of the product.

iv) Overcome critical customer need is neglected.

v) Develop a common understanding of customer needs.

The philosophy behind the method is to create a high-quality information channel that runs directly between customers in the target market and the developers of the product. This philosophy is built on the premise that those who directly control the details of the product, including the engineers and industrial designers, must interact with customers and experience the use environment of the product. Without this direct experience, technical trade-offs are not likely to be made correctly, innovative solutions to customer needs may never be discovered and the development team may never develop a deep commitment to meeting customer needs. Identifying customer needs is itself a process, for which present a five-step method. The five steps are:

1) Gather raw data from customers.

2) Interpret the raw data in terms of customer needs.

3) Organize the needs into a hierarchy of primary, secondary and tertiary needs.

4) Establish the relative importance of the needs.

5) Reflects on the results and the process.

3.3 PRODUCT DESIGN SPECIFICATION

A specification consists of a metric and a value. Note that the value may take on several forms, including a particular number, a range or an inequality. Values are always labeled with the appropriate units. Together, the metric and value form a specification. The product specifications are simply the set of the individual specifications.

Target specifications are established after the customer needs have been identified but before product concept have been generated. The process of establishing the target specifications contains four steps:

1. Prepare the list of metrics.
2. Collect competitive benchmarking information.
3. Set ideal and marginally acceptable target values.
4. Reflect on the results and the process.

3.4 CONCEPT GENERATION

A product concept is an approximate description of the technology, working principles, and form of the product. It is a concise description of how the product will satisfy the customer needs. A concept is usually expressed as a sketch or as a rough three-dimensional model and is often accompanied by a brief simple description. The degree to which a product satisfies customers and can be successfully commercialized depends to a large measure on the quality of the underlying concept. A good concept is sometimes poorly implemented in subsequent development phases, but a poor concept can rarely be manipulated to achieve commercial success. Fortunately, concept generation is relatively inexpensive and can be done relatively quickly in comparison to the rest of the development process.

The concept generation process begins with a set of customer needs and target specifications and results in a set of product concepts from a final selection.

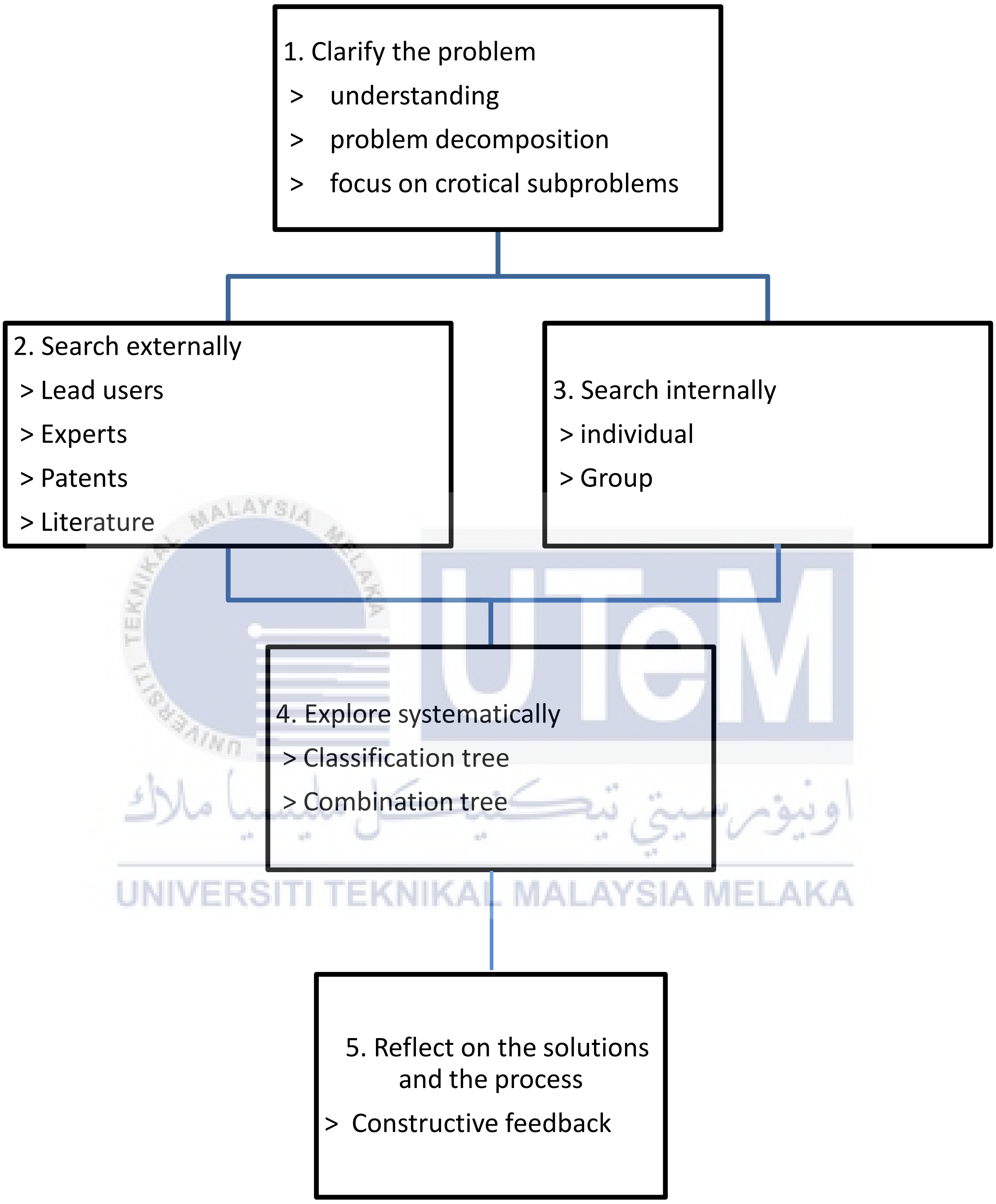


Figure 3.2: The five-step concept generation method.

(Source: George & Linda, 2009)

First step in concept generation process is clarifying the problems. Most design challenges are too complex to be solved. Then, external search is carry out in next step to finding existing solutions to both the overall problem and to the sub problems. External search is an essential information-gathering process. Available time and resources can be optimized by using expand and focus strategy.

Internal search in third step makes use of individual knowledge and creativity to generate solution concepts. Internal search is an open ended and creative process based on knowledge. Accept ideas that may seem not feasible, generate a lot idea, use graphical and physical media, and do not criticism of concepts during concept generation are the four guidelines that is useful for improving internal search. In step four, many of concept fragments and solutions to the sub problems have collected and created. There are two tools for managing this complex problem which are concept classification tree and concept combination table. Lastly, reflect on solution and the process.

3.5 CONCEPTUAL DESIGN

3.5.1 Morphology Chart

A morphological chart is a table based on the function analysis. On the left side of the chart the functions are listed, while on the right side, different mechanisms which can be used to perform the functions listed are drawn. It is a visual aid used to come up with different ideas. The idea generation is accomplished by creating single systems from different mechanisms illustrated in the morphological chart. It is advised to generate several feasible designs using different mechanisms for each function for each concept. Morphological charts is a table that created by decomposing the design problem by listing all the critical functions in a column. Combining one means for each function will produce a possible combined conceptual design solution. Repeating this process with every possible combination contained in the morphological chart will generate a complete list of conceptual design solutions. By this way, morphological charts provide a logic sense of the produc's design. The morphological chart is usually applied in the beginning of idea generation. Table 3.1 show the ways to generate morphology chart.

3.5.2 House of Quality (HOQ)

Quality Function Deployment (QFD) is one of the Total Quality Management quantitative tools and techniques that could be used to translate customer requirements and specifications into appropriate technical or service requirements (Baba etal, 2009). For this project, the basic design tool of the QFD is used known as the House of Quality (HOQ). Usually, this process will capture the voice of customer where it can be used as a method to measure the customer satisfaction. Customer needs is the focal point of the project where it can determined whether the product meet the customer expatiations. To complete the QFD process diagrammed, there are important aspects of QFD process need to be considered:

a) The first stage of the product planning where translates the customer into generally quantifiable design variables, called engineering characteristics.
b) Next, the QFD process which consists of four phases that are connected as a chain with the output from each phase becoming the input to the next.
c) Lastly, the QFD process is created to transform or map input requirements to each house into the characteristics output from the house

After HOQ being develop, the connection between the customers need (CRs) and engineering characteristic (ECs) can be seen clearly. The parameter will be set on each of the categories so it is easier to make a differentiation between the relations. The highest-ranking ECs from the HOQ will be selected as the best variable where it can be used as decision-making criteria to evaluate the design that will be produce. The results from the HOQ act as a guide to continue the next step to produce the product.

3.6 CONCEPT SELECTION

Concept selection is an integral part of the product development process. Concept selection is the process of evaluating concepts with respect to customer needs and other criteria, comparing the relative strengths and weaknesses of the concepts and selecting one or more concepts for further investigation, testing or development. There are seven criteria on which the choice of a product concept would be based:

- Ease of handling.
- Ease of use.
- Readability of dose settings.
- Dose metering accuracy.
- Durability.
- Ease of manufacture.
- Portability.

There are two-stage concept selection methodologies, although the first stage may suffice for simple design decisions. The first stage is called concept screening and the second stage is called concept scoring. Each is supported by a decision matrix which is used to rate, rank and select the best concepts.

Concept selection is often performed in two stages as a way to manage the complexity of evaluating dozens of product concepts. Screening is a quick, approximate evaluation aimed at producing a few viable alternatives. Scoring is a more careful analysis of these relatively few concepts in order to choose the single concept most likely to lead to product success.

During concept screening, rough initial concepts are evaluated relative to a common reference concept using the screening matrix. At this preliminary stage, detailed quantitative comparisons are difficult to obtain and may be misleading, so a coarse comparative rating system is used. After some alternatives are eliminated, next step is choosing to move on to concept scoring and conduct more detailed analyses and finer quantitative evaluation of the remaining concepts using the scoring matrix as a guide. Throughout the screening and scoring process, several iterations may be performed, with new alternatives arising from the combination of the features of several concepts. Both stage, concept screening and concept scoring, follow a six-step process which lead the team through the concept selection activity. The steps are:

1. Prepare the selection matrix.
2. Rate the concepts.
3. Rank the concepts.
4. Combine and improve the concepts.
5. Select one or more concepts.
6. Reflect on the results and the process.

3.6.1 Ergonomic Needs

3.6.1.1 Ease of use

Ease of use may be extremely important both for frequently used products, such as an office photocopier and for infrequently used product, such as a fire extinguisher. Ease of use is more challenging if the product has multiple features and/or modes of operation which may confuse or frustrate the user. When ease of use is an important criterion, industrial designers will need to ensure that the features of the product effectively communicate their function.

3.6.1.2 Ease of maintenance

If the product needs to be serviced or repaired frequently, then ease of maintenance is crucial. Again, it is critical that the features of the product communicate maintenance/ repair procedures to the user. However, in many cases, a more desirable solution is to eliminate the need for maintenance entirely.

3.6.1.3 Safety issues

All products have safety considerations. For some products, these can present significant challenges to the design team. For example, the safety concerns in the design of underwater inspection robot are much more prominent than those for a new computer mouse. The fabrication of the prototype needs to be conduct inside a safe environment such as laboratory and all the personal protective equipment (PPE).

3.6.2 Aesthetic Needs

Products with stable markets and technology are highly dependent upon industrial design to create aesthetic appeal and hence visual differentiation. In contrast, a product such as a computer's internal disk drive, which is differentiated by its technological performance, is less dependent on Industrial Design.

A customer's perception of a product is in part based upon its aesthetic appeal. An attractive product maybe associated with high fashion and image and will likely create a strong sense of pride among its owners. This may similarly be true for a product that looks and feels rugged or conservative.

3.7 DESIGN TOOLS

The tools used to do this cover the entire range of what is available for presentation purposes, from a chalk or pencil through a full-scale real-time simulation on computer and full-size models or prototypes of products of their parts. Such idea communication can include either separately or together things from the following list:

- ✓ Freehand drawings.
- ✓ Measured drawings.
- ✓ Working drawings or drawings with specify details.
- ✓ Two-dimensional or three dimensional drawings created on a computer using CATIA V5R19 software.
- ✓ Sketch model
- ✓ Virtual models, i.e. 3D models or rendering generated on computer.
- ✓ Photography
- ✓ Presentation of image supported by text or voice.
- ✓ Briefing papers, messages of documents

3.7.1 The Uses and Application of Cad

Computer Aided Design (CAD)

There are three essential functions involved in any product development process.

The functions are as follows:

i. Marketing – the identification of customer needs which subsequently in the process result in product specifications or identification.

ii. Design – generation of accurate geometry (form/shape) of a product according to its specifications.

iii. Manufacturing – the process of producing the product as defined by the design.

The design function in modern product development is integrated within the entire process of the development. It is crucial in accelerating product time-to-market, reducing the development cost as well as the manufacturing cost, and producing high quality finished product. These targets could be reached without the help from CAD. In simple term, CAD can be defined as the way of producing a design or drawing by using a computer. Design function takes place at the front end of the development process and finish once the detail design is approved.

3.7.2 Fundamental and Basic Principles of Cad

3.7.2.1 The Architecture of CAD

CAD software is used to create computer-based models during design process enabling other downstream processes to be planned and developed accordingly. The graphic model gives clear information so that the development team members will interpret the model unambiguously. On top of this, the data can easily be accessed for revision, modification, as well as for manipulation. For this purpose, there are four key elements that structure the CAD system:

i. The hardware – the computer and all the peripherals attached to a normal PC/workstation.

ii. The software and operating system – the CAD package used to design geometric models and to analyse the model. The operating system is an interface between the hardware and the software.

iii. Data – the information illustrated by or obtained from the geometric model produced by the designer. Known as engineering data and is normally retrieved from a data storage system (database).

iv. User – the human factor in terms of his/her knowledge in design.

3.7.2.2 Fundamental of CAD

Any graphical model generated by the designer in the design process from the concept phase to the design detail phase, consists of three fundamental elements that are known as:

i. The geometry – the line, arc or curve, used to generate the face/surface.
ii. The topology – the relationship between the geometric symbols. For example the relationship between one line to an adjacent line, between a line and a circle, and between a curve and a point.
iii. Auxiliary information – this could be described as properties associated to the geometry such as the colour, dimension, tolerances and analytical result, etc.

3.7.3 Detail Design

Detail design is the phase where all of the details information are brought together with all the decisions are finalized and a decision was made to release the design for production. The detail design is the most important and difficult phase because of it is very specific and concrete activity where many decisions have been made to get a brilliant detail design.

In detail design phase, a bigger task is to complete the engineering drawings. The drawing of individual parts usually called detail drawing where the detail drawing show the dimensions, tolerance and geometric features of the parts of product. All the parts of the product was put together as a assembly drawing to create the complete product or system. There are some information that need to be includes in detailed drawing:

a) Standard view of orthogonal projection.
b) Auxiliary view.
c) Dimensions.
d) Tolerance.
e) Material specification.
f) Manufacturing details.

3.8 DESIGN ANALYSIS TOOLS

3.8.1 ANSYS Workbench.

The ANSYS Workbench platform is the backbone for delivering a comprehensive and integrated simulation system to our customers. Using Workbench for your product development simulations will result in higher productivity from integrated applications leveraging common and compatible data models. Workbench gives you access to multi-physics and systems level insights that could not be attained before.

3.8.2 Analysis tools

Fluids behaviour is often counterintuitive, making it difficult, if not impossible, to predict the impact of fluid flows on your product. ANSYS CFD gives you the tools to successfully simulate the behaviour of fluid flows — even with complex interactions between multiple physics — and confidently analyze results throughout design and manufacturing, as well as during end use. The tools are:

• ANSYS FLUENT fluid flow *analysis system*

• ANSYS *Design Modeller*.

• ANSYS *Meshing*.

• ANSYS FLUENT *Set Up*, which includes:

– Set material properties and boundary conditions.

– Initiate the calculation with residual plotting.

– Calculate a solution using the pressure-based solver.

– Visually examine the flow and pressure fields using ANSYS FLUENT (and ANSYS CFD-Post).

• ANSYS FLUENT *Result* and *Solution.*

3.8.3 Analyze Results

The analysis of results is often the most difficult step of all. The analysis provides very detailed results data, which can be presented in almost any format. Proper interpretation of results requires that we appreciate the assumptions, simplifications, and errors introduced in the first three steps: building the mathematical model, building the finite element model and solving the finite element model.

3.9 MATERIAL SELECTION

In this material selection phase, it is provides comprehensive treatment of the selection material for manufacturing the design that was selected for the production. The material selection is very important because it can lead not only failure of the part but also the excessive lift-cost for the production. By selecting the best material for the part that involves in design can provide the necessary performance in service and make the flow of process run smoothly. However, the poorly chosen of material for the part that involves in design may affect the manufacturing cost.

In material selection, the materials of the product are selected based on the four general criteria:

1. Performance characteristics.
2. Processing characteristics.
3. Environmental profile.
4. Business considerations.

. The material selection based on the performance characteristics is the process of matching the properties of the material with the requirement and constraint that required by the design. While the material selection based on the processing characteristics is the process to form the material into the required shape based on the design with a minimum defects and least cost. Next, the material selection based on the environmental profile is the process that focused on predicting the impact of the material towards environment. Lastly, the material selection based on the business consideration is the process of considering the cost incurred to the materials to be used for the production.

3.10 BILL OF MATERIAL (BOM)

A Bill of Materials (BOM) defines the complete set of physical elements required to manufacture a product. It may be in a tree form, or more typically in a printed document indented to the lowest level required, to accurately list all parts and raw materials needed to make the unit. With the increasing sophistication in the business processes, a bill of materials has come out to be a full warehouse of information, listing entries such as quantities, details of supplying vendors and prices. It thus easy to define, manage and analyze the products. The E-BOM has context and instruction that allows manufacturing engineers to derive the manufacturing bill of materials (M-BOM). The M-BOM is develop by sequencing the E-BOM in the context of the assembly process, and then derives the process information that will allow the new part to become production ready.

CHAPTER IV

RESULT AND ANALYSIS

4.1 HOUSE OF QUALITY (HOQ)

		Engineering Characteristic				
Improvement Direction		↓	↑	↓	↑	↑
Unit		n/a	n/a	Kg	n/a	n/a
Customer Requirements	Importance Weight Factor	Size of inspection robot	Movement of robot	Weight of inspection robot	Depth of diving	Mechanical operation
Diving ability	5	△		◎	□	□
Easy handling	5	◎	□		◎	□
Small Size	3	◎		△		
Design	4	□	△		△	
Portable	5					△
Power supply	3		◎			□
	Raw Score	65	58	18	64	122
	Relative Weight (%)	19.9	17.7	5.5	19.5	37.3
	Rand Order	2	4	5	3	1

Figure 4.1: House of Quality (HOQ).

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

Figure 4.1: House of Quality (HOQ).

Figure 4.1 shows the house of quality (HOQ) that was constructed for the design of underwater inspection robot which can be used as reference and guide for this project. The most important factor in development of the inspection robot are depth of diving, easy handling, small size, portable, movement of robot underwater and power supply.

Based on the Figure 4.1 shows that the mechanical operation is the most important factor in the ranking of engineering characteristic. Engineering characteristics are variable for the design and can put unlimited variable. Mechanical operation of the underwater inspection robot is important because it relate with the depth of diving, the movement of the robot underwater and the objective for this product also to produce underwater inspection robot.

The second most important factor in designing inspection robot is the design itself. This factor is important to ensure that the robot can give the best performance to dive underwater. This follows with the others importance of engineering characteristic which is size of the robot, and weight of the inspection robot. Other than that, the customer requirements are shown in the HOQ were are more focused on the diving ability, easy handling, small size, portable, good design and power supply for the product.

4.2 PRODUCT DESIGN SPECIFICATION (PDS)

Product Identification

- Product name: Underwater Inspection Robot
- Basic function: For inspection underwater area
- Special features: Portable, easy to handle and good diving ability.
- Key performance targets: Efficiency, cost
- Service environment: Inspection

Product Characteristics

Table 4.1: Product specification details.

No.	Criteria	Characteristic
1	Performance	➢ The robot can dive underwater without any problem. ➢ The movement of the robot are easy to handle ➢ Give a clear view underwater.
2	Safety	➢ Should not harm the user and the environment.
3	Installation	➢ Can be easily install and maintenance
4	Material	➢ Light ➢ Anti-rust ➢ Strong ➢ Low cost ➢ Easy to machine
5	Ergonomics	➢ No sharp edges ➢ Ergonomic design

Physical Description

- External dimensions (Length x Width x Height): 30cm x 22cm x 20cm (min height)

4.3 MORPHOLOGICAL CHART

Figure 2 shows the morphological chart where this method is used to generate ideas in an analytical and systematic manner on designing underwater inspection robot. This morphological chart method gives the systematic exploration of much possible design solution on designing the new product. There are three summarized steps of the general morphological approach to design the product (Book, 2013):

1. Divide the overall design problem into simpler sub-design.
2. Generate solution concept for each sub-design.
3. Systematically combine sub-design solutions into different complete solution and evaluate all the combinations.

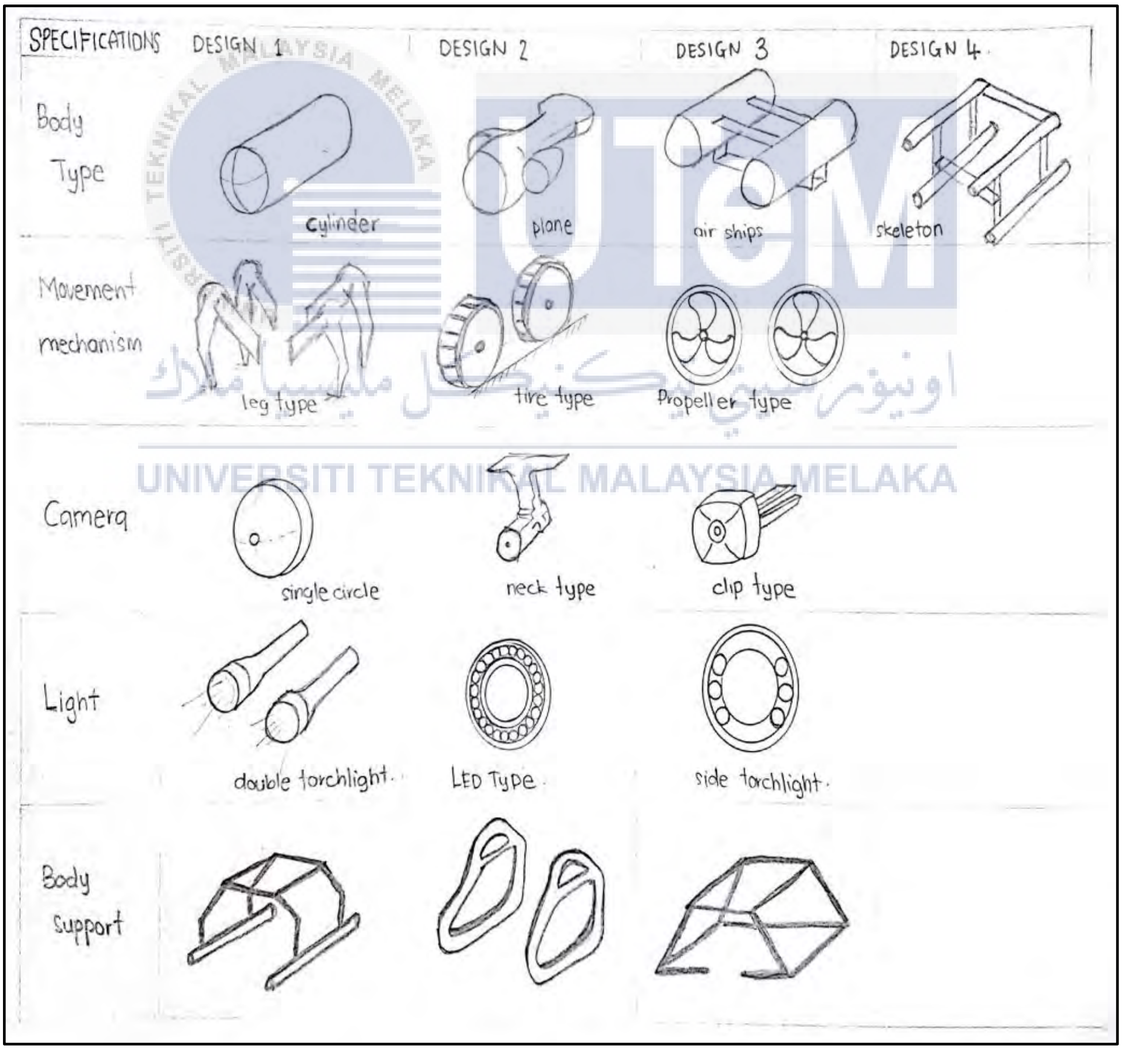


Figure 4.2: Morphological chart of the underwater inspection robot

Based on the morphological chart as shown in Figure 2, the morphological chart was divided into 4 or 3 option and 5 specifications to design the underwater inspection robot. Where the specification of the underwater inspection robots are the body type, camera, light, body support and the main specification is the movement mechanism.

There are four options as the alternatives solution that can be used to build the underwater inspection robot body which is the cylinder type, plane type, airship type and skeleton type. Moreover, the movement mechanism consists of three type which are leg type, wheel type and propeller type. Figure 3 also shows that there are several type of camera can be use in the robot such as single circle, neck type and clip type. The light also consists of three sub-designs which are double torchlight, LED type and side torchlight type. Lastly, body support also consist of three sub-design which can be use to build the robot.

4.4 CONCEPTUAL DESIGN

Conceptual design is the creation and exploration of new ideas from the existing one. From the morphological chart as shown in Figure 3, there are several concept design has been assembly from each option for each specification of the underwater inspection robot.

4.4.1 Concept Design 1

Figure 4.3 shows the concept design 1 of the underwater inspection robot. The robot was designed with the airship type of body for the buoy of the robot. The movement mechanism of the robot is using the wheel type which has four tires and the tire position is the same as car. The robot is complete with the clip type camera and side torchlight. The side torchlight are use to light up the camera vision underwater to get a clear vision and picture. The design does not need any body support because the robot already is stabilized by the wheels.

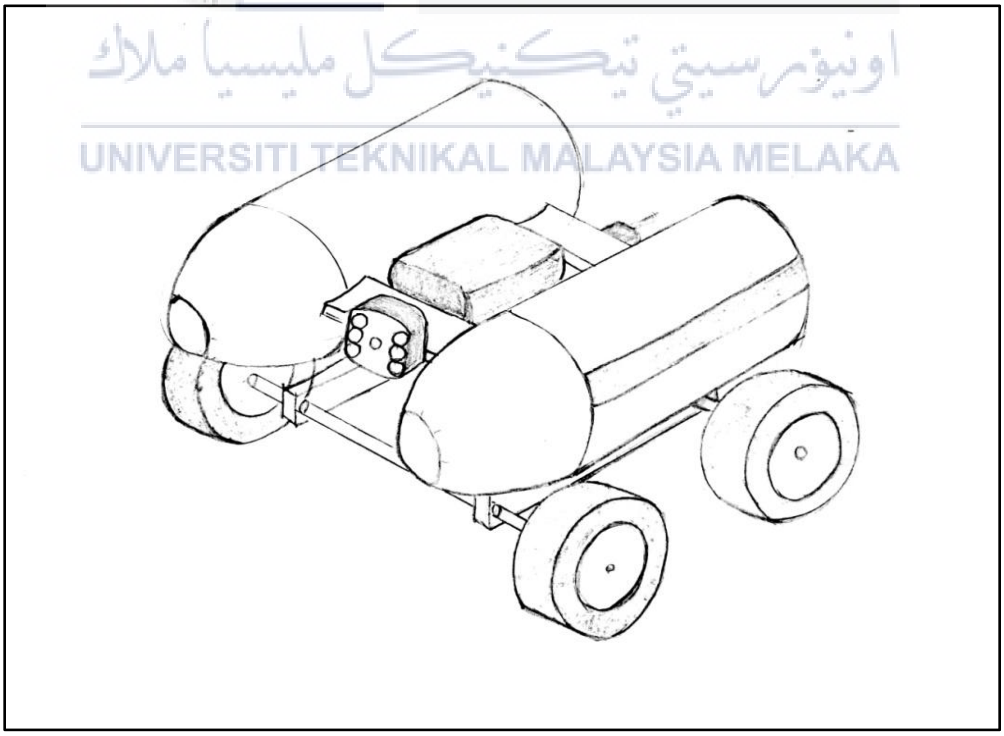


Figure 4.3: Concept Design 1

4.4.2 Concept Design 2

Figure 4.4 shows the concept design 2 of the inspection robot. For this concept design, the robot was designed with a plane type of body that looks like a plane. Besides that, the movement mechanisms used is the propellers. The design consists of three propellers that will move the robot up and down, forward and backward and lastly right or left. The robot also designed with a single circle type of camera. And the light support for the camera vision was by using LED type of light. Lastly, the body support use to stabilize the robot is by using support 3 such as the figure 5 shows.

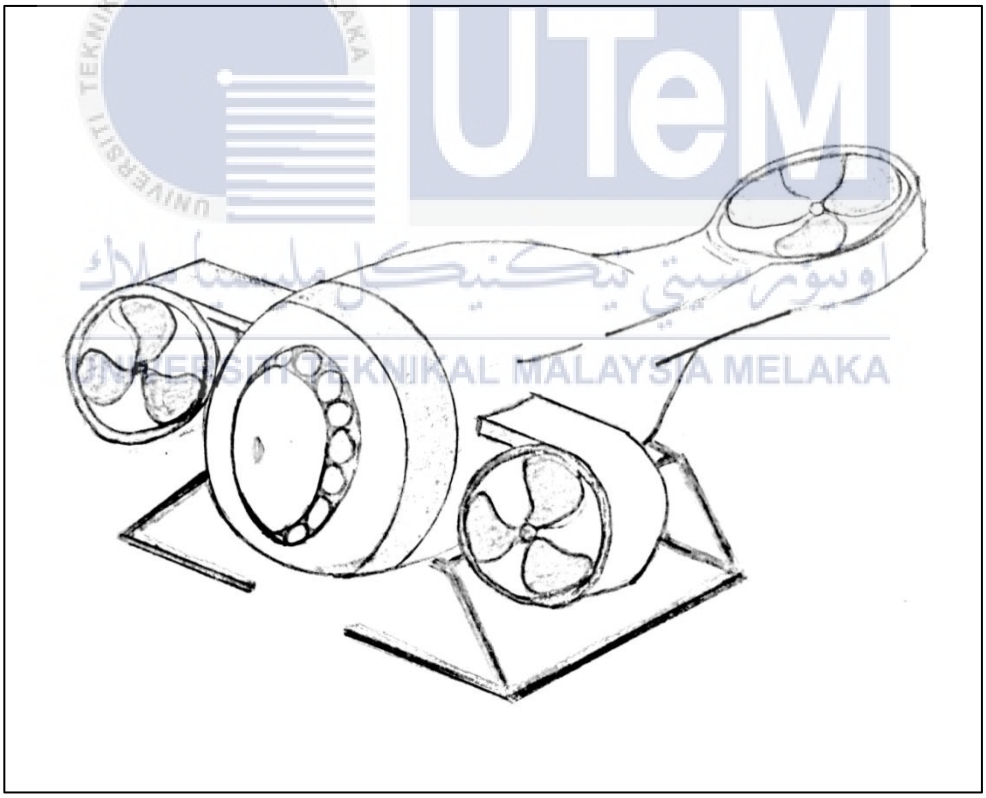


Figure 4.4: Concept Design 2.

4.4.3 Concept Design 3

Figure 4.5 shows the concept design 3 of the inspection robot. For this concept design, the robot were build with a skeleton type of body that only consist of several small hallow pipe that act as the buoy of the robot. The mechanism of movement on the robot was by using several propellers. The camera used for the design was neck type because it can be easily installed at the skeleton body. The light supports are by using single torchlight. And the robot does not need any body support to stabilize because the skeleton body already stabilizes the robot.

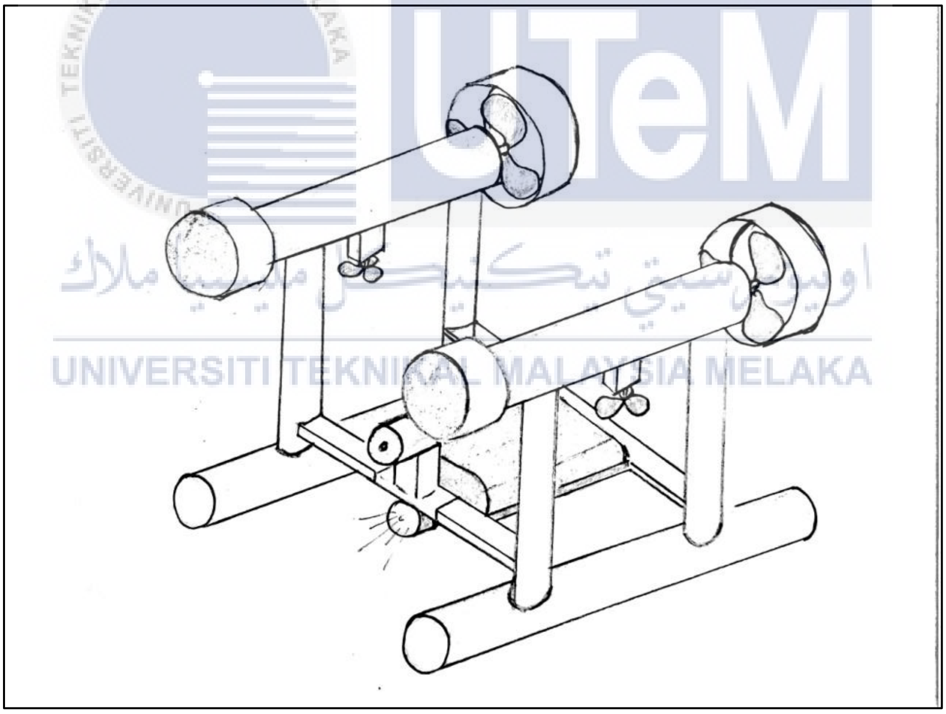


Figure 4.5: Concept Design 3.

4.4.4 Concept Design 4

Figure 4.6 shows the concept design 4 of underwater inspection robot. The concept design for this robot was equipped by a cylinder type of body that at as a buoy for the robot. It also equipped by installing the propeller as the movement mechanism at the behind and the below body of the robot. The added fin is to control the left and right movement. The robot also embedded with a double torchlight and a single circle camera. The torchlight are placed next to the robot body right and left. And lastly, the body supports used was the first support shows in the morphological chart.

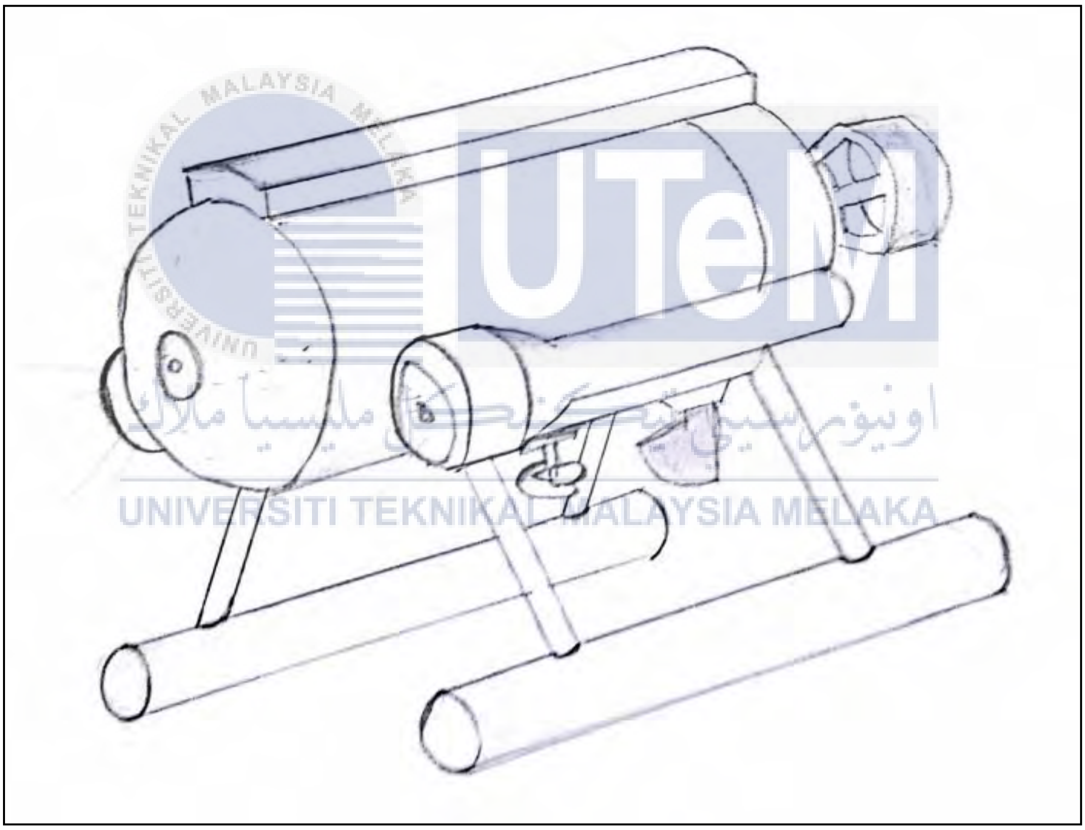


Figure 4.6: Concept Design 4.

4.5 CONCEPT SELECTION

All concept designs were evaluated using selection matrix method. A concept designs with highest net score will be the final design.

Table 4.2: Concept selection list table.

	Concept Design			
Selection Criteria	1	2	3	4
Diving Ability	+	+	+	+
Easy Handling	-	0	0	0
Design	0	+	-	+
Movement Of Robot	-	0	+	+
Power Supply	+	+	+	+
Robot Size	0	-	-	+
Flexibility	-	+	0	+
Portable	+	+	+	+
Sum +'s	3	5	4	7
Sum 0's	2	0	2	1
Sum -'s	3	1	1	0
Net Score	0	4	3	6
Rank	4	2	3	1
Recommended Concept	×	×	×	√

The selection criteria are set by referring the product design specification. In this evaluation, the concepts is rated against the reference concept using a simple code (+ for "better than", 0 for "same as", - for "worst than") in order to identify best concept for further consideration.

4.6 BEST CONCEPT

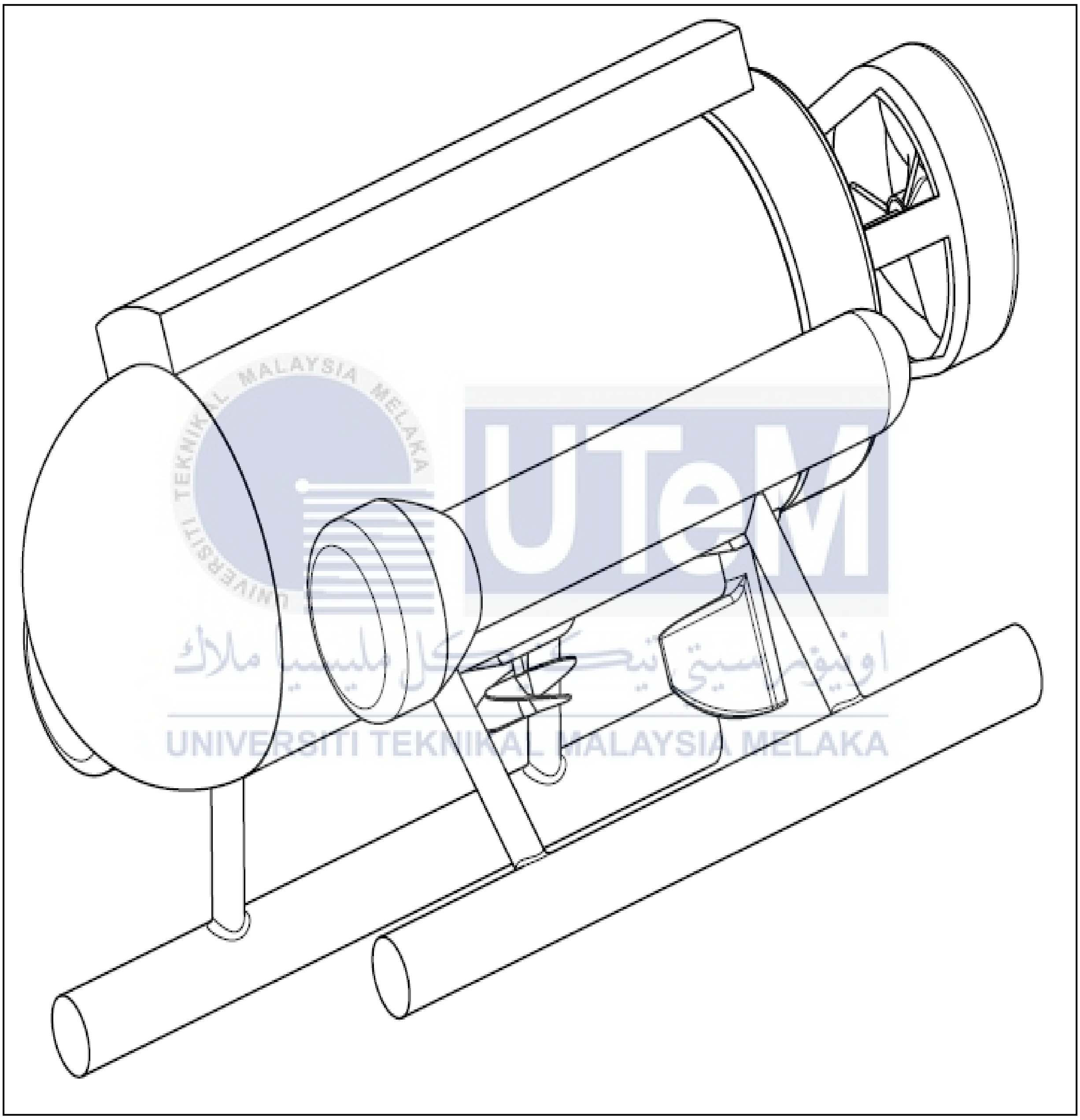


Figure 4.7: Concept design 4 is chosen as the best concept.

4.7 MATERIAL SELECTION

After the concept design was chosen. Then the material is selected for the underwater inspection robot. The characters of material for this inspection robot are:

- Water proof
- Affordable
- Easy to find
- Pressure withstand
- Shape

4.7.1 Main body

The body of the robot are the important part of the product. The material chosen was Polyvinyl chloride (PVC). PVC is a thermoplastic made of 57% chlorine (derived from industrial grade salt) and 43% carbon (derived predominantly from oil / gas via ethylene). One of the plastics characteristic is water proof because of the use of this material is often use in water piping. The material also is easy to find in any hardware store with different type of sizes and shape.

4.7.2 Base structure.

For the base structure, the material used is aluminium. There are many kinds of Alloys to choose from but often, aluminium is chosen as it is lightweight (about 2700 kg/m3 density), it is comparatively soft and its process-ability is good. From a machining viewpoint pure aluminium (JIS A1000) greatly differs from Al-Cu alloy (JIS A2000).

4.8 STRUCTURE MODELLING

The design of underwater inspection robot is inspired by different type of vehicle and shapes to product more interesting design. The body is design by adapting the cylinder shape with a semi-sphere on the front and a flat surface on the back. The back body of the robot will be combining with the engine structure. The side body are consists of side lamp that also adapt with a cylinder shape design. Besides that, the base of the robot is design with a cylinder shape that connects to each other and produces a skeleton body type.

The robot movement mechanism consists of two engine fan and a single paddle. The mechanism is design and adapt with the movement of submarine the different is only submarine consist of single propeller but the inspection robot consist of two different propellers. The two propeller work as the movement for forward and backward, another is for the movement for up and down. Meanwhile the paddle is use for the right and left movement. Therefore, the robot can be moved in three different axes.

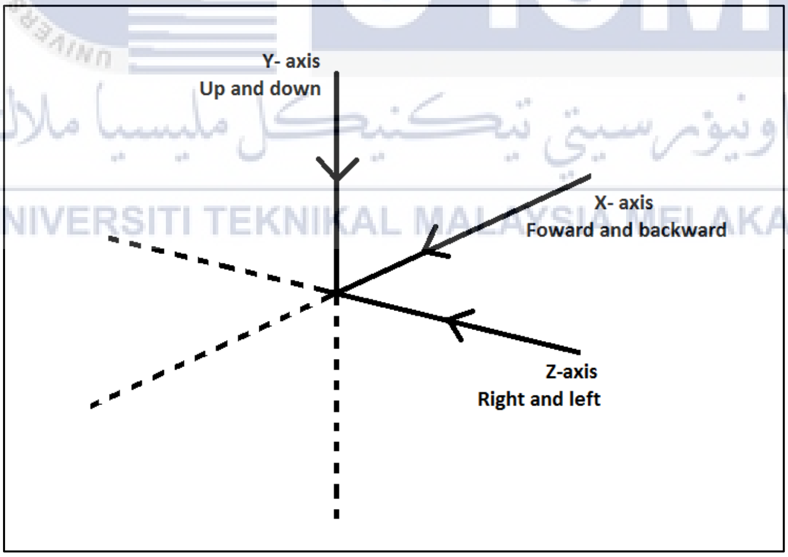


Figure 4.8: Direction and axes of robot movement.

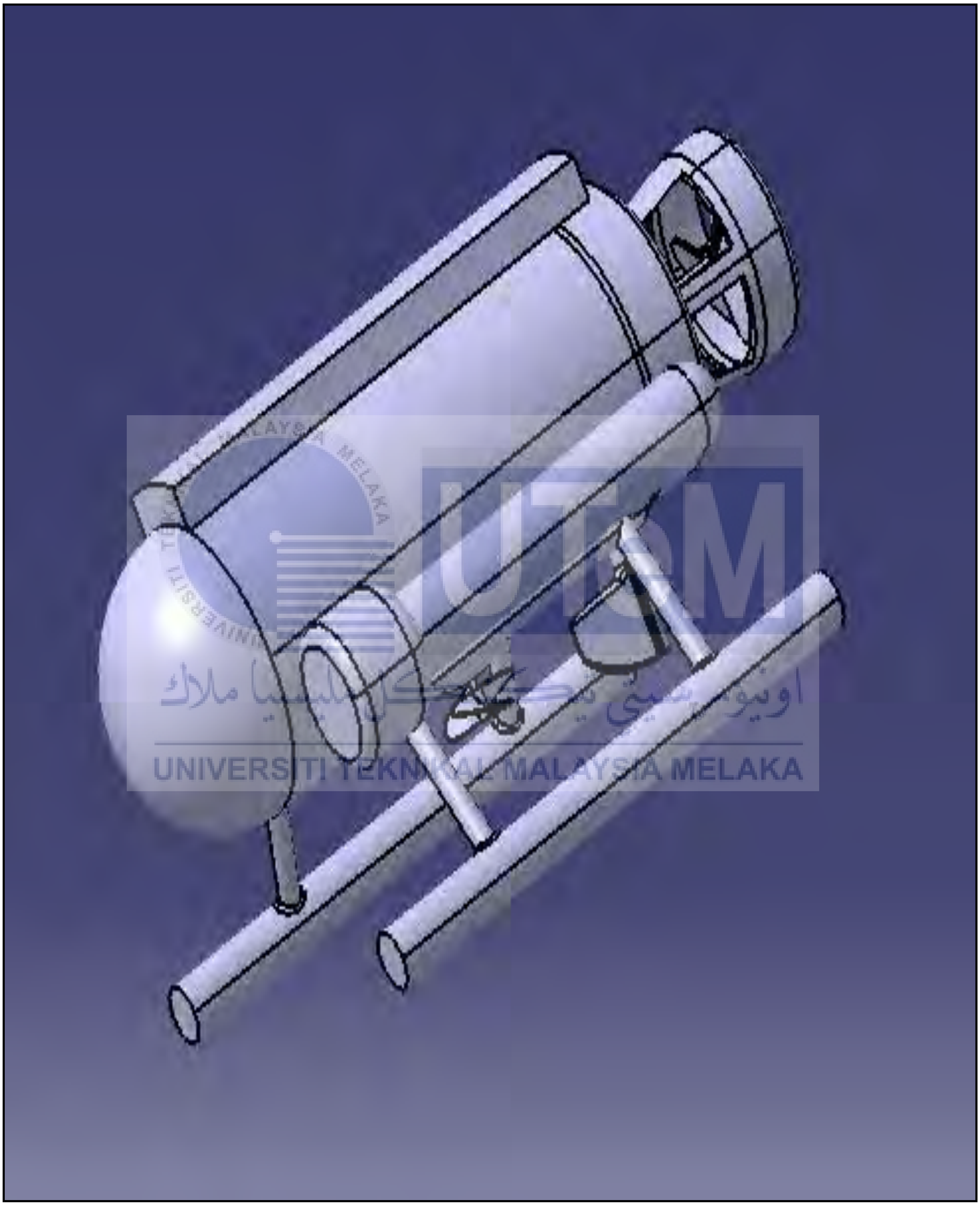


Figure 4.9: 3D rough modelling.

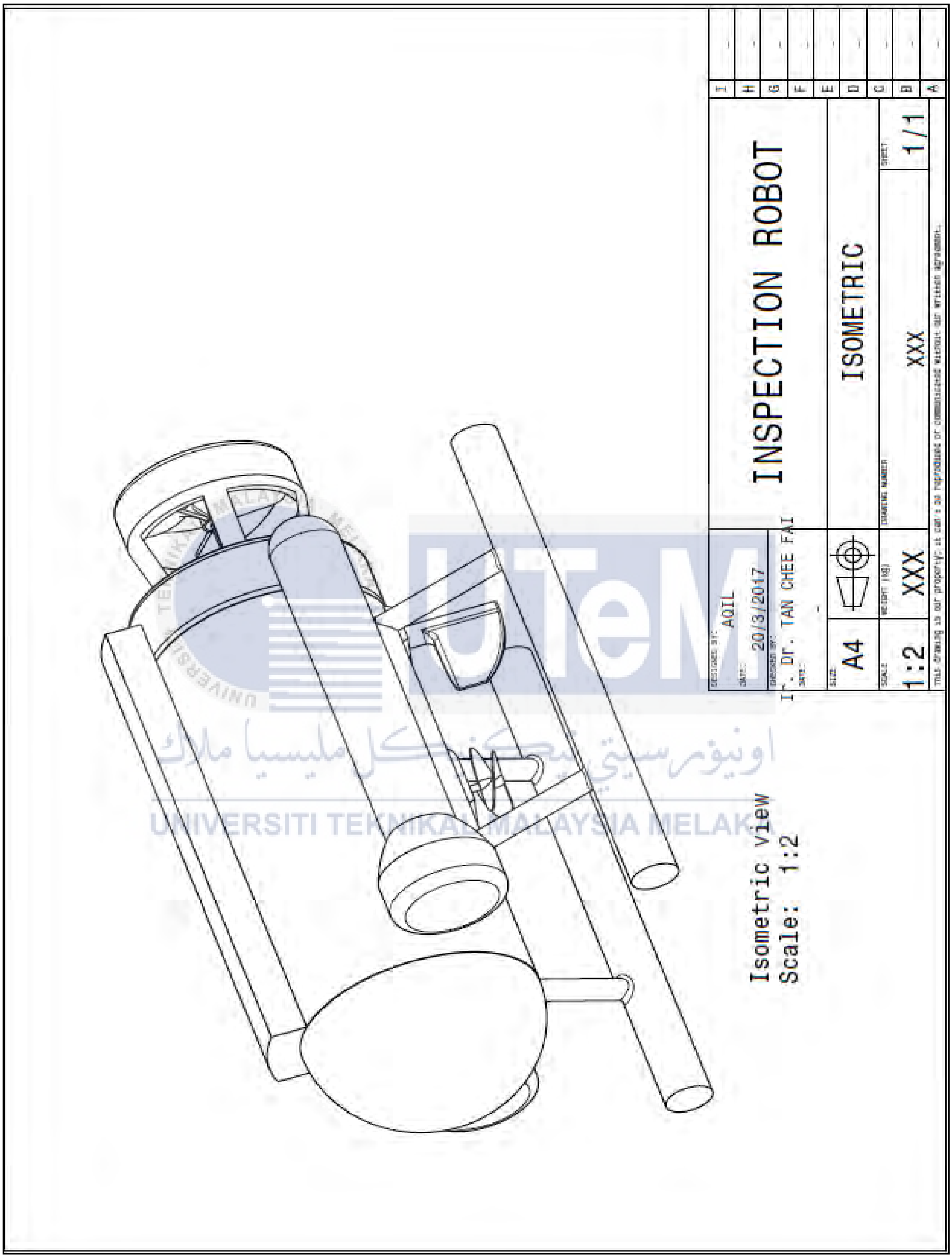


Figure 4.10: 3D Rough Modelling Isometric View

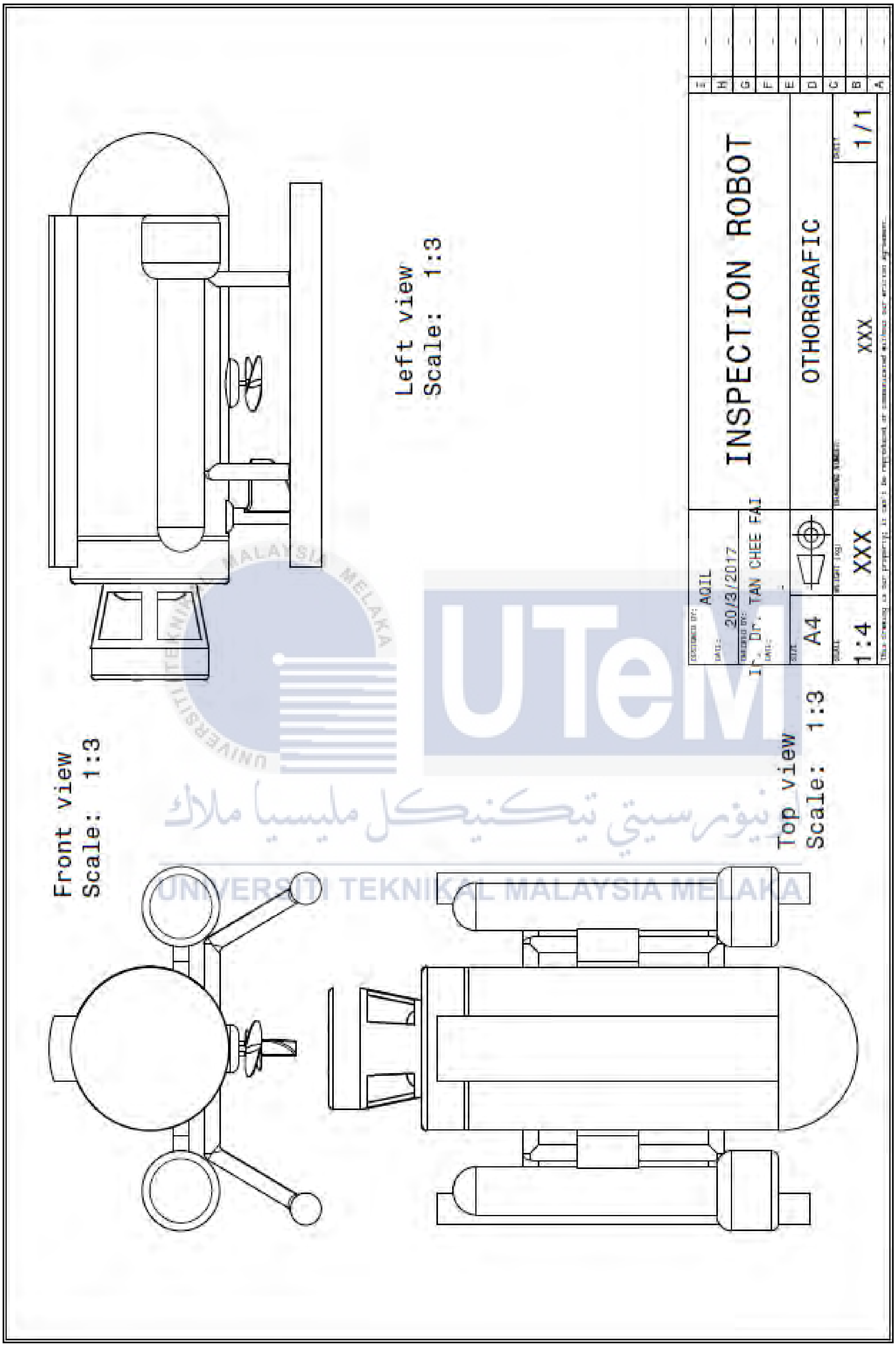


Figure 4.11: 3D modelling Orthographic View

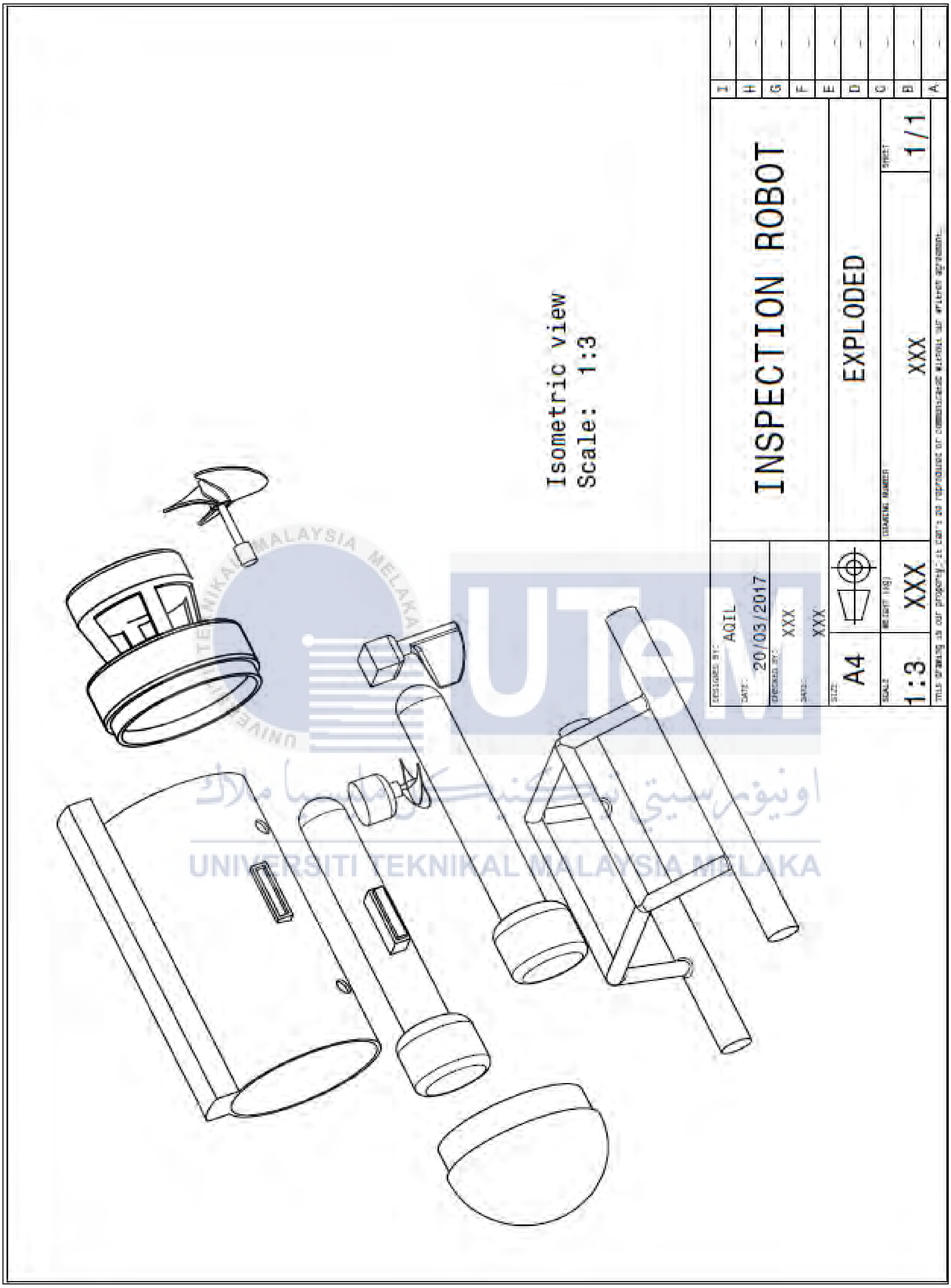


Figure 4.12: 3D modelling exploded view.

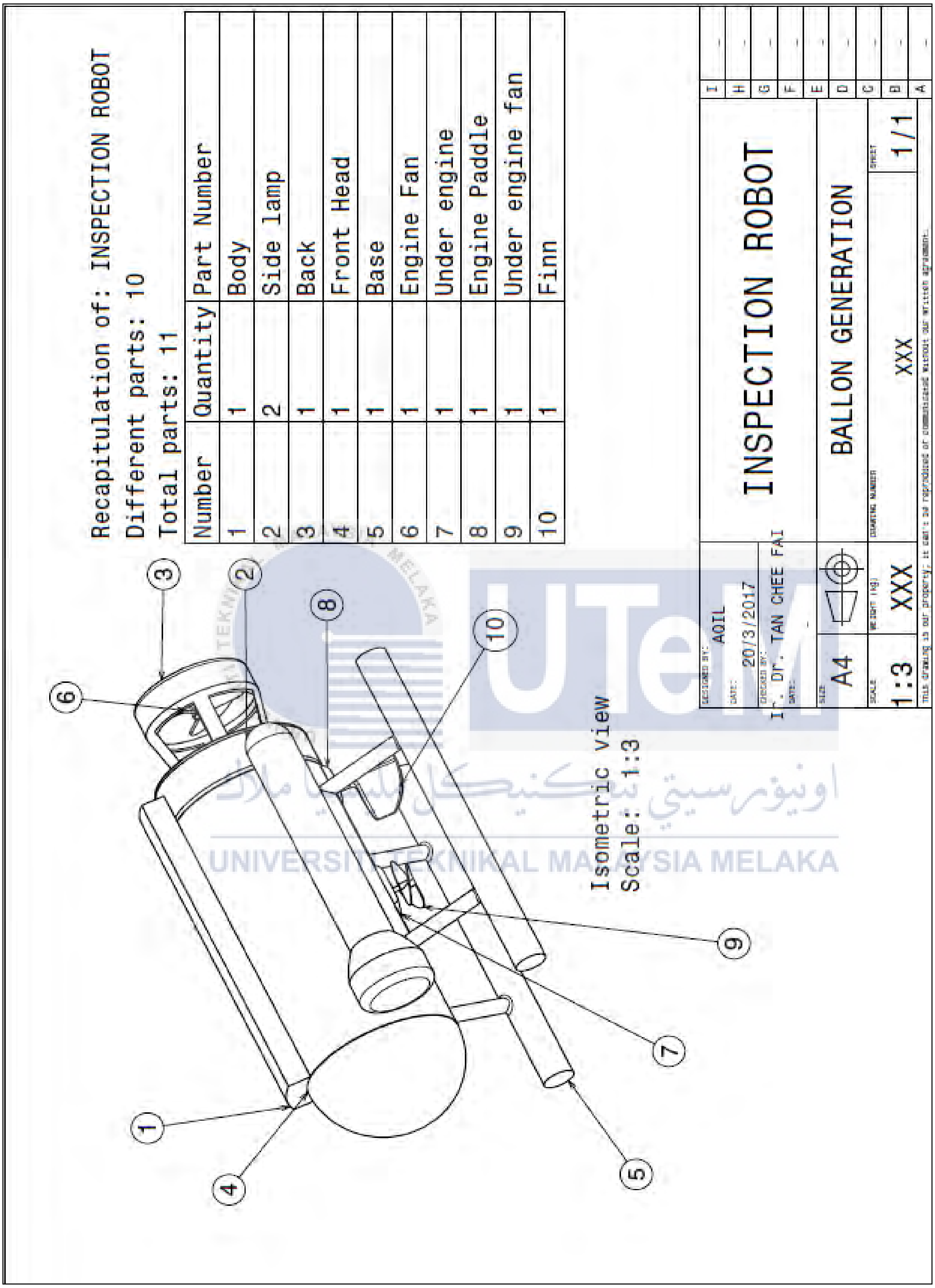


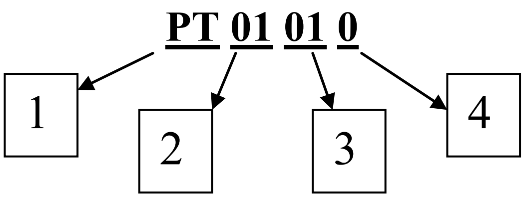
Figure 13: 3D modelling ballon view

4.8.1 Numbering Part

A part number is an identifier of a part used in a particular industry. Its purpose is to simplify referencing to that part. A part number unambiguously defines a part within a single manufacturer. In this section, we will determine the part number of each part of our robot. Table below shows the way to numbering the part.

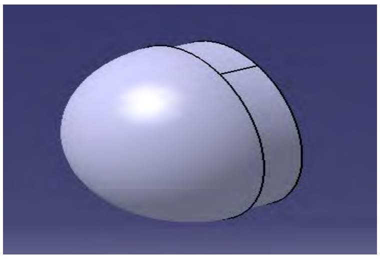
Table 4.3.: Numbering Part

No	Characteristic	Description
1	Part Model	Put the part model with 2 ~ 3 alphabets. For **Inspection Robot** project, the part model is **IR**.
2	Sub - Assembly (Cluster) Number	This number imagine part location occur on products design. **01** is main part position followed with further number which imagines the part position is on top then went down. This inspection project have 3 cluster, thus the number is from **01** to **04**
3	Position of Sub - Assembly	This number imagines interior position each sub assembly (cluster) which **01** is last part once would be assemble in that sub assembly.
4	Position of the part	This number imagine that part position be left, right or middle. Number **0** imagine that part in the middle of. Number **1** imagines the part is left and number **2** imagine the product was in right. Number 3 imagine the part is in front and number 4 imagine the part is at the back. All the clusters of our design were in middle position. Hence we are not using this number.



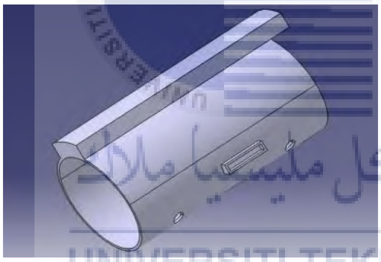
4.8.2 Product Structure Tree

In products structure tree, part compilation would be vital especially in that products cluster assembly process. As such products structure tree is one of the solutions to look how part form one sub assembly (cluster) before sub assembly (cluster) this form one product. The part compilation for the inspection robot is done according to the region.



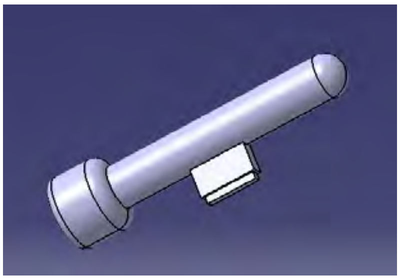
Part name: Front head

Part no.: IR 01 01 3



Part name: Main Body

Part no.: IR 01 02 0

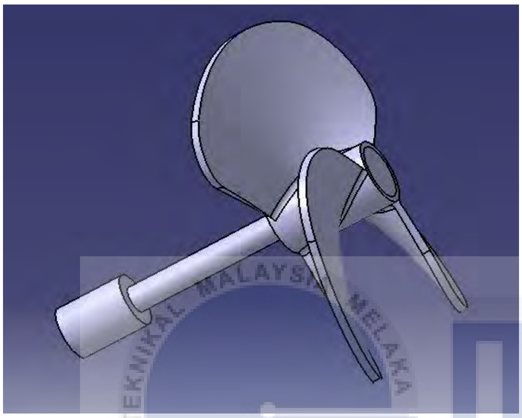


Part name: Side Lamp

Part no.: IR 01 03 1.2

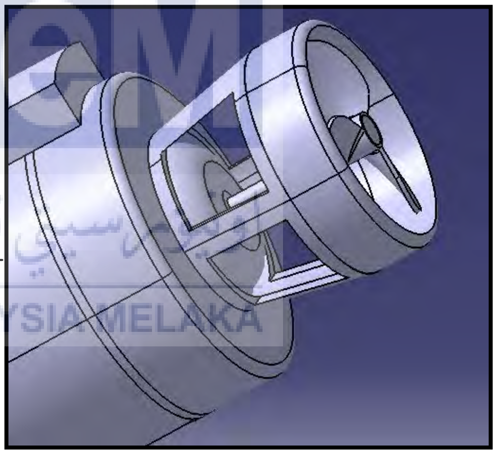
Part name: Main Body Region

Part no.: IR 01



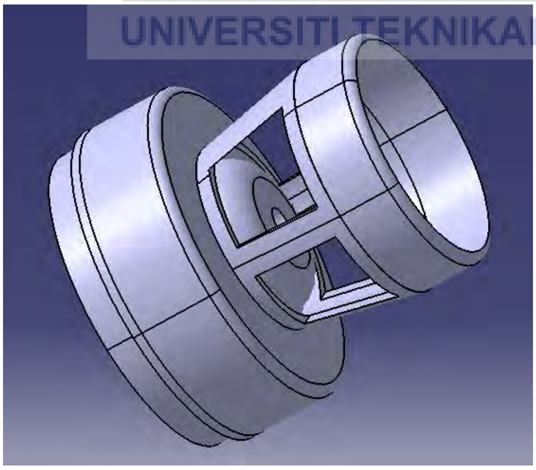
Part name: Back Engine Fan

Part no.: IR 02 01 4



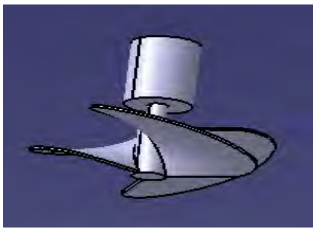
Part name: Back body region

Part no.: IR 02



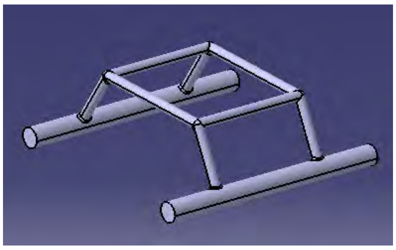
Part name: Back body

Part no.: IR 02 02 4



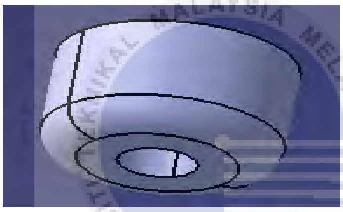
Part name: Bottom Fan

Part no.: IR 03 01



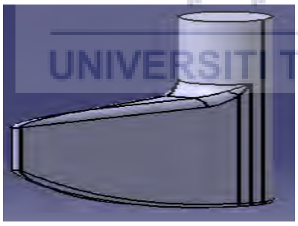
Part name: Base

Part no.: IR 03 02



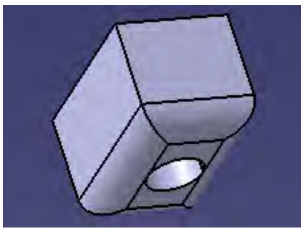
Part name: Bottom fan holder

Part no.: IR 03 03



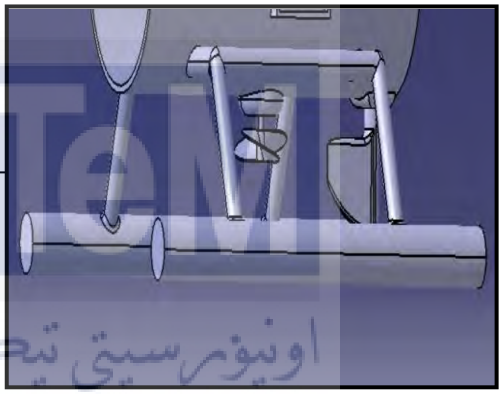
Part name: Paddle

Part no.: IR 03 04



Part name: Paddle Holder

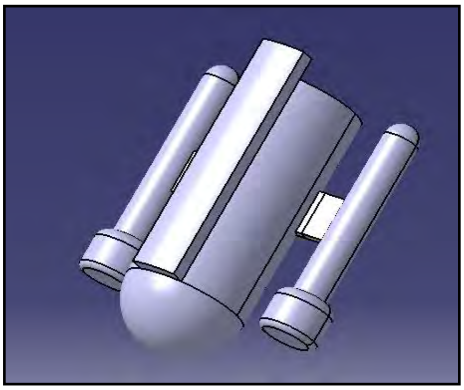
Part no.: IR 03 05



Part name: Bottom region.

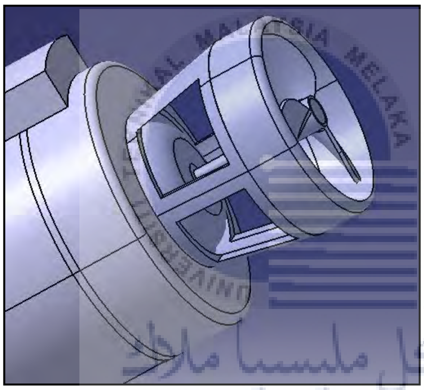
Part no.: IR 03

4.8.2.1 Product Structure Tree Cluster Assembly



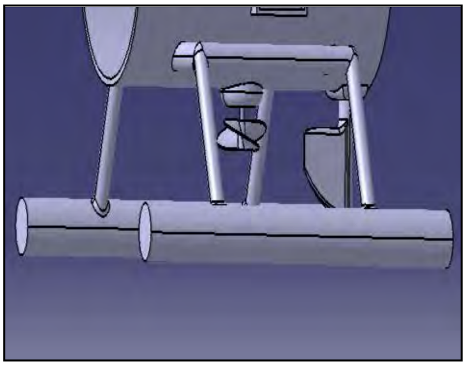
Part name: Main Body Region

Part no.: IR 01



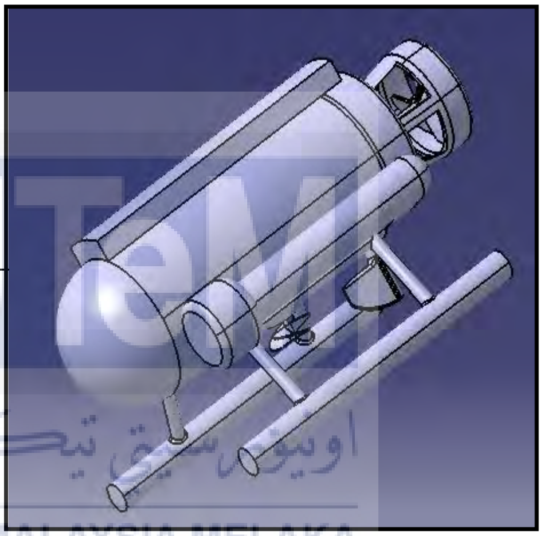
Part name: Back body region

Part no.: IR 02



Part name: Bottom region.

Part no.: IR 03



Cluster Assembly

4.8.2.2 Product Structure Chart

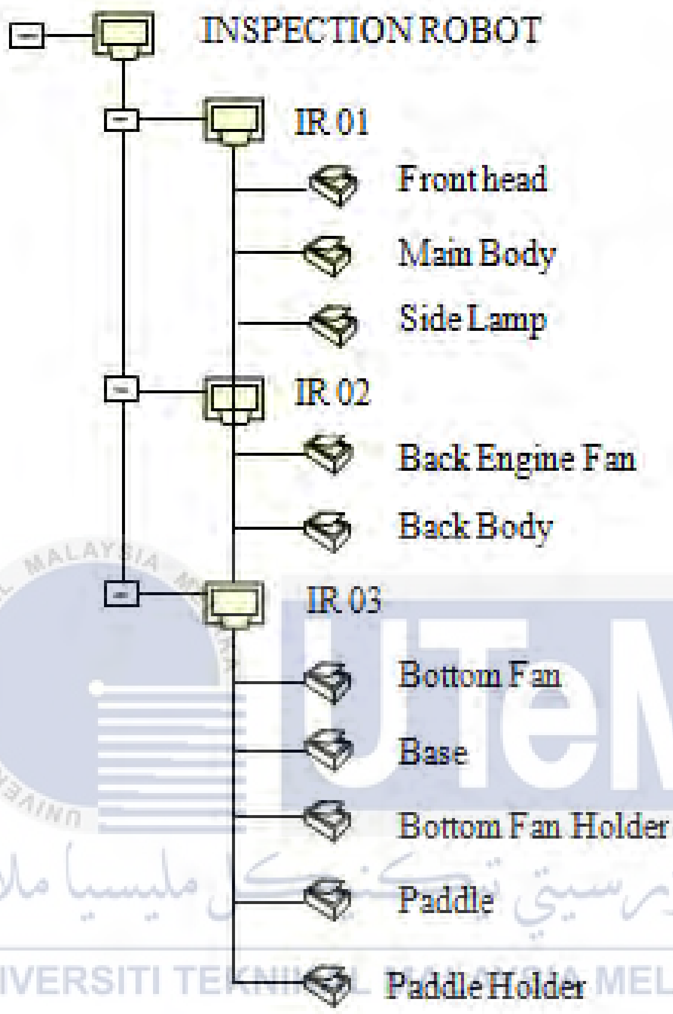


Figure 4.14: Product structure tree

4.9 DESIGN ANALYSIS.

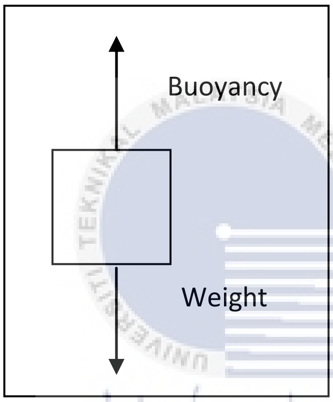
4.9.1 Basic Analysis

<u>Archimedes Principle</u>

When an object is submerged completely in the fluid, the pressure under the object is higher than the top. This creates a net upward force on the object so the object is buoy up against the gravity. The buoyant force is equal to the weight of the fluid displaced by an object, not the weight of the object.

Weight of object > buoyant force: Sink

Weight of object < buoyant force: Float.



Buoyancy = $F_{Buoyancy} = \rho_{fluid} \times V_{disp} \times g$

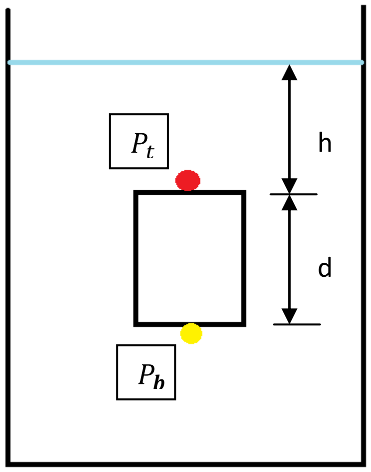
Neutral buoyancy – the situation in which an object's density is equal to the density of displaced fluid

Weight = $m_{obj} \times g$

$$\sum F = m\,a$$

$$F_{weight} - F_{buoyancy} = m_{obj} \times a_{obj}$$

$$(m_{obj}\, g) - (\rho_{fluid}\, V_{disp} g) = m_{obj} \times a_{obj}$$



P_t = Pressure on top body

P_b = Pressure on bottom body

h = Height body from fluid surface

d = Length of body

$$Force_{\ net,}\ F_N = P_b d^2 - P_t d^2$$
$$= (P_b - P_t) d^2$$

$$\boxed{P_t = \rho_{liquid}\, h\, g} \qquad \boxed{P_b = \rho_{liquid}\,(h + d)\, g}$$

$$F_N = P_b d^2 - P_t d^2$$
$$F_N = (\rho_{liquid}\, h\, g) d^2 - (\rho_{liquid}\,(h + d)\, g) d^2$$
$$F_N = (\rho h\, g + d\rho g - \rho h g)\, d^2$$
$$F_N = d^3 \rho g$$

Example calculation

Density of water, $\rho_{water} = 1000\ \frac{kg}{m^3}$

Gravitational acceleration, g = 9.81 $\frac{m}{s^2}$

Length of body submerged, d = 18 cm = 0.18m

Pressure at top, $P_t = \rho_{liquid}\, h\, g$

P_t= (1000) (1)(9.81) $\left[\left(\frac{kg}{m^3}\right)(m)\left(\frac{m}{s^2}\right)\right]$

P_t= 9.81 kpa.

Pressure at bottom, $P_b = \rho_{liquid}\,(h + d)\, g$

P_b= 1000 (1+0.18) (9.81) $\left[\left(\frac{kg}{m^3}\right)(m)\left(\frac{m}{s^2}\right)\right]$

P_b= 11.575 kpa

Force nett, $F_N = d^3 \rho g$

F_N = (0.18^3) (1000) (9.81) $\left[(m^3)\left(\frac{kg}{m^3}\right)\frac{m}{s^2}\right]$

F_N = 57.21 N

Table 4.4: The pressure in different depth of body underwater.

Length of body submerged, d (m)	Pressure at top, P_t (kpa)	Pressure at bottom, P_b(kpa)	Force nett, F_N (N)
1	9.81	11.575	57.21
2	19.620	21.386	"
3	29.430	31.196	"
4	39.240	41.006	"
5	49.050	50.816	"

From the table of calculation, the table shows that the value of pressure in the top and the bottom are increasing constantly when the value of the depth increase constantly. Therefore the pressure values are directly proportional to the depth value. The pressure will exerted on the robot body will increase when the robot dive dipper underwater. The material selection of the robot needs to surpass the pressure that will be exerted on the robot.

4.9.2 Apply 'ANSYS Fluent' Analysis On 3d Rough Modelling.

4.9.2.1 Analysis on main body structure

The material of the fluid and solid had been modified to the actual condition. The material for the solid was water and material of solid is Polyvinyl chloride (PVC). It specific properties had been modified in the workbench as figure below.

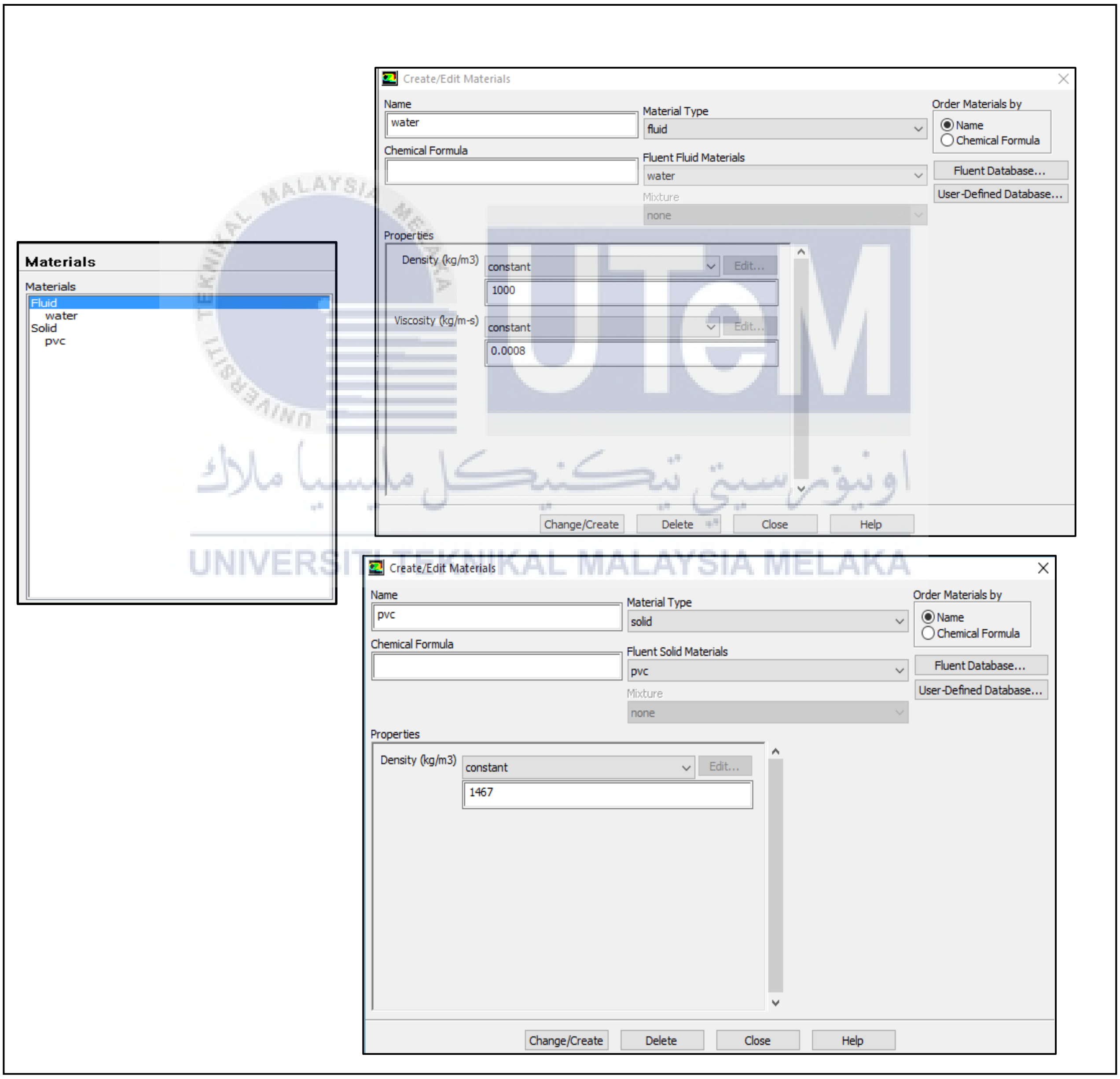


Figure 4.15: Material set up in ANSYS workbench

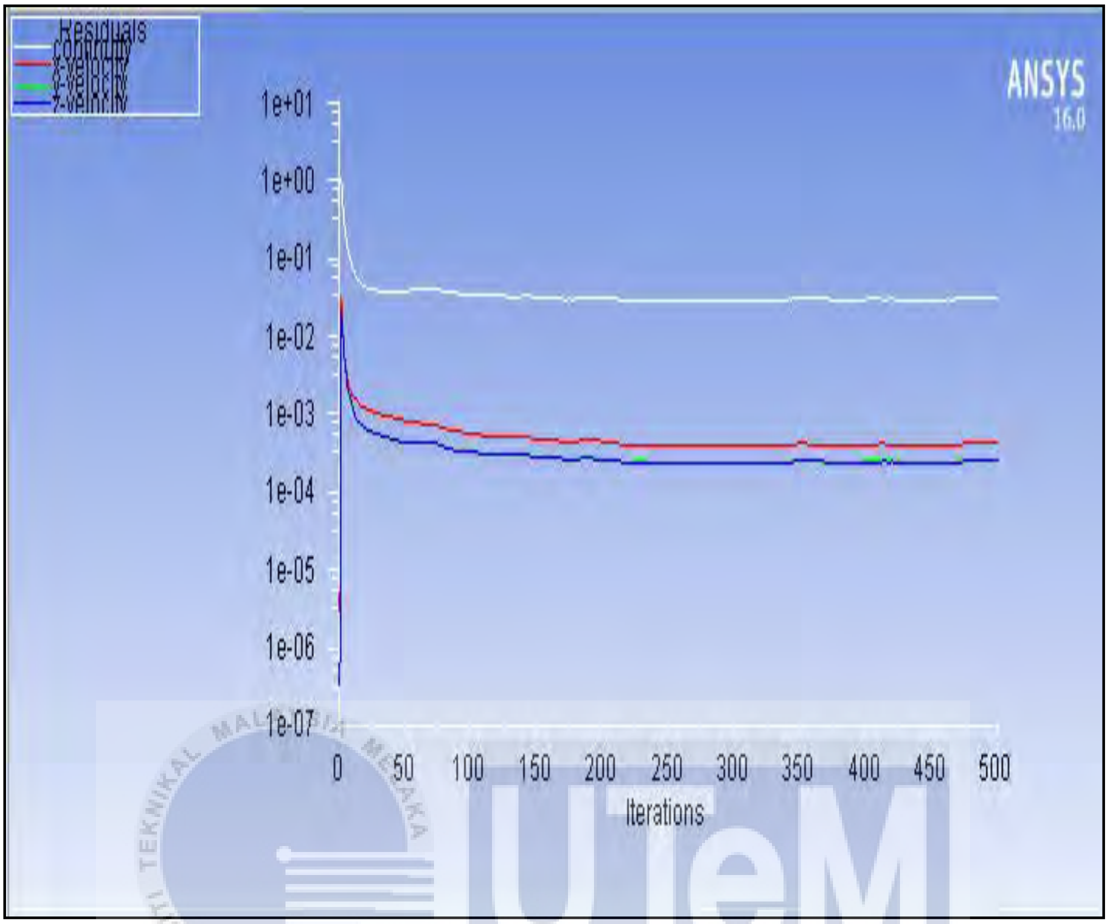


Figure 4.16: The iterations on the 3D modelling.

One of the first indicators that your simulation calculation is progressing on the right path is through monitoring the convergence of the iteration. The different color plots shows the convergence rate of each solved equation, all these tools help the user to quickly identify. Convergence of simulation is achieved after a number of time steps. Iteration means the act of repeating a process with the aim of approaching a desired goal, target or result, so that leads us to asking what is the desired goal? that is specified by the researcher on how many zeros he wants to see after a dot meaning 0.00000....., that would require a reasonable amount of allocated software depending on the wanted accuracy. In this project the number alteration is set to be 500 times. Therefore the accuracy of this project had been calculated 500 times to ensure that the data and analysis are more accurate.

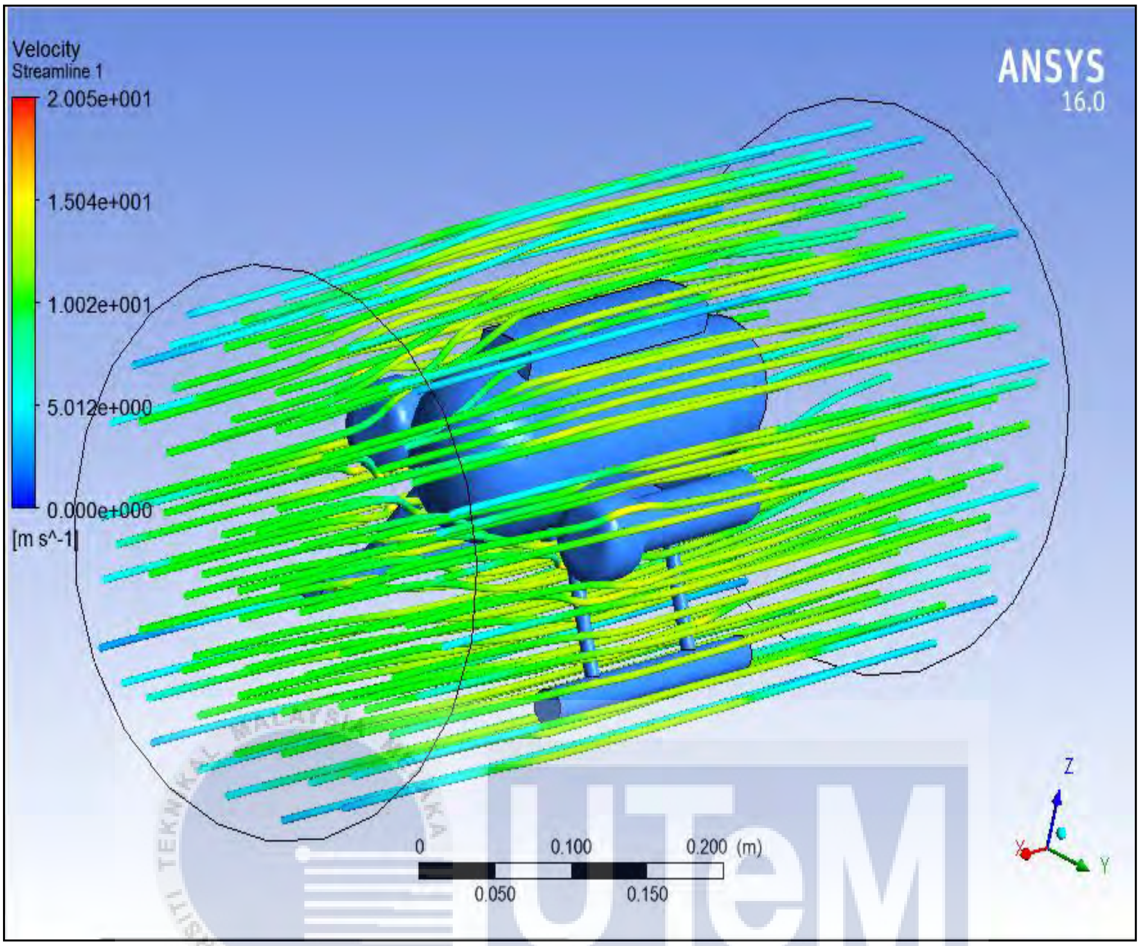


Figure 4.17: The velocity streamline on rough 3D modelling.

Figure 4.17 shows that the velocity distribution along the surface of the robot. From the data collected, the minimum value of velocity distribution is 0 m/s meanwhile the maximum value were 20.05 m/s. from the streamlines shows in the analysis there were no maximum streamline which is red in colour. The highest velocity distribution that can be seen was the yellow colour. And the lowest was the light blue. Therefore, the maximum value of velocity distribution was 15.04 m/s and the minimum value is 5.012 m/s. from the result in figure 15, the highest path created along the main body and the side lamp. When the path line contact the surface of the robot, it will be deflated and create a higher amount of velocity distributed along the surface.

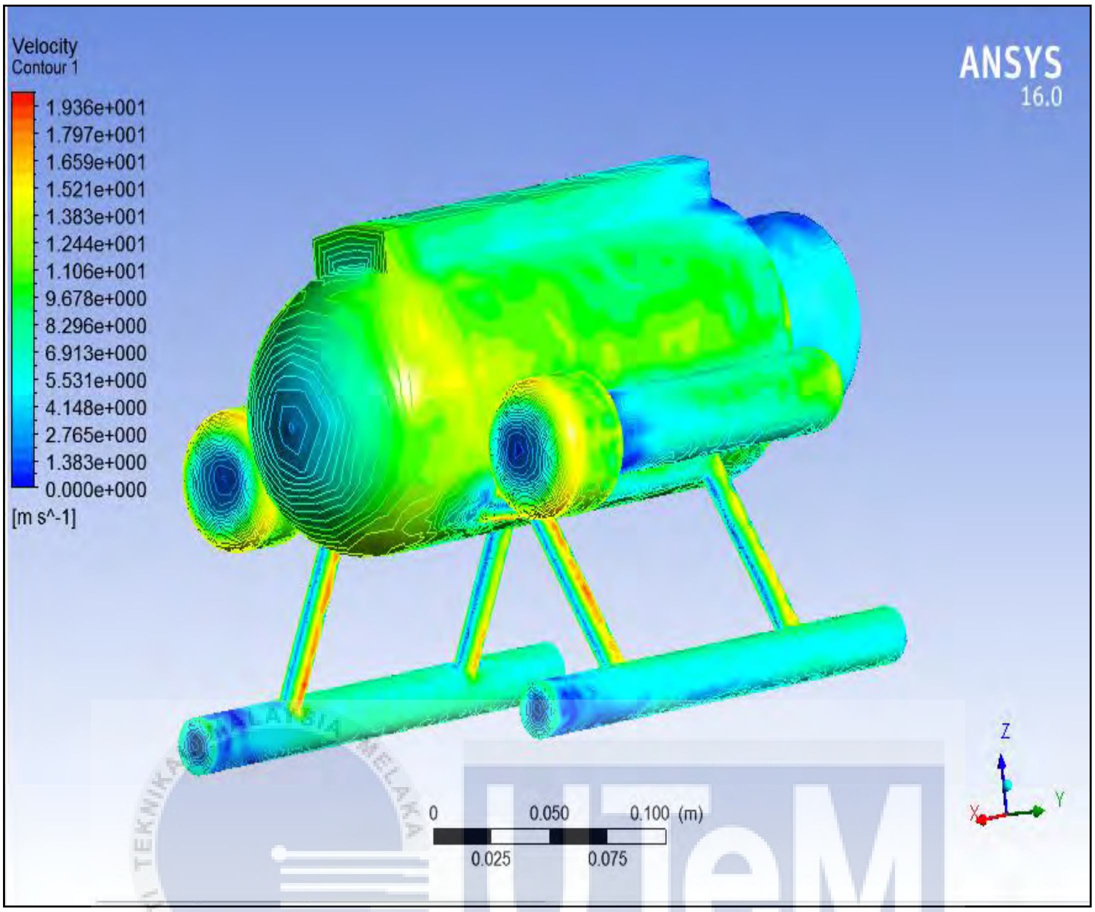


Figure 4.18: Velocity contour on the 3D modelling.

The velocity contour form the figure above shows that the velocity distribution that acts on the robot surface. The pressure is show on the form of contour on the surface of the robot body and the contour is set to be drawn as smooth shading. Therefore the whole pressure can be seen. The red colour present the highest number of pressure and the blue colour present the lowest value of pressure. There was a slight red region found under the robot on the bottom surface of the robot base. The other surface didn't have the same amount of velocity distribution as the bottom base robot surface. The maximum value collected was 19.36 m/s and the lowest were 0 m/s.

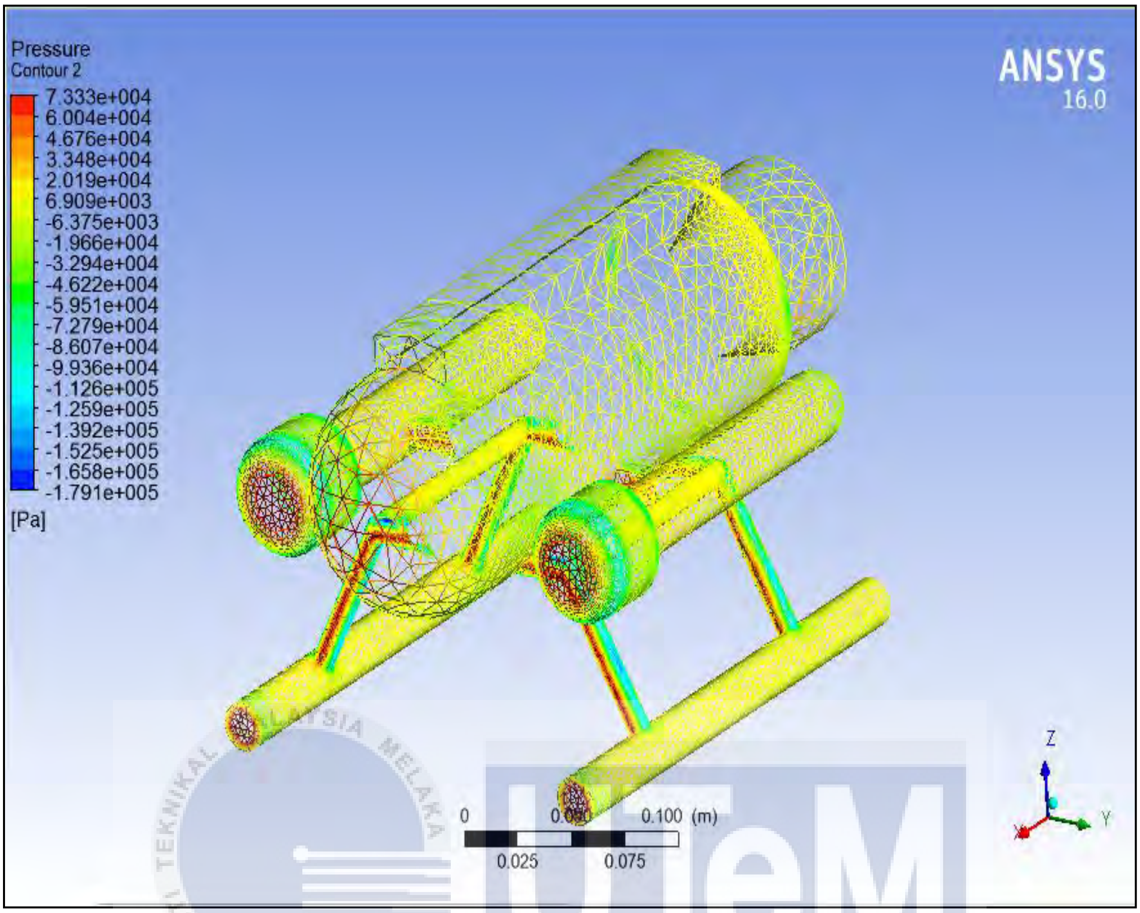


Figure 4.19: Pressure contour on the 3D modelling.

Figure 4.19 shows the pressure act on the robot body when the body is place underwater. The pressure is show on the form of contour on the surface of the robot body and the contour is set to be drawn as lines. Therefore the whole pressure can be seen. The red colour present the highest number of pressure and the blue colour present the lowest value of pressure.The maximum value from the analysis is 6.462e+004 pa and the minimum value of pressure is -1.791e+005 pa. From the data collected and figure 17, the highest pressure distributed was red in colour. From the figured the reddest region was on the contact surface of the robot. This is because the red regions on the surface were the surface that makes a direct contact with the water flow.

4.9.2.2 Analysis on Propeller structure

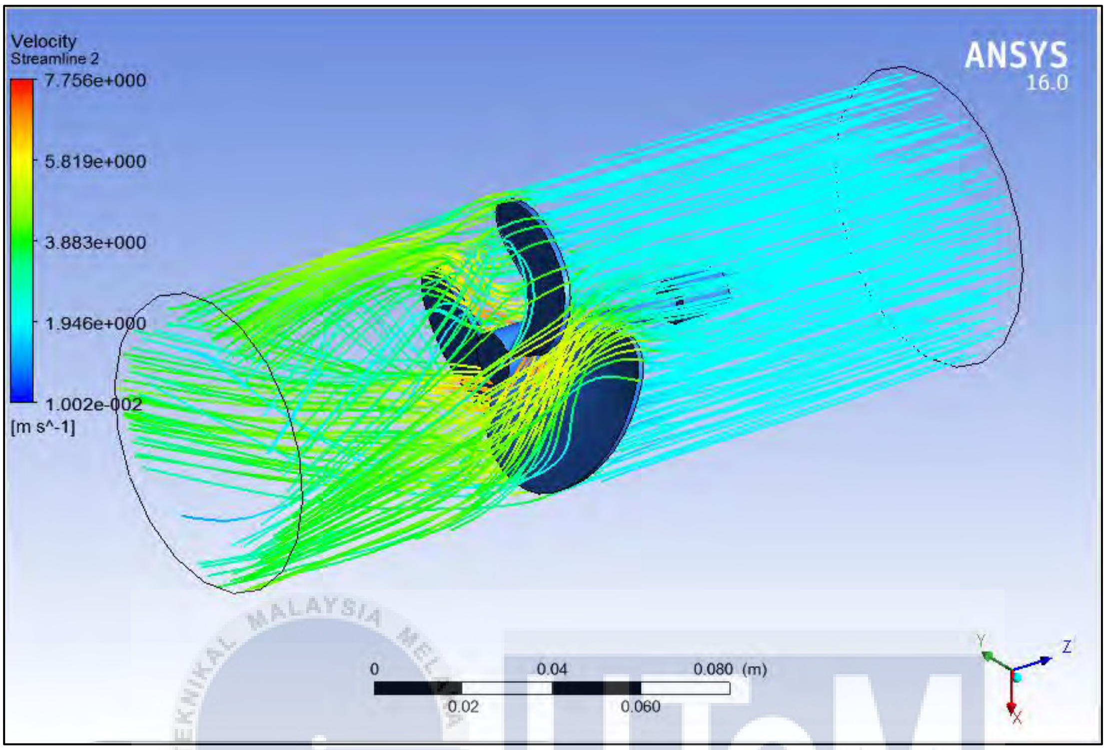


Figure 4.20: The velocity streamline on propeller 3D model.

From the figure above, shows that the velocity distribution along the propeller fan. From the data collected, the minimum value of velocity distribution is 0.01 m/s meanwhile the maximum value were 7.756 m/s.. The highest velocity distribution that can be seen is in red in colour. And the lowest was the blue colour. From the rotation of the propeller, the velocity distribution act the highest was between the blades. This is due to the deflection of water after making the contact on the propeller blade.

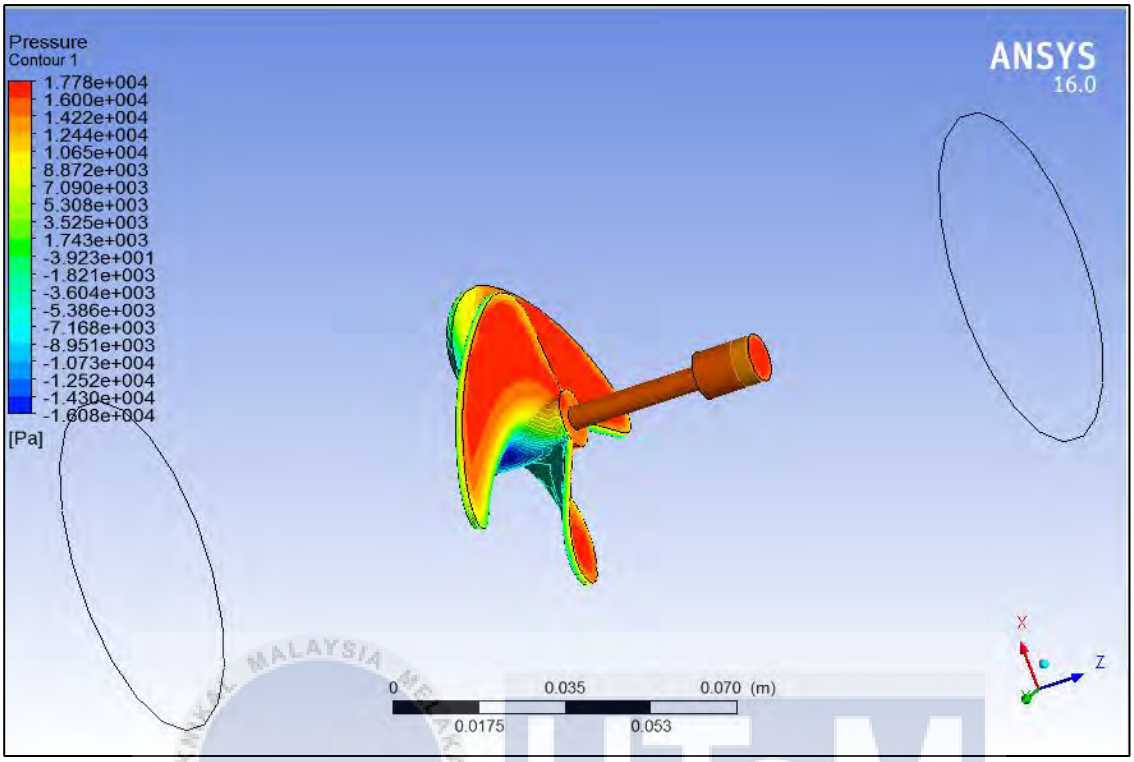
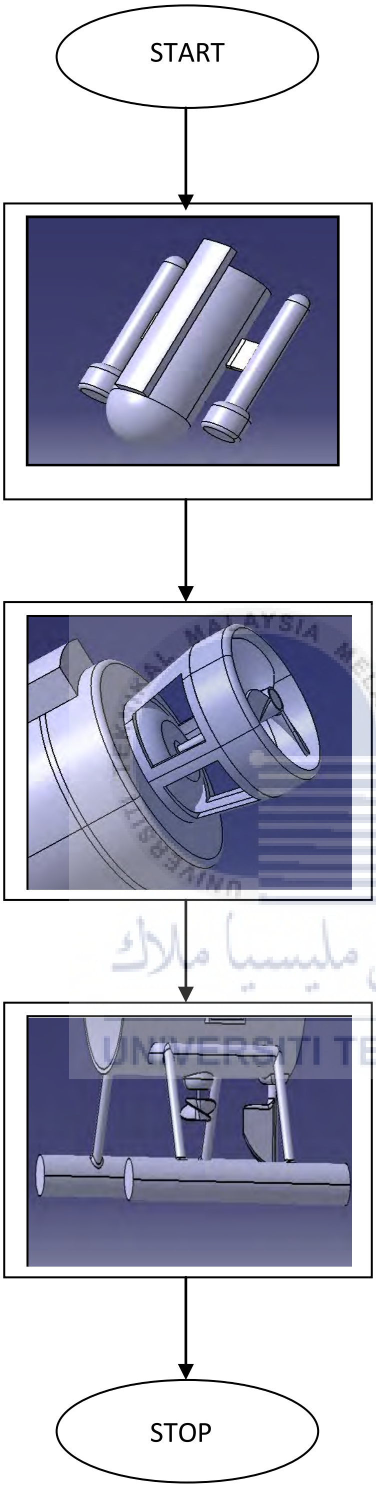


Figure 4.21: Pressure contour on the propeller 3D model.

Figure 4.21 shows the pressure distributed along the propeller when the body moves underwater. The maximum value from the analysis is 17780 pa. From the data collected and figure 17, the highest pressure distributed was red in colour. From the figured the reddest region was on from the inlet flow which contact surface of the propeller first. This is because the red regions on the surface were the surface that makes a direct contact with the water flow.

4.10 MANUFACTURING PROCESS



1) BODY
    - Side Light
    - Main Body
    - Front Head

2) BACK
    - Propeller Engine 1
    - Back Cap
    - Propeller Cover

3) UNDER BODY
    - Propeller Engine 2
    - Propeller
    - Paddle
    - Base
    - Paddle Engine

4.11 MANUFACTURING COMPONENT.

4.11.1 Control System

Control system is made as simple as it can so that the maintenance phase can be done easily. The basic of circuit is made base on the control car toy system. The control system is not embedded inside the robot main body, therefore the maintenance work can be easily done. The control system is easy to assemble and dissemble because the control system is foreign made from the main body of the robot. The robot movement can be control by using a joystick that connected to the control system.

4.11.2 Engines

The engine which drive the propellers and the paddle are by using 6V motor. The motor are connected to the control system. The motors use for the movement of the inspection robot underwater.

4.11.3 Driving component.

The movement of the robot are being drive by two propellers and a single paddle. The propeller are connected to the back engine and the under engine for the movement of up and down and forward and backward. As for the paddle, it controls the right and left movement of the robot.

4.11.4 Robot vision.

The inspection robot is installed with a camera as for the vision underwater. The camera use for this robot is the webcam camera that can be found in any computer store in a very affordable price. The camera is placed in front of the robot body and it will be connected directly to the main display.

4.11.5 Power supply

The control system and the engine are powered by a 6V battery. The battery will be connected directly to the control system to power all the components. The power supply is not embedded inside the robot body. The power supply will only be connected by a long wire to connect to the control system inside the main body of the robot.

CHAPTER V

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

For the conclusion, the main objective is to design a modular underwater inspection robot that easy to be operated and manufactured based on the simple design of every important aspect. From the first stage of this project which is conceptual design, there are four concept designs was generated by hand sketching. Before a concept was generated, there were targeted objective set as the guide line of generating concepts. These concepts were evaluated in many important criteria to make the final concept selection. Some major criteria were given more weight in the evaluation process. Designing of underwater inspection robot often requires a designer to consider the criteria of good design such as surface shape , functional, easy to fabricate and many other aspects of an object or a process, which usually requires considerable research, thought, modeling, interactive adjustment, and re-design. This project covered the structure 3D modeling, applying CAD operation on 3D rough modeling; generate 3D detail modeling, product structure tree, manufacturing process and manufacturing detail. The drawing process is by using engineering software, CATIA V5R21. After the 3D modeling had completed the 3D model then been analyze in engineering software, ANSYS workbench 17.0. In ANSYS, the velocity and pressure of the inspection robot are been calculated and simulated. The data is been visualize in the report. Basically, this underwater inspection robot is build to minimize the cost and the maintenance work. Therefore the design are created as simple as it can while it can function as the expensive one.

5.2 RECOMMENDATION

It is recommended that the laboratory should provide more measuring equipment such as force measurement. It is also recommended to use different material to reduce manufacturing cost. There were lots of rooms of improvement need to be done to improve the product. For example, the movement mechanism of the robot for the right and left can be transfer from using paddle to using a new pair of propeller. This will ensure the turning point of the robot more effective and consistent. Suggestion for new candidates to improve this project and to innovate the product to become better.

REFERENCES

Azis, F.A, Aras, M. S. M, Rashid, M.Z.A, Othman M. N, and Abdullah, S.S, Department of Mechanical, Faculty of Technology Engineering, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka Malaysia.

Ciszewski Michał, Buratowski Tomasz, Giergiel Mariusz, Kurc Krzysztof,d, and Małka Piotr. Mobile Inspection Robot. University of Science and Technology, Poland.

D. J. Christensen, J. C. Andersen, M. Blanke, L. Furno, R. Galeazzi, P. N. Hansen and M. C. Nielsen. Collective Modular Underwater Robotic System for Long-Term Autonomous Operation. Technical University of Denmark.

Edwin Dertien (2014). Design of an inspection robot for small diameter gas distribution mains: Department of Electrical Engineering, Math and Computer Science at the University of Twente,

Fei Yanqiong and Song Libo (2008). Design and Analysis of Modular Mobile Robot with Magnetic Wheels. Research Institute of Robotics,Shanghai Jiaotong University, Shanghai. China.

Gabriel Martos, Ashley Abreu, Sahivy Gonzalez and Andres Tremante (2013). Remotely Operated Underwater Vehicle(ROV). Florida International University.

Howard H. Wang, Stephen M. Rock, and Michael J. Lee. Otter: The Design And Development Of An Intelligent Underwater Robot. Department Of Aeronautics And Astronautics, Stanford University.

Junichi Akizono, Mineo Iwasaki, Takashi Nemoto and Osamu Asakura (1978). Filed Test of Aquatic Walking Robot for Underwater Inspection. Port And Harbor Research Institute, Yokosuka, Japan.

J. YUH (2000). Design and Control of Autonomous Underwater Robots: A Survey. University of Hawaii, Honolulu, Hawaii

Kentarou. Nishijima, Yixiang. Sun, Rupesh Kumar. Srivastava, Harutoshi.Ogai1 and Bishakh. Bhattacharya (2010). Advanced pipe inspection robot using rotating probe. *Waseda* University, Japan.

Louis L. Whitcomb (2000) . Underwater Robotics: Out Of The Research Laboratory And Into The Field. Department of Mechanical Engineering, Johns Hopkins University.

Robin Bradbeer, Stephen Harrold, Frank Nickels and Lam F Yueng (2014). An Underwater Robot for Pipe Inspection. Department of Electronic Enginnering City University of Hong Kong.

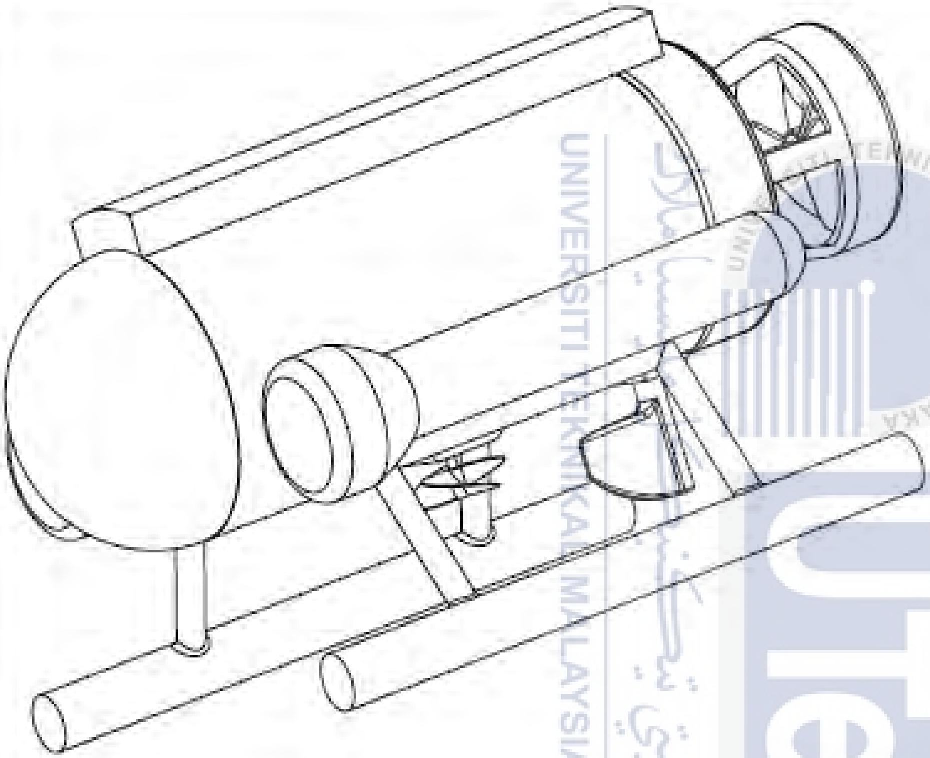
APPENDICES A&B

APPENDIX A

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														

Week / Activities	PSM II (GANTT CHART)													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Concept selection														
Detail design														
CAD drawing														
Material selection														
Design analysis														
Data collection														
Model fabrication														
Report writing														
Report submission														
Seminar II presentation														

APPENDIX B



Isometric view
Scale: 1:2

Recapitulation of:
Inspection Robot
Different parts: 10
Total parts: 11

Quantity	Part Number
1	Body
2	Side lamp
1	Back
1	Front Head
1	Base
1	Engine Fan
1	Under enngine
1	Engine Finn
1	Under engine fan
1	Finn

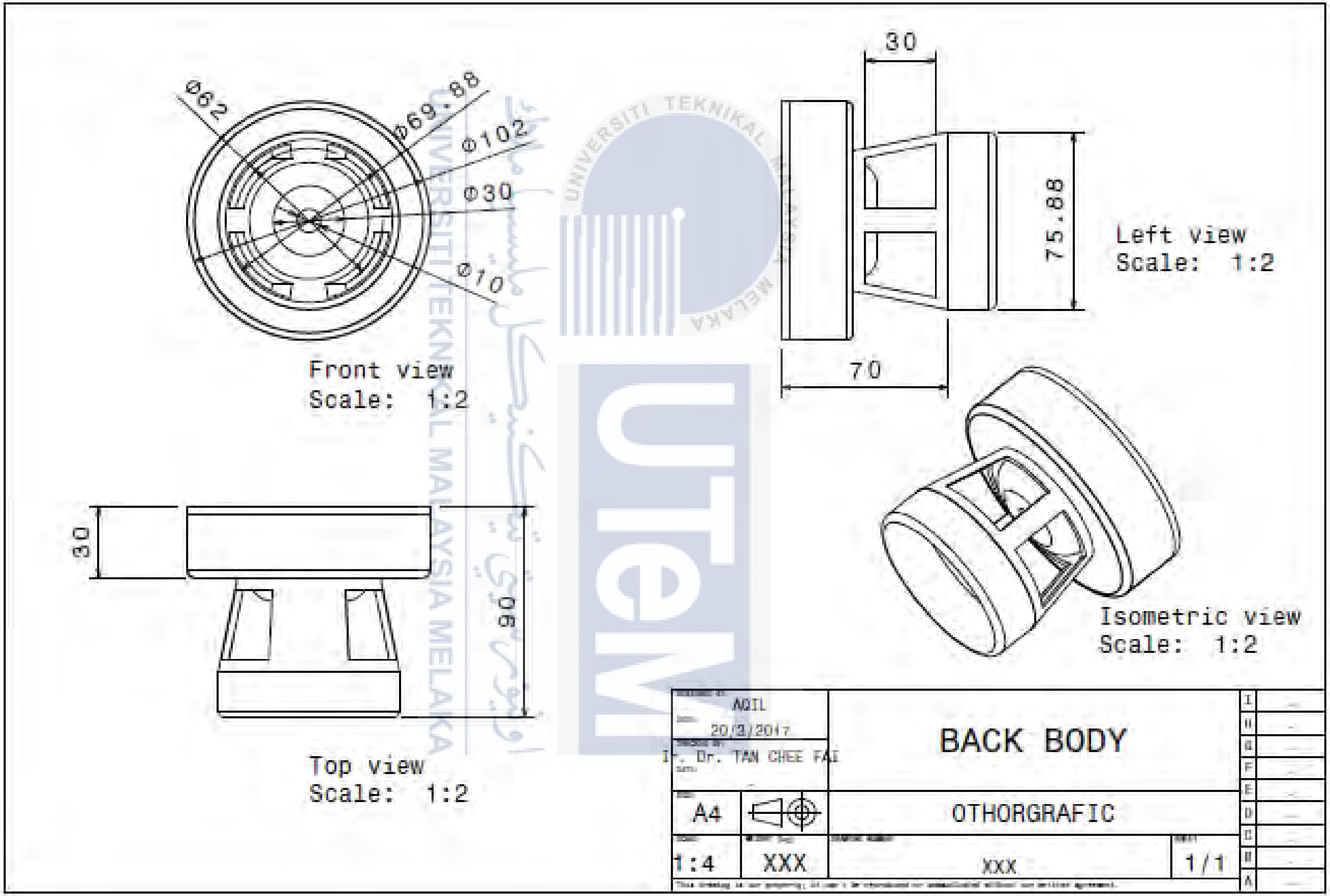
AQIL
20/3/2017
Ir. Dr. TAN CHEE FAI

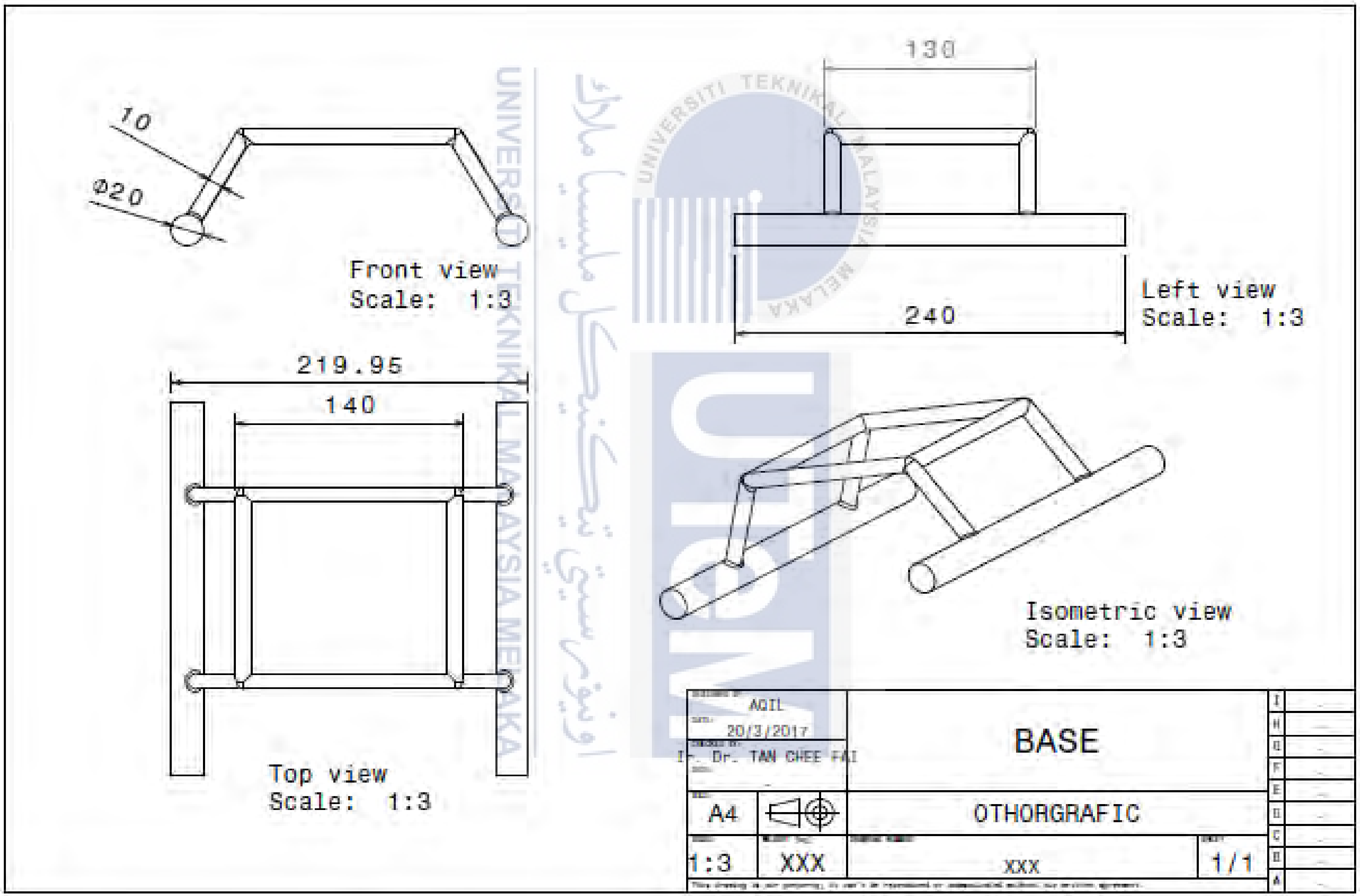
INSPECTION ROBOT

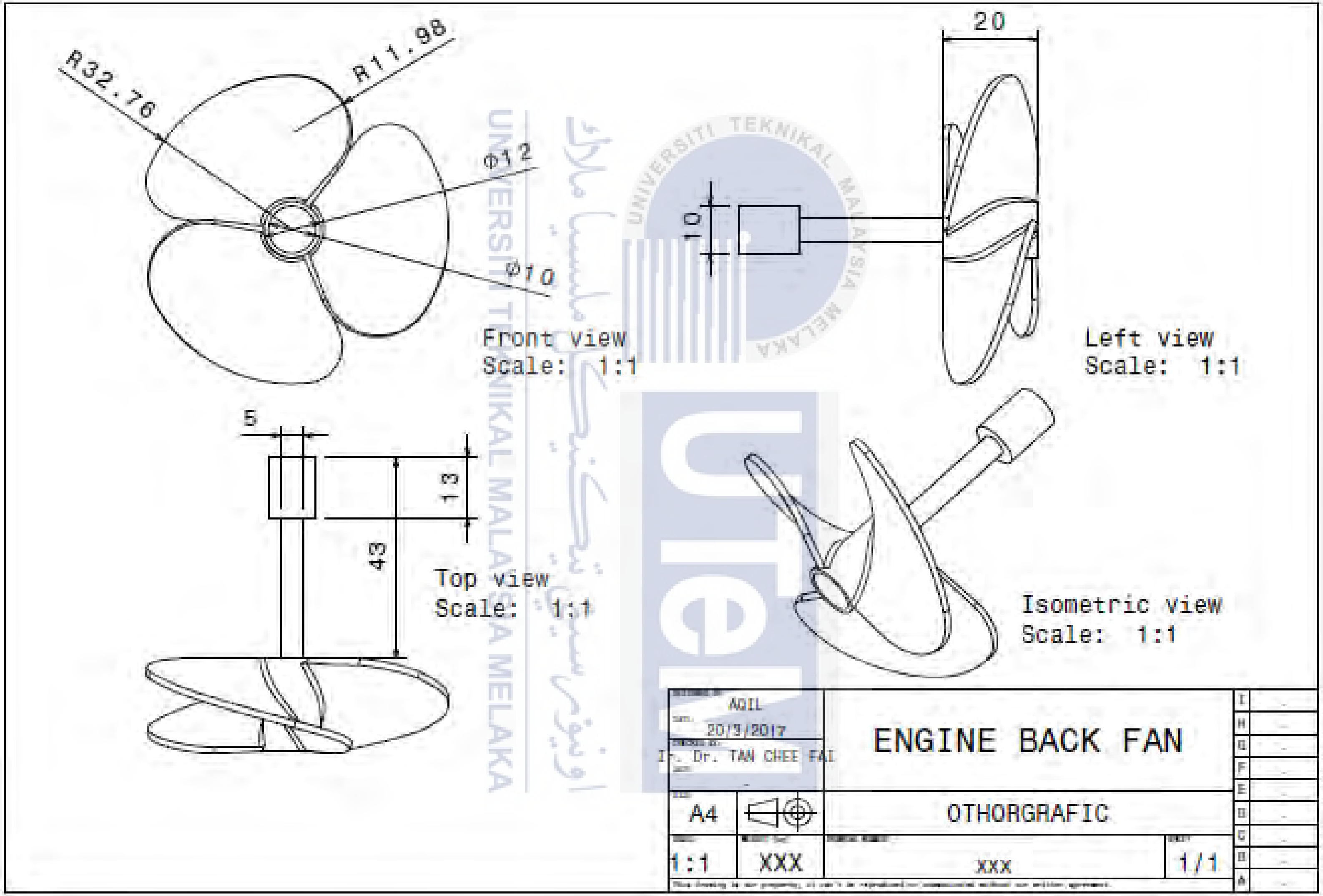
A4

BILL OF MATERIAL

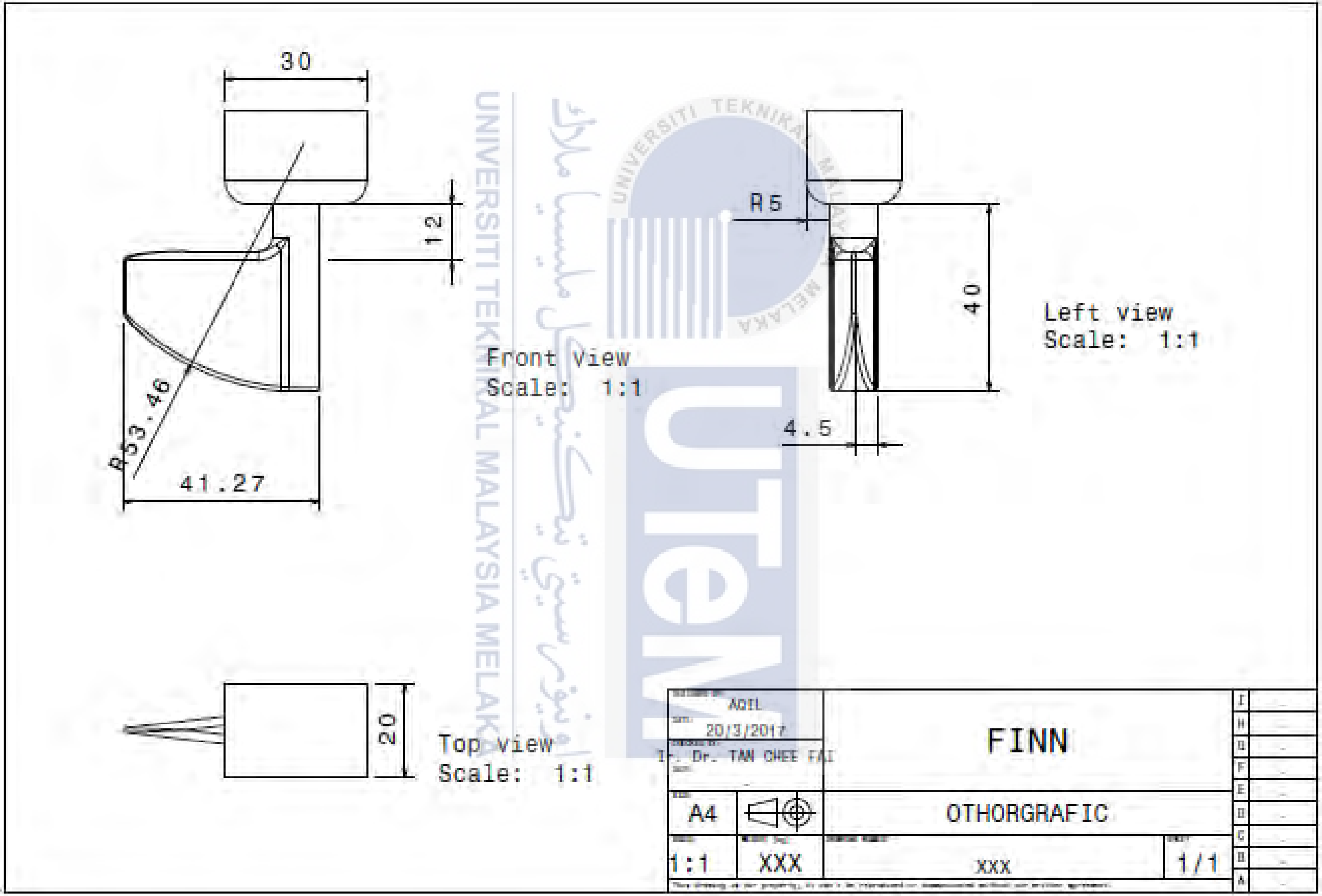
1:2 XXX XXX 1/1

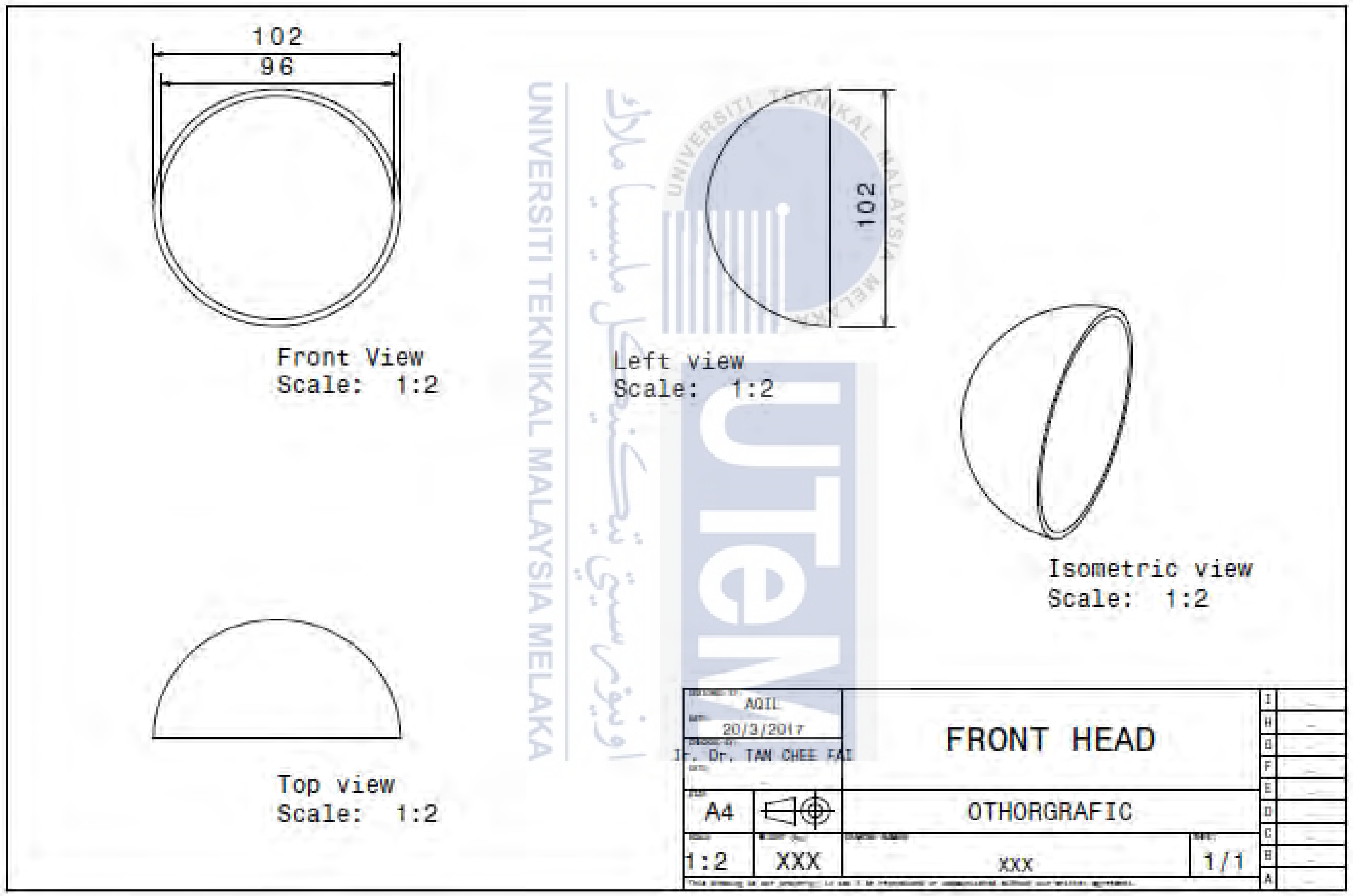

Ø62
Ø69.88
Ø102
Ø30
Ø10
Front view
Scale: 1:2
30
75.88
70
Left view
Scale: 1:2
30
90
Top view
Scale: 1:2
Isometric view
Scale: 1:2
AQIL
20/3/2017
Ir. Dr. TAN CHEE FAI
BACK BODY
A4
OTHORGRAFIC
1:4
XXX
XXX
1/1


10
Ø20
Front view
Scale: 1:3
130
240
Left view
Scale: 1:3
219.95
140
Top view
Scale: 1:3
Isometric view
Scale: 1:3
AQIL
20/3/2017
Ir. Dr. TAN CHEE FAI
BASE
A4
OTHORGRAFIC
1:3
XXX
XXX
1/1

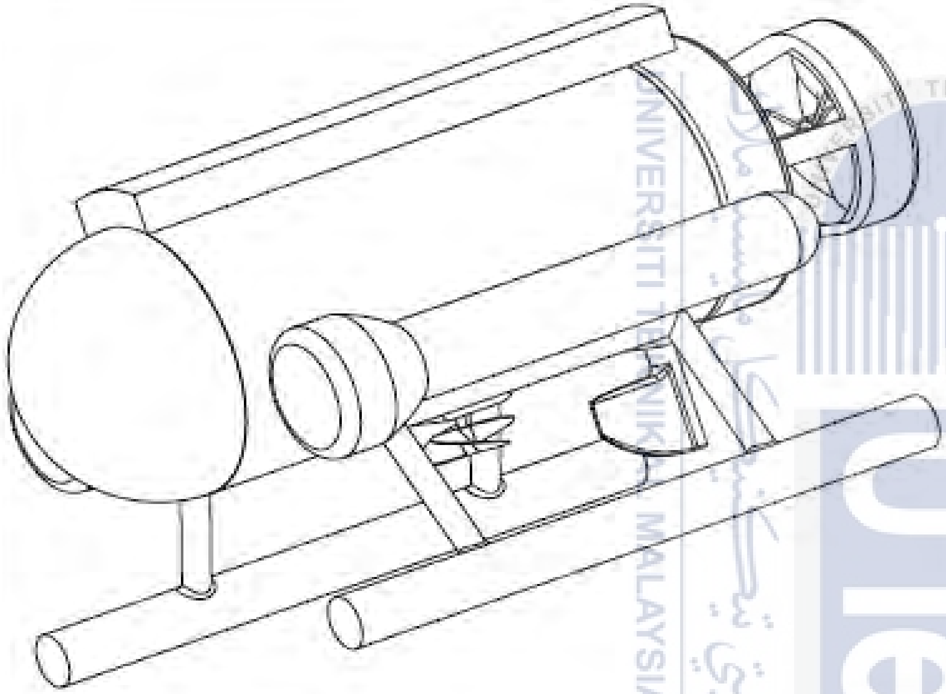


R32.76
R11.98
Φ12
Φ10
Front view
Scale: 1:1
10
20
Left view
Scale: 1:1
5
13
43
Top view
Scale: 1:1
Isometric view
Scale: 1:1
AQIL
20/3/2017
Ir. Dr. TAN CHEE FAI
ENGINE BACK FAN
A4
OTHORGRAFIC
1:1
XXX
XXX
1/1
I
H
G
F
E
D
C
B
A


30
12
R53.46
41.27
Front view
Scale: 1:1
R5
40
4.5
Left view
Scale: 1:1
20
Top view
Scale: 1:1
AQIL
20/3/2017
Ir. Dr. TAN CHEE FAI
FINN
A4
OTHORGRAFIC
1:1
XXX
XXX
1/1
I
H
G
F
E
D
C
B
A



102
96
Front View
Scale: 1:2
102
Left view
Scale: 1:2
Isometric view
Scale: 1:2
Top view
Scale: 1:2
AQIL
20/3/2017
Ir. Dr. TAN CHEE FAI
FRONT HEAD
A4
OTHORGRAFIC
1:2
XXX
XXX
1/1
I
H
G
F
E
D
C
B
A



Isometric view
Scale: 1:2

Recapitulation of:
Inspection Robot
Different parts: 10
Total parts: 11

Quantity	Part Number
1	Body
2	Side lamp
1	Back
1	Front Head
1	Base
1	Engine Fan
1	Under enngine
1	Engine Finn
1	Under engine fan
1	Finn

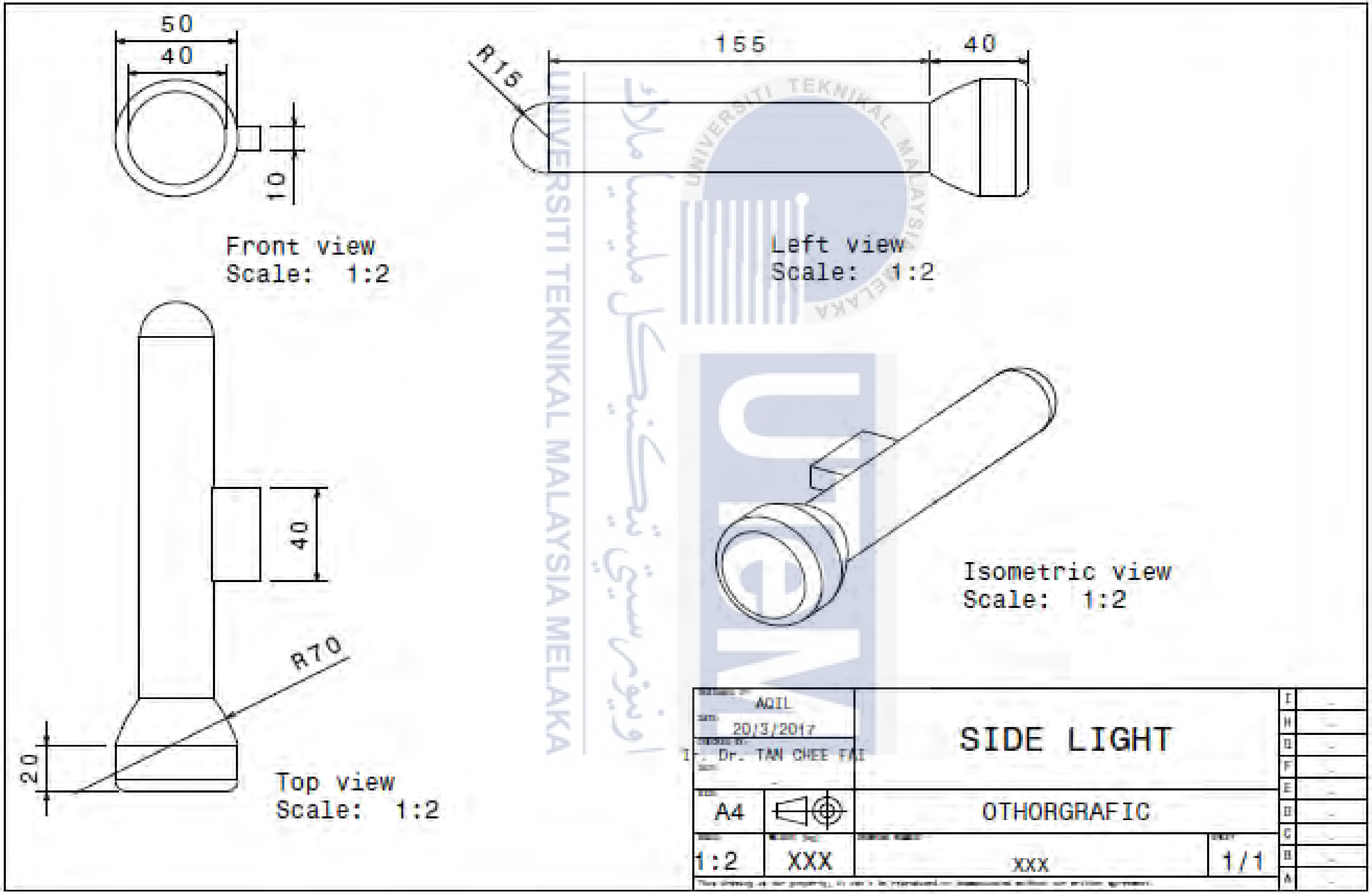
AQIL
20/3/2017
Ir. Dr. TAN CHEE FAI

INSPECTION ROBOT

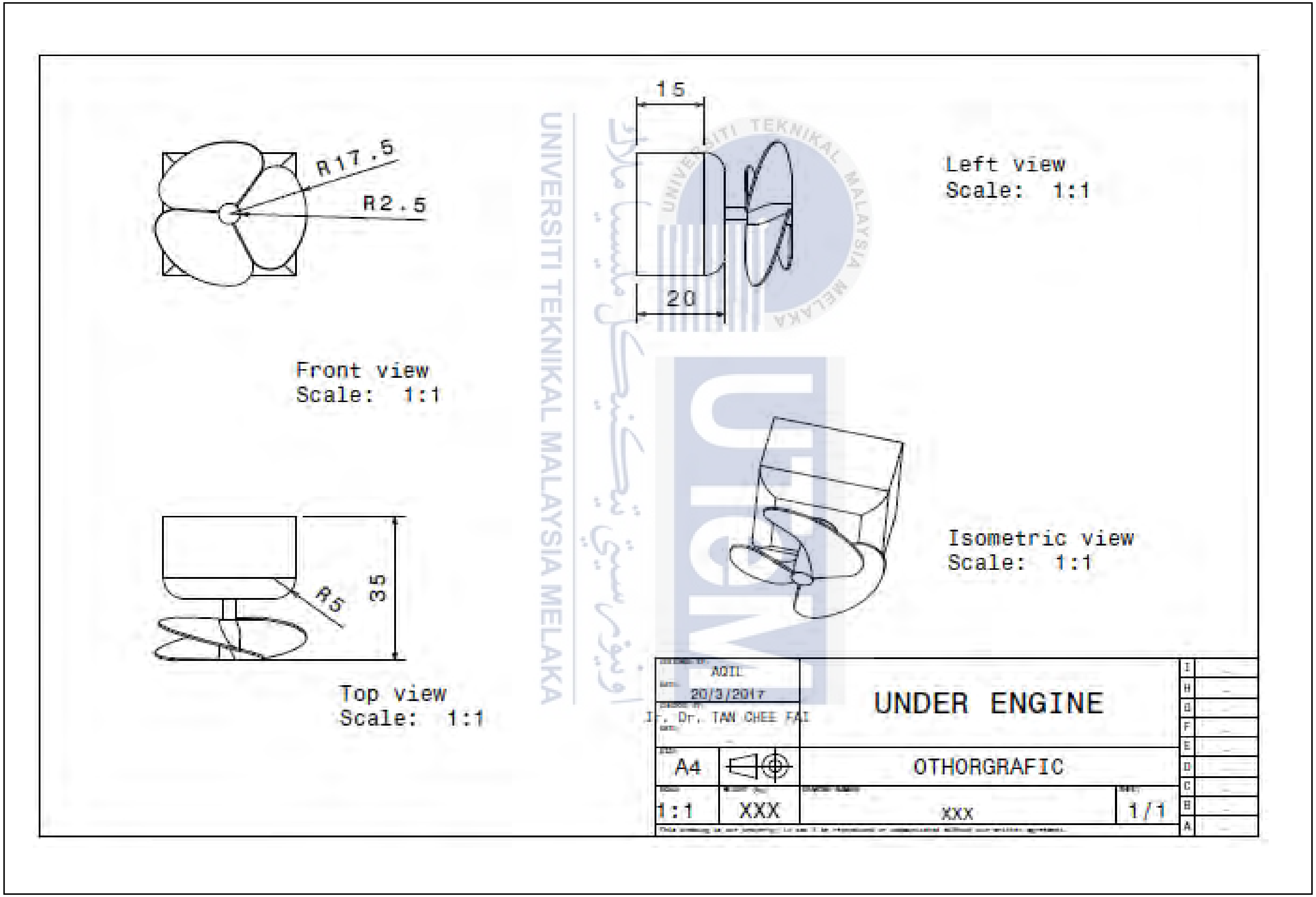
A4

BILL OF MATERIAL

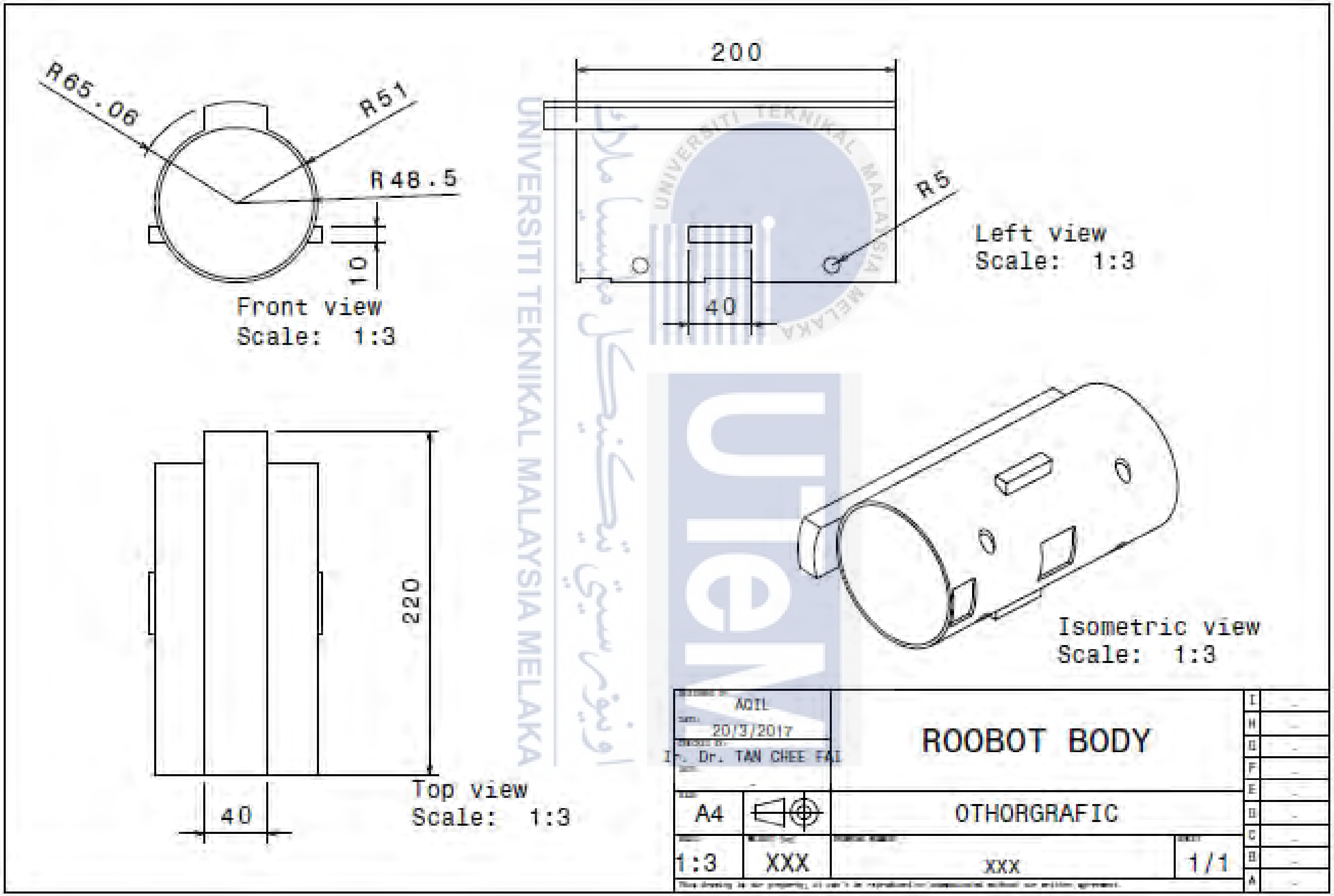
1:2 XXX XXX 1/1



50
40
10
Front view
Scale: 1:2
R15
155
40
Left view
Scale: 1:2
40
R70
20
Top view
Scale: 1:2
Isometric view
Scale: 1:2
AQIL
20/3/2017
Ir. Dr. TAN CHEE FAI
SIDE LIGHT
A4
OTHORGRAFIC
1:2
XXX
XXX
1/1
I
H
G
F
E
D
C
B
A



R17.5
R2.5
Front view
Scale: 1:1
15
20
Left view
Scale: 1:1
R5
35
Top view
Scale: 1:1
Isometric view
Scale: 1:1
AQIL
20/3/2017
Ir. Dr. TAN CHEE FAI
UNDER ENGINE
A4
OTHORGRAFIC
1:1
XXX
XXX
1/1
I
H
G
F
E
D
C
B
A


R65.06
R51
R48.5
10
Front view
Scale: 1:3
200
R5
40
Left view
Scale: 1:3
220
40
Top view
Scale: 1:3
Isometric view
Scale: 1:3
AQIL
20/3/2017
Ir. Dr. TAN CHEE FAI
ROOBOT BODY
A4
OTHORGRAFIC
1:3
XXX
XXX
1/1
I
H
G
F
E
D
C
B
A