Faculty of Mechanical Engineering

THE DEVELOPMENT OF UNDERWATER MANIPULATOR FOR MINI-ROV APPLICATION

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Bachelor of Mechanical Engineering

2018

THE DEVELOPMENT OF UNDERWATER MANIPULATOR FOR MINI-ROV APPLICATION

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A thesis submitted
in fulfilment of the requirements for the Degree of Mechanical Engineering

Faculty of Mechanical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2018

DECLARATION

I declare that this project report entitled "The Development of Underwater Manipulator for Mini-ROV Application" is the result of my own work except as cited in the references.

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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.

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Date : 16/01/2019

ABSTRACT

Manipulator is an important tool for remotely operated vehicle (ROV) to perform various tasks such as picking up object from the ocean bed, grasping and transferring equipment underwater and joining parts. This paper presents the designing and development of underwater manipulator for BlueROV2 application. This study also aimed to conduct a testing of manipulator in the water. The details design of manipulator are developed by using CATIA software. The characteristics of new design of manipulator are low cost, low complexity of structure, high portability, ease of handling and ease to manufacture. The position of manipulator on the BlueROV2 is at the center that under the vehicle (inside of Payload Skid). The center position of manipulator can vertically align the center of buoyancy and the center of gravity thus balance the vehicle. This paper also presents the determination of the gripping force of the gripper by using different mass of load. As the mass of load increase, the gripping force is also increase. In addition, the testing results also show low coefficient of friction causes the high force is required to grasp the object by gripper. The maximum gripping force of gripper is obtained in this paper. The testing result based on functionality of manipulator in water is presented. The manipulator is able to grasp and hold the load in water without continuous force generated by motor. The design of finger of gripper enable the manipulator to reach the load at the corner and perform the grasping task underwater successfully.

ABSTRAK

Manipulator merupakan alat yang penting untuk kenderaan beroperasi jarak jauh (ROV) untuk melaksanakan pelbagai tugasan seperti mengambil objek dari katil lautan, menggenggam dan memindahkan peralatan di dalam air dan menyambungkan bahagian. Kertas ini membentangkan reka bentuk dan pembangunan manipulator untuk aplikasi BlueROV2 di dalam air. Kajian ini juga bertujuan untuk melakukan pengujian manipulator di dalam air. Reka bentuk manipulator dikembangkan dengan menggunakan aplikasi CATIA. Ciri-ciri reka bentuk manipulator baru adalah kos rendah, kerumitan struktur yang rendah, mudah untuk dialihkan, mudah untuk mengendalikan dan mudah untuk menghasilkan. Kedudukan manipulator pada BlueROV2 adalah di tengah-tengah di bawah kenderaan (di dalam Payload Skid). Kedudukan manipulator di tengah-tengah adalah untuk menegak pusat keapungan dan pusat graviti secara vertikal supaya mengimbangi kenderaan. Kertas ini juga membentangkan penentuan daya mencengkam penggenggam dengan menggunakan jisim objek yang berlainan. Apabila jisim objek meningkat, daya mencengkam juga meningkat. Di samping itu, keputusan ujian juga menunjukkan pekali geseran yang rendah menyebabkan daya tinggi diperlukan untuk mencengkam objek oleh penggenggam. Kekuatan gripper maksimum telah diperolehi dalam kertas ini. Hasil ujian berdasarkan fungsi manipulator di dalam air dibentangkan. Manipulator dapat mencengkam dan menahan objek dalam air tanpa daya yang berterusan yang dihasilkan oleh motor. Reka bentuk jari penggenggam membolehkan manipulator menyentuh objek di sudut dan berjaya melaksanakan tugas menggenggam objek di dalam air.

ACKNOWLEDGEMENTS

I am grateful and would like to express my sincere gratitude to my supervisor, Dr. Ahmad Anas Bin Yusof for his invaluable guidance, continuous encouragement and constant support in making this project possible. I really appreciate his guidance from the initial to the final level that enabled me to develop an understanding of this project thoroughly. Without his advice and assistance, it would be a lot tougher to completion. I also sincerely thanks for the time spent proofreading and correcting my mistakes.

I acknowledge my sincere indebtedness and gratitude to my parents for their love, dream and sacrifice throughout my life. I am really thankful for their sacrifice, patience, and understanding that were inevitable to make this work possible. Their sacrifice had inspired me from the day I learned how to read and write until what I have become now. I cannot find the appropriate words that could properly describe my appreciation for their devotion, support and faith in my ability to achieve my dreams.

Lastly, I would like to thanks any person which contributes to my final year project directly or indirectly. I would like to acknowledge their comments and suggestions, which was crucial for the successful completion of this study.

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LIST OF ABBEREVATIONS

UVMS	Underwater Vehicle Manipulator System
ROV	Remote Operated Vehicle
DOF	Degree of Freedom
PVC	Polyvinyl Chloride

LIST OF SYMBOLS

ρ	=	Density
μ	=	Coefficient of friction

CHAPTER 1

INTRODUCTION

1.1 Background

Nowadays, the underwater vehicles which is considered as useful and efficient equipment are widely utilized in underwater exploring and research. Unmanned underwater vehicles, can be addressed as UUVs, are unoccupied underwater vehicles that are able to submerge underwater without the occupying of a human physically. These underwater vehicles may be divided into two main categories: Remotely Operated Vehicles (ROVs) and Autonomous Underwater Vehicles (AUVs).

Remotely Operated Vehicle (ROV) is used in this study and the type of ROV used is BlueROV2. The BlueROV2 as shown in Figure 1.1 is the world's most affordable high-performance ROV. It consists of the 6-thruster vectored configuration and strong static stability which ensure the vehicle smooth, stable and highly maneuverable. It is able to navigate to a standard 100m and up to 300m depth. The whole rig weighs about 22 lb (10 kg) in the air, provided a 100-m tether adds around 10 lb (4.5 kg) depending on the intensity of use (BlueRobotics, n.d.).

Figure 1.1: BlueROV2 (BlueRobotics, n.d.)

The underwater vehicle can only perform various survey tasks when equipped with underwater manipulator (UWM). Manipulator is defined as arm-like mechanism on a robotic system. It is composed of revolute and prismatic joints, as well as other mechanism such as slider, that can move and manipulate objects under human control (Ya'akob, 2010). With the manipulator, the underwater vehicle are able to perform various tasks such as picking up object from the ocean bed, grasping and transferring equipment underwater, joining parts and even part assembly.

In this study, the manipulator is designed to be fixed on BlueROV2. This is due to there is no manipulator for BlueROV2 to perform grasping task underwater. The manipulator is designed by modifiying the robot arm trainer [model is MR-999CP] as shown in Figure 1.2. The robot arm trainer is comprised of five main components which are gripper, wrist, elbow, shoulder and base arm. It is capable to perform a lot of works with high flexibility of movement (EK JAPAN, 2008).

Figure 1.2: Robot arm trainer [MR- 999R] (EK JAPAN, 2008)

In this project, the gripper of the robot arm trainer is modified and utilised as the manipulator for BlueROV2. The gripper is able to open and close its finger up to 50 mm. The gripper is fixed with the semi-transparent arm and LED lights. During operation, the LED light attached on gripper will light up. This will be useful for users to observe its arm movement clearly when it is used in shallow water.

The underwater manipulator is helpful for human as no direct contact with the items underwater is required if the items is radioactive and hazardous. It also can control and manipulate materials in inaccessible places. The maximum depth it can reach underwater and the pressure it can withstand definitely better than human. It also can perform better than human from the aspect of visibility underwater. Therefore, the development of underwater manipulator (UWM) is important in the marine science and engineering field.

1.2 Problem statement

Nowadays, the improvement of ROV has been carried out to ensure it consists of multiple function. For the BlueROV2 that sold in the market, it is one type of ROV that required an operator to control its navigation underwater. However, it is a type of ROV without any manipulator. It is unable to perform multi tasks underwater without a manipulator. Therefore, this underwater manipulator project is proposed in order to increase the functionality of BlueROV2.

1.3 Objectives

The objectives of this project are as follows:

1. To design and develop underwater manipulator for mini-ROV application.
2. To conduct the testing in the aspect of functionality for manipulator in water.

1.4 Scopes

The scopes are identified based on the objectives of this project. The scopes are:

1. To design and fabricate a small scale of underwater manipulator for BlueROV2 model.
2. To determine the gripping force of the gripper by using different mass of load.
3. To test the functionality of manipulator in water and to investigate whether it can perform tasks underwater successfully.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction to underwater vehicles

The underwater vehicles can be categorized into two types as shown in figure below: Manned Underwater Vehicles and Unmanned Underwater Vehicles (UUVs). The constant operator attention is needed for ROV with the use of tether or cable for power, video, and controls (Soffar, 2016). The AUV, is free from a tether and can run either a pre-programmed or logic-driven course. Figure 2.1 shows the taxonomy of underwater vehicle.

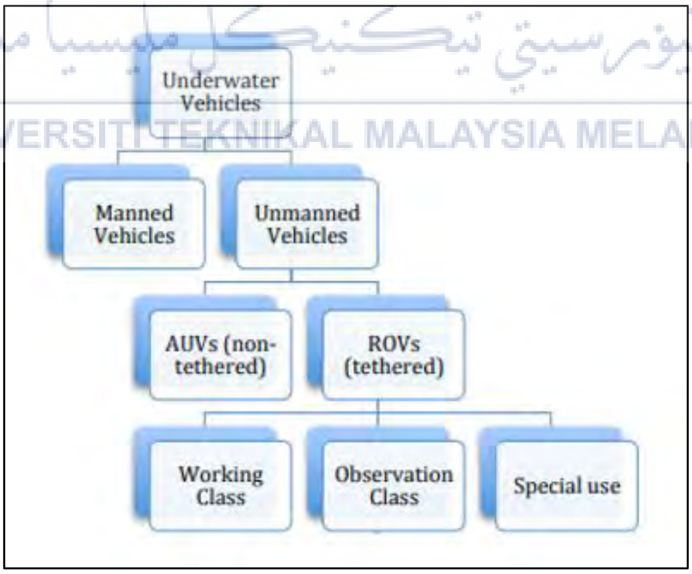


Figure 2.1: Underwater Vehicle Taxonomy (Chris and Wernli, 2007).

2.1.2 Remotely Operated Vehicle (ROV)

A Remotely Operated Vehicle (ROV) is unoccupied and highly maneuverable underwater robot connected with a series of cables to the ship. Generally, there are five types of underwater which are: small electric ROVs, high-capability electric ROVs, general class ROV, work class ROV and heavy class ROV. Different type of ROV has different properties and different application. The remote navigation of ROV is performed by transmitting the command and control signals through cables. The functions of ROV include: search, inspection, equipment repair, scientific analysis, and surveying. If in deep or rough water, the usage of robust umbilical cable of ROV is high. The ROV can be equipped with things such as video camera, lights, sonar systems, an articulating arm and a wide range of sampling options (NOAA, 2018). The limitations of human divers and human-occupied diving vehicles can be overcome by developing the ROV. Figure 2.2 shows one of the small work-class ROV system called COMANCHE.

Figure 2.2: Small work-class ROV system- COMANCHE

2.1.3 Autonomous Underwater Vehicle (AUV)

Autonomous Underwater Vehicle (AUV) is an underwater robot which conducting its survey mission without real-time control from a human operator. AUV is widely used for underwater survey missions. For example, inspection of underwater structure, submarine rescue, underwater exploration. One of the ways of navigation of AUVs is work on a pre-decided route which is programmed in the AUV (Raunekk, 2010). Another ways is AUV navigate through direction provided by the control and command centre. They equipped with various types of sensors, cameras, and spot lights, along with a GPS system. The parameters such as depth, speed and length of the desired target also can be determined by AUV. By using AUV, data is collected along a predetermined route (UST, 2017). It will return to a pre-programmed location when a mission is completed. Figure 2.3 shows an Autonomous Underwater Vehicle (AUV).

Figure 2.3: Autonomous Underwater Vehicle (AUV)

2.1.4 Difference between ROV and AUV

The difference between Remotely Operated Vehicle (ROV) and Autonomous Underwater Vehicle (AUV) is ROV controlled by a remote human operator while AUV operated without operator intervention. An AUV works independently from the ship and no connecting cables is required, whereas cables connection is required for ROV to connect robot and operator.

2.2 Type of ROVs

There are three types of ROVs include: world-class ROVs, observation class ROVs and eyeball class ROVs. Apart from the depth rating, ROVs are typically classified according to their size.

2.2.1 World-class ROVs

It is a large and powerful vehicles and its sizes is up to 2m high and 4m long. Work-class systems generally have large frames with multi-function manipulators. World-class ROVs can be used to perform complex operations and carry large volume of instruments. The maximum depth it achieved is down to 6000 m water depth (Aaron Micallef et al., 2018).

Figure 2.4: The scientific world class ROVs

2.2.2 Observation class ROVs

Observation class ROVs can be addressed as inspection ROVs. Observation-class ROVs are normally a ‘flying eye’ designed specifically for lighter usage with propulsion systems to gather data or take photo by using camera and sensor (Christ and Wernli, 2014). Its smaller size is suitable for video surveys use. Normally it consist of one manipulator arm only. The water depth it can achieved is down to 3000m to 4000m depth.

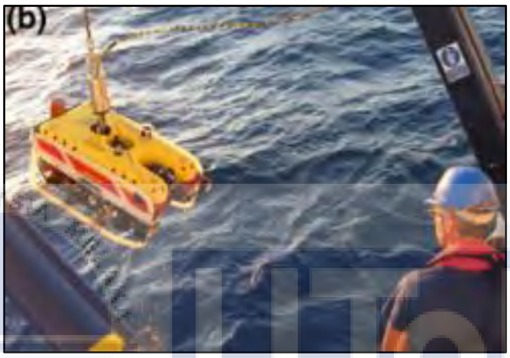


Figure 2.5: Inspection or Observation class ROVs

2.2.3 Eyeball class ROVs

Eyeball class ROVs, also named as mini- and micro- ROVs, are even smaller in size. This type of ROVs are used for inspection work, generally in calm and shallow water. The depth it can access is not more than 200 m (Aaron Micallef et al., 2018).

Figure 2.6: Eyeball class ROVs

2.3 Power source for the vehicle

There are three types of power source of the underwater vehicle: surface-powered vehicles, vehicle powered vehicles and hybrid system (Anthony, 2008).

2.3.1 Surface-powered vehicles

Since the power source is obtained from the surface to the vehicle, the vehicles must be tethered. The no vehicle-based power storage is categorized within this power category.

2.3.2 Vehicle-powered vehicles

All power-producing capacity on the vehicle is stored in the form of a battery, fuel cell, or other power storage which is needed for vehicle propulsion and operation.

2.3.3 Hybrid system

It involves a mixture of surface and submersible supplied power. For examples, battery-powered submersible with a surface-supplied charger (through a tether) for recharging.

2.4 ROVs history

Dimitri Rebikoff is credited with designing and fabricating the first ROV, called the POODLE in 1953 (Chris and Wernli, 2007). However, the technology was originally developed for the US Navy by VARE Industries to retrieve lost torpedoes and it is addressed as the Cable-Controlled Underwater Research Vehicle (CURV).

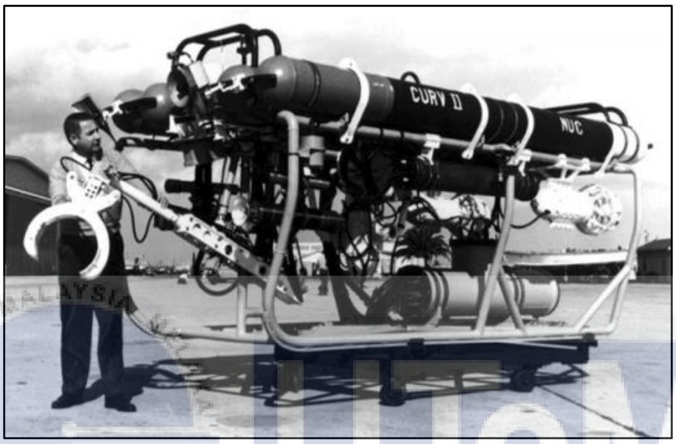


Figure 2.7: The Navy's CURV II vehicle

The project had achieved success and led to the development of a more complex vehicle that is work-class-style ROV, called the Pontoon Implacement Vehicle (PIV) as shown in Figure 2.8.

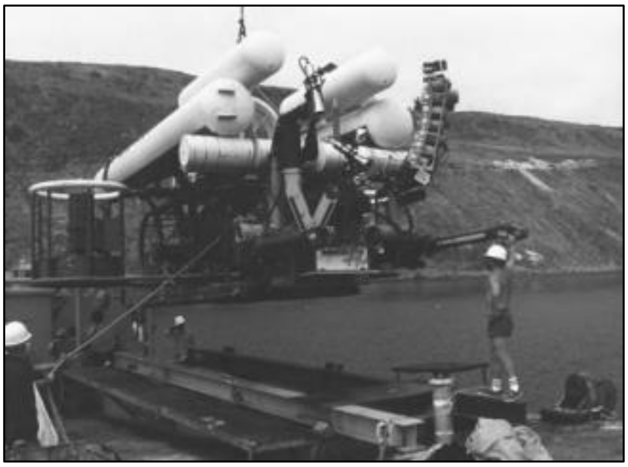


Figure 2.8: Pontoon Implacement Vehicle (PIV)

US Navy also developed the first portable mini class style ROVs called SNOOPY vehicle, which was hydraulically operated from the surface. SNOOPY was eventually outfitted with sonar and other sensors, marking the beginnings of small ROVs (Chris and Wernli, 2007).

Figure 2.9: US Navy's hydraulic SNOOPY

In 1974, there were only 20 vehicles had been constructed, and most of the vehicles built were government-funded. During the late 70s and 80s, the private industry funded almost all of the newly-built ROVs new vehicles produced. The application of ROV technology were developed by the private industry technology, driving its development to its present-day state (Chris and Wernli, 2007).

ROV is used to detect the location of many historic shipwrecks. In 1985, JASON Jr ROV is developed by Dr. Ballard's team at the Woods Hole Oceanographic Institution to discover the location of The Titanic on the ocean floor at a depth of 3798 m (Aranda, 2004). After ten years, Japan navigated the deepest point in the Mariana Trough 35 791 feet (10 909 meters) by using JAMSTEC's Kaiko ROV as shown in Figure 2.10.

Figure 2.10: The world's deepest diving ROV-Kaiko

2.5 Application of underwater ROVs

Underwater remotely operated vehicles are important tools for marine researchers and workers (Michael, 2013). It can serve a wide range of purposes. In general, ROVs, a highly reliable tool for both offshore and inshore operations are used to perform the following:

Table 2.1: Application of Underwater ROVs (Marine, n.d.)

Diver Observation	ROVs act as a dive buddy to ensure diver safety and provide assistance.
Platform Inspection	By using instruments, ROVs can monitor the effects of corrosion, fouling, locating cracks, estimating biologic fouling, etc.
Pipeline Inspection	It can check for leaks underwater pipelines, determine overall health of the pipeline and ensure the installation is acceptable.
Surveys	Both visual and acoustic surveys are necessary prior to installing pipelines, cables and offshore installations.
Debris Removal	ROVs provide a cost effective method of keeping the offshore platforms area clean and safe.
Platform Cleaning	By using manipulators and suction cups for positioning and 100-horsepower systems driving brushes, water jets and other abrasive devices.
Subsea Installations	ROVs have begun to support the construction, operation, inspection, maintenance and repair of subsea installations.
Object Location and Recovery	ROVs may have received their highest level of recognition from tragedies such as passenger jet crashes and the space shuttle disaster. ROVs help in search, location, and recovery of lost objects.

2.6 Introduction to manipulator arm

In robotics, a manipulator is an equipment used to control and manipulate things without direct contact. The common industrial manipulator consists of robot arm, with links and joints. For the purpose of interaction with environment, the vehicle can be equipped with one or more manipulator and this system is addressed as Underwater Vehicle Manipulator System (UVMS) (Gianluca, 2018). The Remotely Operated Vehicles, ROVs have design and apply manipulator arms since the first ROVs were deployed by the US Navy in the 1960s to recover objects underwater (Aquabotix, 2016). The application of manipulator arm also including famously, a hydrogen bomb that sank to the bottom of the western Mediterranean following a B-52 crash in 1966. Nowadays, modern Underwater Vehicle Manipulator System (UVMS) has gain popularity in the robotic research community recently. It provide more flexibility and wider range of application of underwater robot (Irfan, 2007).

Figure 2.11: Underwater Vehicle Manipulator System (UVMS)

2.6.1 The components of manipulator

The manipulator is composed of an assembly of individual parts such as base, links, joints and end effector. Generally, the base of manipulator connected to joints and the end effector can be find in a link-joint-link fashion.

2.6.1.1 The base

The manipulator base is the mechanical hard point which acts as the connecting point for both vehicle and series of joints, links and end effector. It is rigidly mounted due to the concentration of the force acting on entire manipulator system is on the vehicle attachment point. Generally, the base of manipulator system will be mounted to a rotary joint to allow left and right movement. It also can be fixed in horizontal or vertical plan depends on the desired orientation and range of motion (Christ and Wernli, 2007).

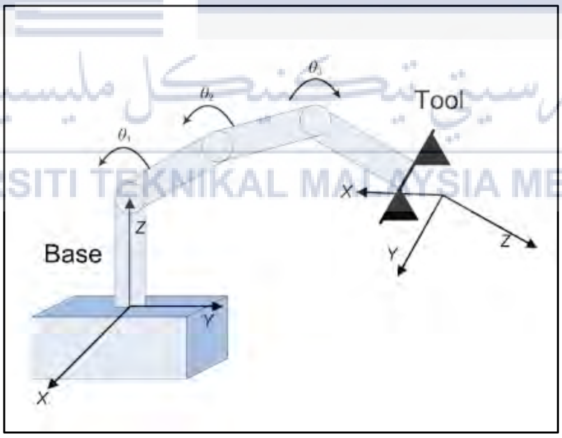


Figure 2.12: The base frame of manipulator

2.6.1.2 The links and joints

Links are defined as the rigid sections that make up the mechanism. The links are rigid strength member between the joints and the bearing. The joints are the connection between two links and they allow restricted relative motion between two links. For the manipulator system, the joints allow DOF or ranges of relative motion between adjacent links (Christ and Wernli, 2014). Figure 2.13 shows the revolute (rotational) joints.

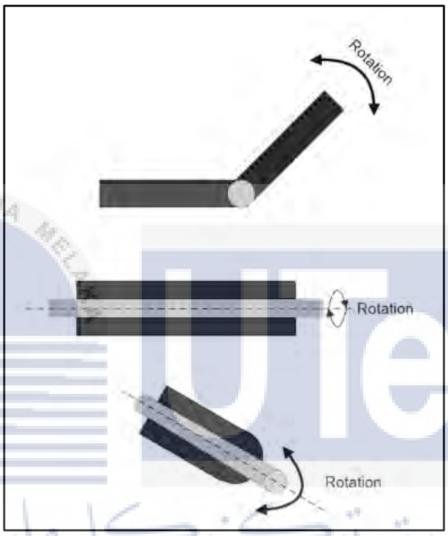


Figure 2.13: Revolute (rotational) joints

2.6.1.3 The end effector

The device attached to the manipulator which interacts with its environment to complete the work is called the end-effector. It is mounted at the free end of the base or joints or links that actually perform intervention. In Figure 2.14, link 6 is the end effector. End effectors can be any mechanical device such as jaw, a bolt or a water jet. The end effector is usually a general purpose claw with either pivoting or parallel acting jaws (Andrew, 1992). End effectors may consist of a gripper (the simplest end effector) which used to grip and maneuver a tool.

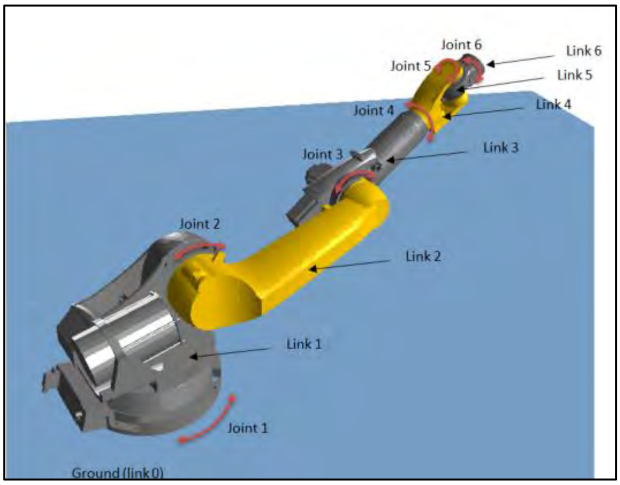


Figure 2.14: End effector at link 6

2.6.2 Design criteria of manipulator underwater

Underwater Vehicle Manipulator System consists of different challenge upon designer and engineering specification due to the fact that it has to take the hydrodynamics that underwater into account. There are five design criteria used to design a manipulator underwater and all these criteria will affect the working principles on the mini-ROV.

2.6.2.1 DOF (Degrees of Freedom)

The number of degrees of freedom, of a robot is defined as the number of independent joint variables required to particularize the location of all the links of the robot. There are two types of movement for manipulator which is translation and rotation. Translation means the linear motions along three perpendicular axes while rotation means angular motions about the three axis, X, Y and Z axis. Translation specify the position of the body while rotation specify the rotation of the body. According to Irfan et al. (2007), it is optimum to design the manipulator with the minimum DOF to reduce cost and simplify the analysis. Figure 2.15 shows the manipulator arm with four degree of freedom. Figure 2.16 shows the manipulator arms with multiple degrees of freedom named as advanced Kraft Tele-Robotics Predator-7.

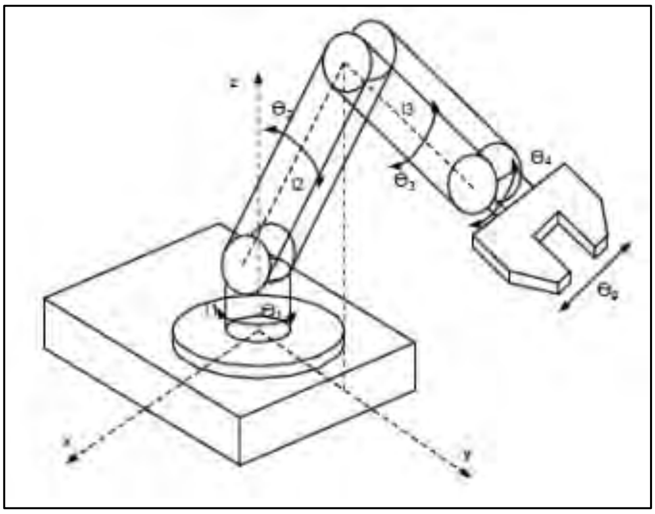


Figure 2.15: Manipulator arm with four degree of freedom

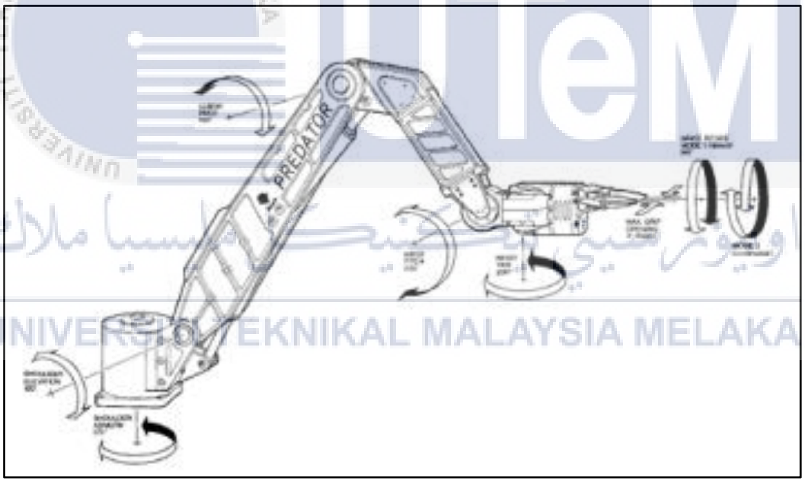


Figure 2.16: Kraft Tele-Robotics Predator-7

2.6.2.2 Workspace extent

The workspace of a manipulator is the volume of space in which the manipulator is able to locate its end-effector. The movement's factors on manipulator end-effector that can make it reach every point from all orientations are influences by the degree of orientation axis and the length of arm component part.

2.6.2.3 Load carrying capacity

The size of the motors and the integrity of its joints and links of manipulator is determined by the load capacity. The load capacity means the size and weight of load to be carried by using manipulator. With the rise of workspace volume, the payload capacity will reduce for the same level of structural integrity.

2.6.2.4 End effector maximum speed

End effector maximum speed represents how fast a task can be completed with shortest time. The faster a task can be achieved by using manipulator means the higher the performance and capability to perform task.

2.6.2.5 Repeatability and accuracy

The design of manipulator should aim for the minimum accuracy and repeatability. If we design a manipulator with high accuracy, it is costly when requiring stiffer links, tighter tolerance joints and redesign and modelling. The usage of manipulator should be repeatability. It is to ensure long lifespan so that it can used in long term condition without huge damage and costing maintenance.

2.6.2.6 Type of actuator

The type of actuation is one of the design criteria. The selection of method of actuation depends on the torque requirements, speed of actuation and accuracy. There are three types of actuation including electric, hydraulic and pneumatic. Each type of actuation consists of advantages and disadvantages. For example, hydraulic actuation can transmits more power than electric actuation. However, leakage of hydraulic fluid can lead to degradation of performance (Max, 2006).

2.6.3 Application of underwater manipulator

An underwater manipulator is designed and developed for sampling and grasping an underwater object with a number of degrees of freedom. The underwater manipulator is also used for dealing with radioactive or biohazardous materials. By manipulate the underwater robotic arm using hand controller or control panel, the items in hazardous or inaccessible locations can be accessed. In more recent developments, the manipulator which used in diverse range of applications including welding automation, robotically-assisted surgery and in space.

2.6.4 The current research of underwater manipulator

J. Geng et al. (2005) proposed that two degrees of freedom (2-DOF) underwater manipulator which is designed to the ROV. The manipulator can be used to grasp small parts such as bolts and nuts by using its gripper. Its neutral buoyancy enables it to adapt any depth in water. The presence of buoyancy module is to provide the buoyancy and balance the ROV. In this study, the manipulator is installed in the front below the control cabinet as shown in Figure 2.17. It is driven by the DC motor. The double seal is processed to all joints to protect the inside electric components from water leakage.

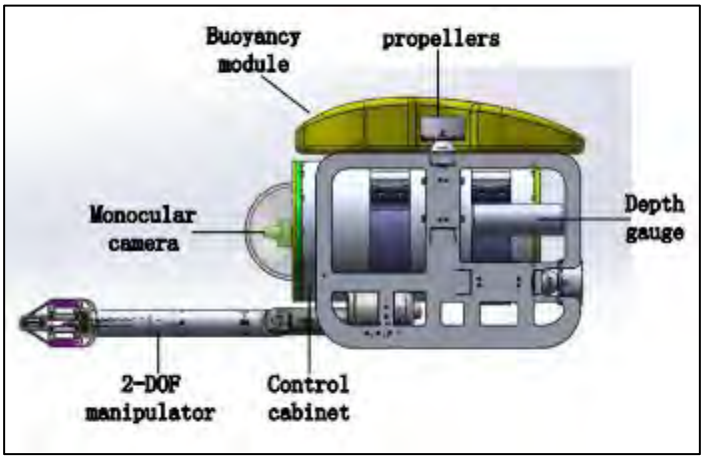


Figure 2.17: 2-DOF manipulator

This study proposed that ROV acts as diver to perform its tasks with two hands. This ROV is tested at the depth of 10-20 meters in Biwa Lake, Japan (Sakagami et al., 2010). With 56 kg weight, the ROV has six thrusters for driving force. Each of the underwater manipulator with 3.6 kg weight in water has five degree of freedom, four arm joints and a gripper hand. This ROV consists of dual manipulator system as shown in Figure 2.18 and Figure 2.19.

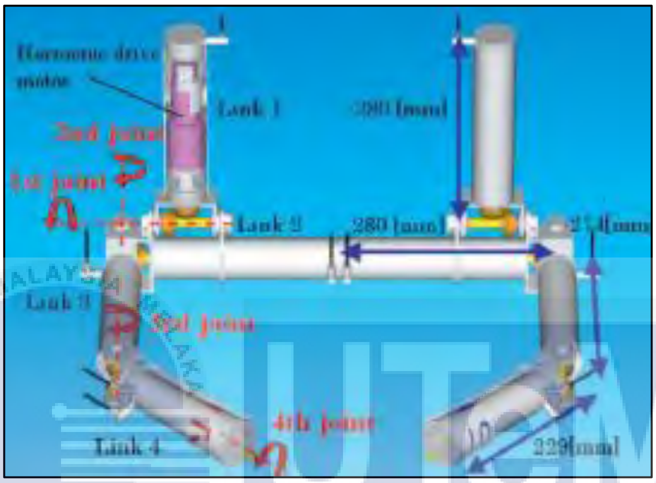


Figure 2.18: Human-sized manipulator

The attitude control system enable it to control the attitude angle and keep the vehicle in horizontal plane. It is based on the concept by changing of the center of “Buoyancy” with respect to the center of “Gravity”. In this study, a master-slave control system has been developed and implemented to control multi- DOF of this ROV. An operator can control the ROV including the dual manipulator system and the attitude control system by using the developed master-slave controller.

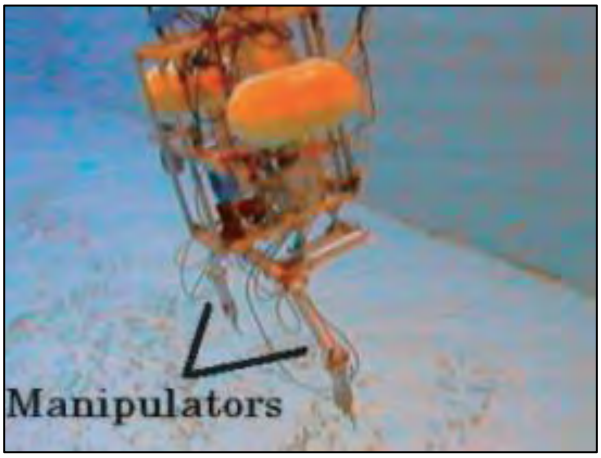


Figure 2.19: A Human-Sized ROV with a Dual-Manipulator System

KIOST (Korea Institute of Ocean Science & Technology) has developed a 200 m-class seabed walking robot named CRABSTER 200 (CR200) as shown in Figure 2.20. CR 200 has 4 dedicated legs and 2 arm-combined legs. There are six legs used during walking. The front two legs are used to perform underwater work. CR 200 is used to conduct seabed survey and underwater precision work in coastal area with strong tidal current.

Figure 2.20: CRABSTER 200 (CR 200)

Hangoo et al. (2012) presented that the development factors of CRABSTER 200 (CR 200) such as design points, fabrication factors and experiments. Normal design of multi-legged robots only have degree of freedom at hip yaw, hip roll and knee roll joint. Unlike most multi-legged robots which have only three degrees of freedom, all legs of CR200 were designed to have one more degree of freedom at the hip pitch joint. The extra degree of freedom enable it to transform the body posture flexibly at the inclined plane and generate downward force in a coastal area with high tidal current. For performance verification, the actuator driving experiment is performed by using the weight lifting experiment up to 60 kg. The pressure resistance is set to 200 m depth and the O-rings are used at the contact surface for watertight. A hydraulic pressure-resistant experiment is carried out under maximum 25 bar pressure to verify the design of pressure-resistance and watertight.

Figure 2.21: Leg with arm (folded arm)

Hyungwon et al. (2013) proposed the CRABSTER 200 (CR 200) for the use of seabed walking and underwater works. By using simple force analysis such as calculation of maximum required torque, a suitable joint actuators and reduction gears are determined. To verify the performance of joint actuator of the robotic arm, the torque capacity test is carried out. The torque capacity test involves the weight lifting test by using water tank of 10 kg. The tracking control of posture change pattern as shown in Figure 2.22 is performed to verify the walking capability.

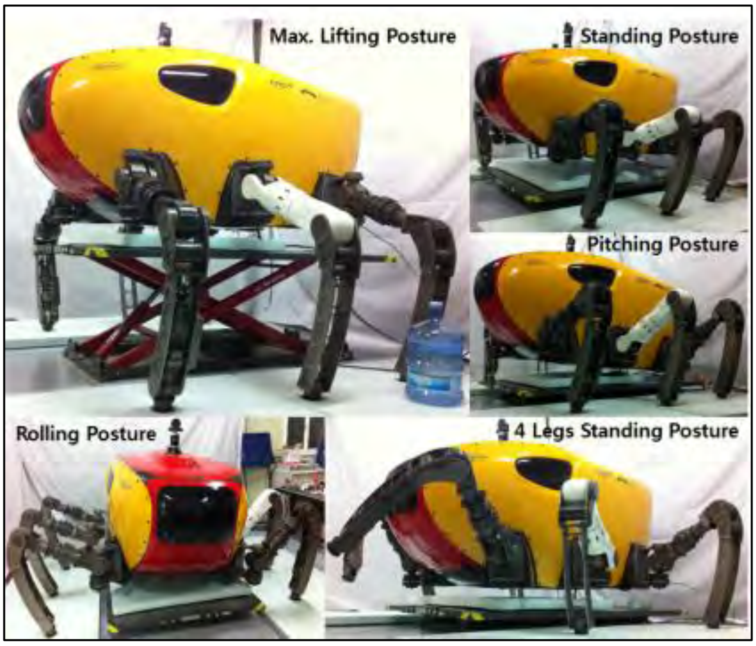


Figure 2.22: Posture change test by using 6 legs and 4 legs

This study proposed the use of F/T sensor and a disturbance observer based controller to reduce the dynamic effects of the underwater manipulator to the ROV and increase the maneuverability of the underwater manipulator. The attitude and position of the ROV which should remain stationary in seabed operation can be influenced by the motions of an underwater manipulator (JH. Ryu et al., 2001). The dynamic and kinematic couplings that arise between the vehicle and the manipulator act as disturbances on the vehicle, and affect the end-effector position and orientation. To compensate for the dynamic effect of the underwater manipulator on the ROV, a base force-torque (F/T) sensor is attached to vehicle, and its signal is used to regulate the states of the ROV. The compensating control force can be obtained using the base F/T sensor signals as Eq. (2.1):

$$\tau_c = -\begin{bmatrix} F_x \\ F_y - (m_1 + m_2 - b_1 - b_2)g \\ M_z + r_o\,(F_y - (m_1 + m_2 - b_1 - b_2)g \end{bmatrix} \quad (2.1)$$

An F/T sensor is replaced by a disturbance observer when it is practically unavailable. A disturbance observer as shown in Figure 2.23 is used to estimate the interaction forces between the ROV and the manipulator. Figure below shows the structure of the controller based on the disturbance observer. Finally, the numerical simulations are performed to demonstrate the improvement on the maneuverability of the proposed controller.

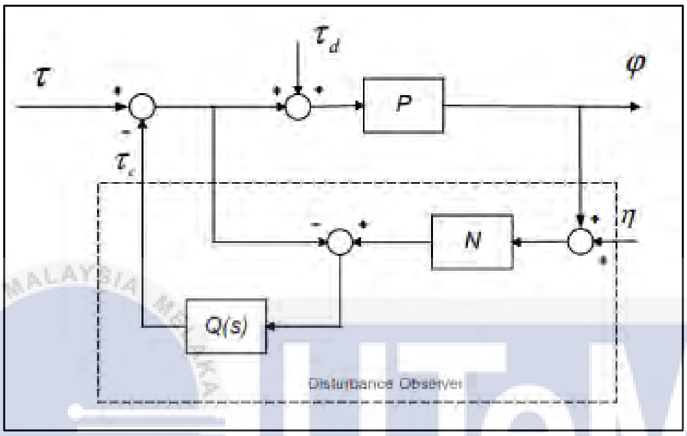


Figure 2.23: Disturbance observer based control scheme of the ROV

Fernandez et al. (2013) stated that the AUV is required to overcome the large reaction of the manipulator once it is equipped with manipulators. Therefore, the characteristics of manipulator to be assembled to AUV should be determined. Each mobile part of the arm should be neutrally buoyant in order to reduce dynamic disturbances on the vehicle. For the balancing of the vehicle, the position of the robotic arm should be as close as possible to the center and as low as possible. It is always a good characteristics for arm to maintain a position when it is not operative. This can reduce the water resistance while the vehicle moves through the water. The arm should be as slender and lightweight to reduce the dynamic coupling between both subsystems. The lightweight of robotic arm can be targeted and achieved by not more than 30 kg if the mass of the vehicle is around 200 kg in air. In this study, the CSIP Light-Weight ARM 5 E with 5 DOF as shown in Figure 2.24 is chosen to be implemented on AUV vehicle.

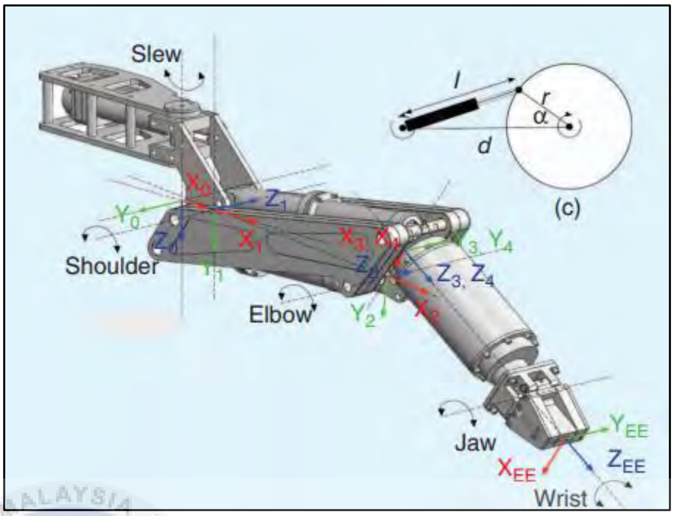


Figure 2.24: The CSIP Light-Weight ARM 5 E kinematic model

The three options involve the position of arm on vehicle are analysed. The position which the arm is placed facing downward in the center of the vehicle as shown in Figure 2.25 is chosen because of its clear advantages and relatively minor drawbacks.

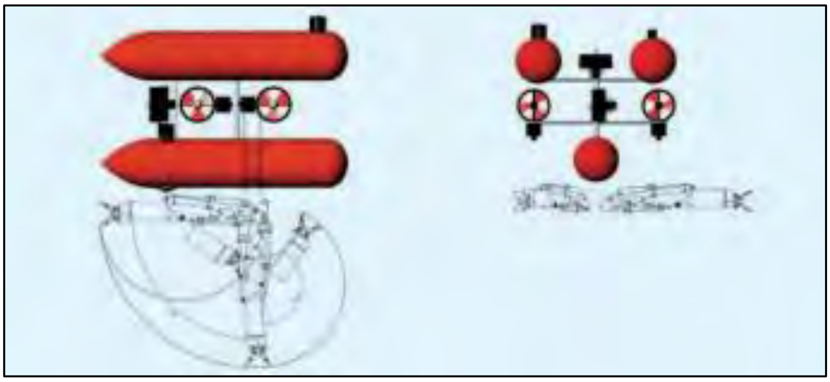


Figure 2.25: The arm located in the center of the vehicle

The autonomous capabilities of the system are demonstrated by recovering a flight data recorder (FDR), commonly called a black box, from the bottom of a water tank. The result shows that I-AUV is very stable with the implementation of manipulator arm in autonomous mode. However, the manipulator arm is move with slow and moderate speed in order to minimize the dynamic coupling between the manipulator and the vehicle (Fernandez et al., 2013).

Figure 2.26: The grasping capabilities of the arm

Wang et al. (2016) proposed that the novel mechanism of an underwater manipulator with a lightweight multilink structure. This study involves a 5 DOF manipulator which is include waterproof base, a multilink structure, Waist joint, and Gripper. Figure 2.27 shows the mechanism design of manipulator. The multilink structure can minimizes the coupling between the manipulator and the vehicle and achieve free-floating autonomous manipulation at a relative high speed. In the end, the experimental results shows that the average execution time is about 2.96 s and prove that the underwater manipulator can complete the autonomous operation quickly.

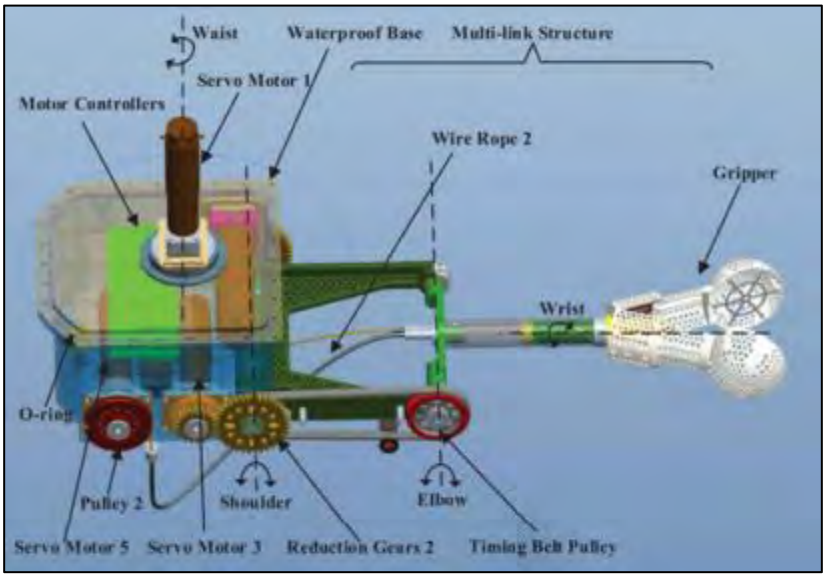


Figure 2.27: Mechanism design of the manipulator

B.H. Jun et al. (2008) proposed that the task-oriented manipulability of tele-operated robotic arms mounted on a remotely operated vehicle (ROV). This is aimed to minimize the tele-operator's burden in performing underwater tasks. By enhancing the functionality of the manipulator, it can help human operator to control the manipulator precisely. In this study, a manipulator has 6 degrees-of-freedom (DOF) to perform function in Cartesian workspace. By referring from research (Hemami and Labonville, 1988), human arm has 7 degree of freedom is capable to do a lot of works with high flexibility of movement. Generally, the industries mostly apply only 5 to 6 degree of freedom of manipulator arm. A scientific vehicle named KORDI ROV is equipped with dual ORION manipulator as shown in the Figure 2.28.

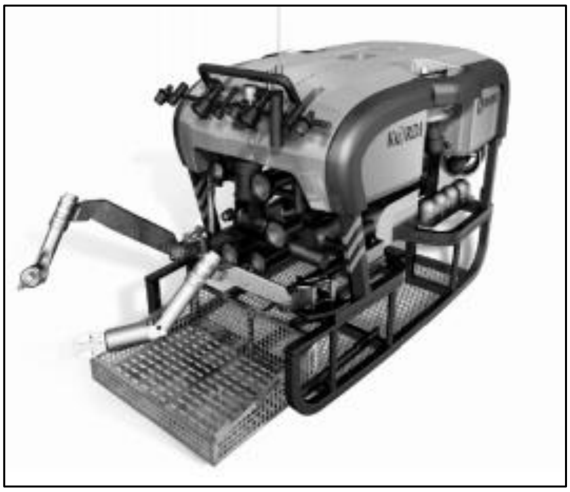


Figure 2.28: KORDI ROV with a dual tele-operated manipulator

In this study, high degree of freedom of the manipulator have redundancy according to task types and order of task-priority. This paper proposes a scalar function as an object of optimization to utilize and solve the redundancy based on the pseudo inverse of the task-oriented Jacobian matrix. (B.H. Jun et al., 2008). The scalar function is includes task oriented manipulability measure (TOMM) and joint limit measure (JLM). In the end of the study, the optimal postures of the manipulator is obtained for a given position constraint of the end-effecter by using sequential quadratic programming (SQP) algorithm under the boundary determined by joint limit.

2.6.5 Analysis of Gripping force

A multi-fingered robot gripper is designed and the contact force of the gripper in handling different objects is analysed (Widhiada et al., 2016). To obtain the contact force between fingertips and object surface, Hooke law concept and equation as shown in Eq. (2.2) is applied in the study.

$$F = - k. \Delta x \tag{2.2}$$

The surface of object will be pressed by the spring which is mounted on the tip of the finger. The Newtonian law, a mass spring damper model algorithm is used to compute the force reaction. The value of force (F) is used to drive the joint of servo motor. The force can be calculated when the tip of the motor lever moves from point A to B with the angle θ and the length of the lever of r. Figure shows a link of gripper finger which is installed at shaft servo motor.

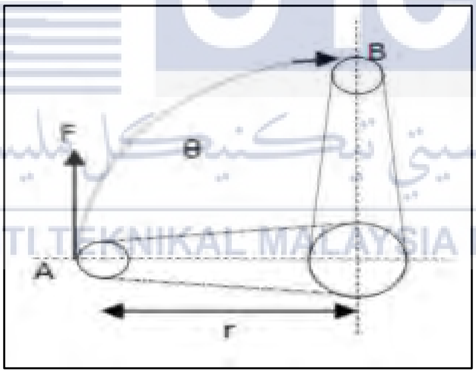


Figure 2.29: The lever of servo motor

In this study, the gripper is instructed to grasp objects: bottle, disc and ping pong ball. The average force acting on each finger when gripping are recorded respectively for three objects. In the study, the contact response force for each finger to grasp object is different. When the finger reached the surface of object, the actual output response is less than the input reference. There is presence of contact force when the finger is touching the surface of object by force displacement the lever of motor.

There are study investigated the efficiency of grip force scaling in the context of collisions. Slip ratio is the minimum grip-to-load-force ratio which is required to prevent object slippage (Turrell et al., 2001). In this study, the slip ratio are determined. The equipment set up included a sturdy load cell and two linear potentiometers. Load cell is used to measure grip force and linear potentiometers is used to provide detailed description of finger movements. To determine the slip ratio, the magnitude of finger movement against the grip-to-load-force ratio at the time of impact is plotted. The slip ratio is depends on the direction of loading.

In order to ensure an object is hold in precision grip stably, application of sufficient grip force (GF) normal to the surfaces of the object through the fingers is important in overcoming load force (LF) tangential to the surfaces. If GF is less, the object may accidentally slip or drop. However, the excessive GF is not recommended to the system as muscle fatigue and possible damage to the object might occur. Therefore, GF needs to be scaled to the LF from impact in order to avoid an object fall from precision grip during collision.

Ardhendu (2010) stated that the when a gripper is being designed, there are two main elements which should be taken into account which are gripping force and sliding torque. These factors must be calculated correctly to ensure that the gripper can functioning successfully and last for 5 to 25 million cycles. In this study, a pneumatic gripper is being design. Type of gripper jaws used is important in determining the gripping force of gripper. There are two type of grippers: friction grip and encompassing grip.

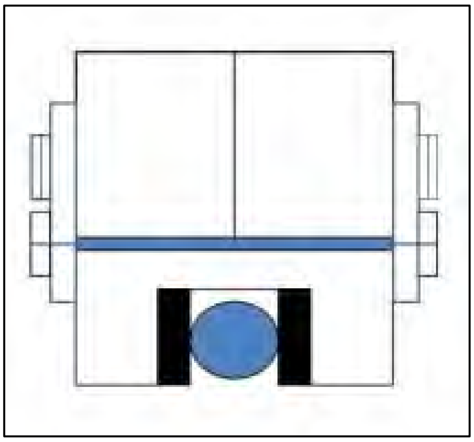


Figure 2.30: Friction grip

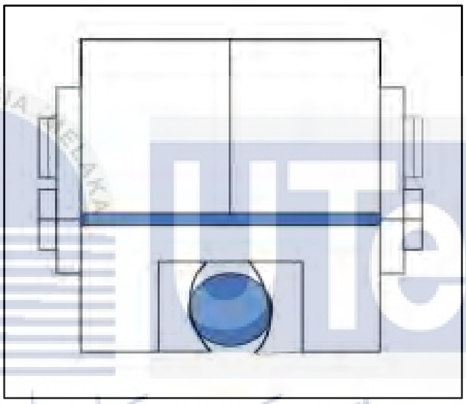


Figure 2.31: Encompassing grip

To determine the gripping force, the jaw style factor must be assumed. The formula to calculate the gripping force is:

Force required to grip = Part weight (1+Part Gr) x Jaw style factor (2.3)

The torque in a gripper is generated by two sources which are torque developed by the gripper arms on itself and torque developed by the acceleration & weight of the part. The total torque that is developed on the gripper is the sum of the torque developed on the jaw and the torque developed on the part. The result in this study is the encompassing gripper is generally better than the friction grip from the aspect of strength and stability. The gripping force of encompassing gripper is higher than friction grip. The encompassing gripper is provides more strength and it is more stable (Ardhendu, 2010).

The gripping device is a system that consists of actuator at the input and creates gripping action at the output (Chen, 1982). In this study, the pneumatic cylinder is created to produce force (P) to activate the gripper. There is relationship between the actuating forces and resulting gripping force. By using static force analysis, the gripping force which is the reactional forces at each joint of the gripping mechanism can be determined. Force equilibrium at point C as shown in Eq. (2.4) is:

$$F_{23} + F_{56} + P = 0 \tag{2.4}$$

The moment equilibrium is applied to determine the relationship between the grasping force F and the input force P. Figure shows the gripper mechanism and its illustration of determination of gripper input-output force ratio.

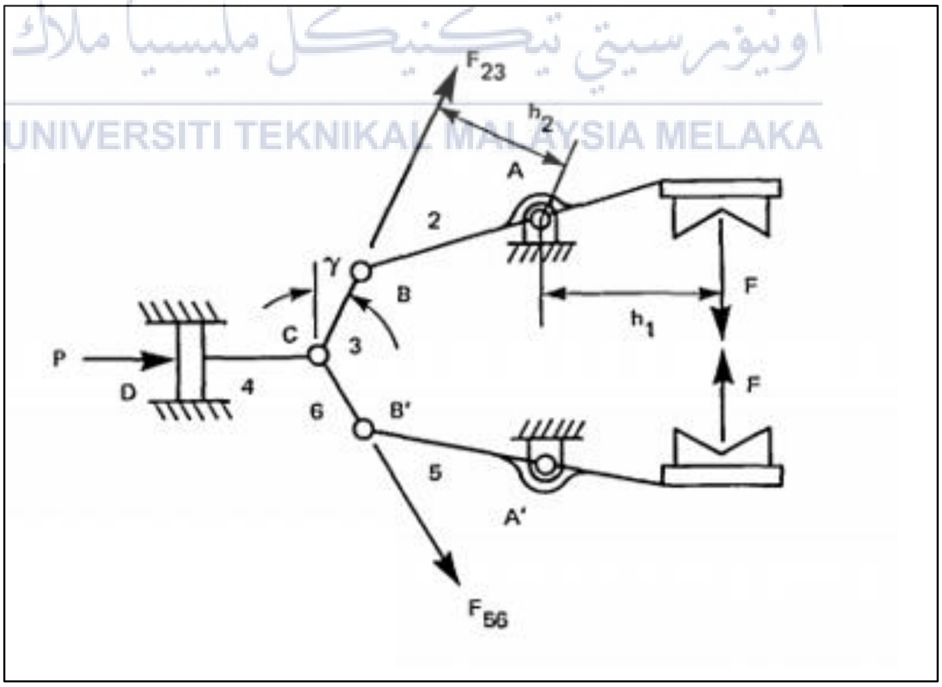


Figure 2.32: Gripper mechanism

In addition, the gripping surface of the gripper must contain higher coefficient of friction relative to the material to be grasped (Chen, 1982). The gripper jaws can be surfaced with rubber-like material, wood, steel, brake-lining, and other materials. High friction coefficient provide the sufficient strength and wear-resistance and enhance long life span.

The interaction between grippers and the object is occur by the force exerted on object's surface. There is presence of two type of forces: grasping (prehension) and holding (retention) forces. The application of grasping force is occur at the initial point of prehension (only during the grasping process). Meanwhile, the holding force is maintained thereafter (until object is released). There are many cases show that the prehension force is higher than the retention force. When the grasped object is being moved, the acceleration will rise the prehension force needed (Anna, 2015).

CHAPTER 3

METHODOLOGY

3.0 Introduction

Methodology is one of the part of a project where all the actions and activities are listed out and arrange in systematic ways. This is to describe in particular how the project flows and the routines used to complete the project. The procedures and steps used to complete the objectives stated are explained in this chapter. In this chapter, the schematic flow chart diagram which showing the overall activities carried out in this research is introduced.

3.1 Flow chart

The overall research activities carried out in this study are presented in the following schematic flow chart diagram as shown in Figure 3.1.

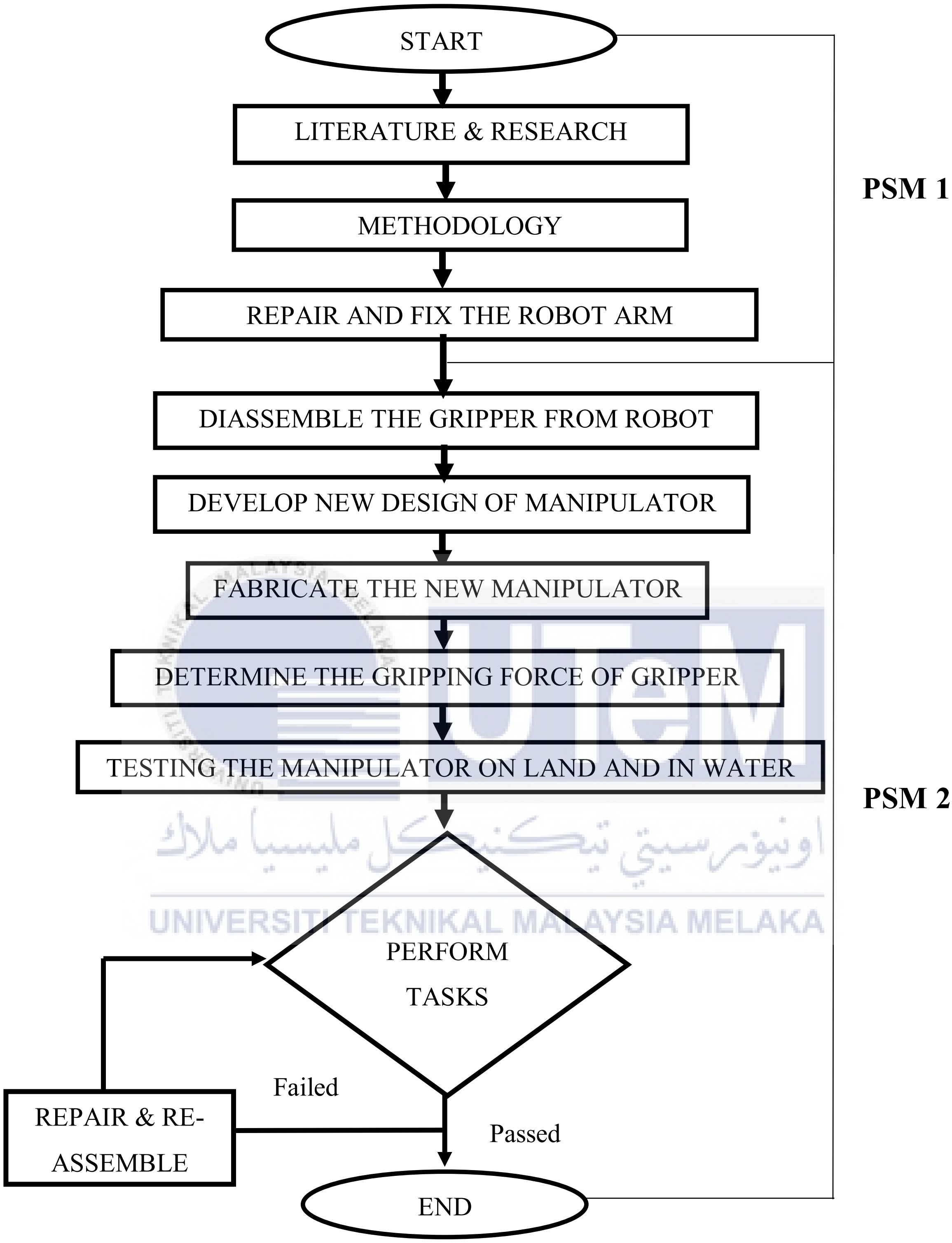


Figure 3.1: Schematic flow chart diagram of project

3.2 Equipment used in this study

3.2.1 BlueROV2

In this study, the type of ROV used is called BlueROV2 which is a type of remote operated vehicle without manipulator. The product technical specification is important in designing and developing the robot arm on BlueROV2. For example, from the aspect of weight, the weight of manipulator should not more than 30 kg if the mass of the vehicle is around 200 kg in air (Fernandez et al., 2013). Table 3.1 shows the technical specification (physical) of BlueROV2.

Table 3.1: Technical specification (physical) of BLUEROV2 (Bluerobotics, n.d.)

Parameters	Value (mm)	Value (in or Ib)
Length	457 mm	18 in
Width	338 mm	13.3 in
Height	254 mm	10 in
Weight in Air (with Ballast)	10-11 kg	22-24 lb
Weight in Air (without Ballast)	9-10 kg	20-22 lb
Watertight Enclosure Inner Diameter	102 mm	4 in
Watertight Enclosure Inner Length	298 mm	11.75 in

3.2.2 Robot arm

The robotic arm trainer MOVIT MR-999 is a type of robot arm which is capable to perform a lot of works with high flexibility of movement. The robot arm trainer is comprised of mechanical section and a controller. There are five main components for this type of robot arm which are gripper, wrist, elbow, shoulder and base arm. In this study, the gripper of robot arm trainer is modified and utilised as manipulator to be mounted on BlueROV2.

3.2.2.1 Remote controller

A remote controller is used to control the movement of robot. The wire is connected between controller and robot arm to transmit signal to robot arm for task performing. The weight of controller is 150 g including the cable with length of 950 mm. Figure 3.2 shows there are five control levers on a remote controller such as gripper, wrist, elbow, shoulder and a waist of human arm. A circuit board called control PC board as shown in the Figure 3.3 is used to control the movement of robot arm. For this project, the control lever of wrist, elbow, shoulder and base will be disabled. The control lever of gripper is only used in this project.

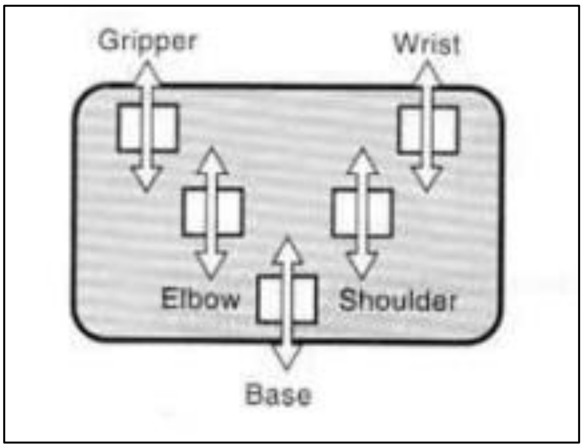


Figure 3.2: Names on the controller

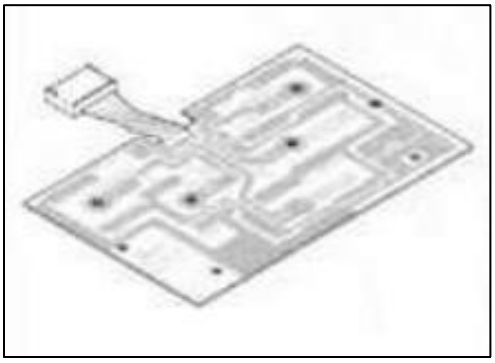


Figure 3.3: Control PC board

3.2.2.2 Gripper of robot arm

In this study, the gripper will be modified into new design of manipulator to grasp and hold the objects underwater. The other parts of robot arm are removed from this project. This is due to high degree of freedom of the manipulator might have redundancy according to task types and order of task-priority. Furthermore, BlueROV2 can move freely enough in water, thus it can reach the target with the manipulator which doesn't have so many degree of freedoms. Reducing the degrees of freedom allow the user to concentrate on intuitive one degrees of freedom spatial control environment and improve dramatic efficiency. Figure 3.4 shows the new mechanism of gripper which have 1 DOF. The moving range of the gripper is 0-50 mm.

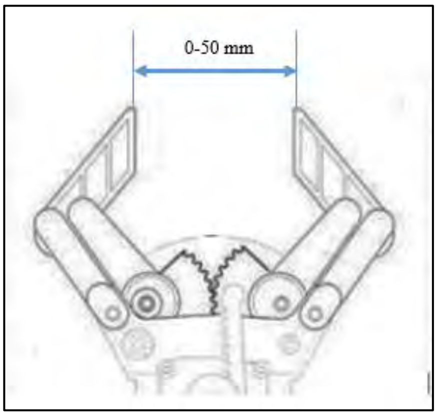
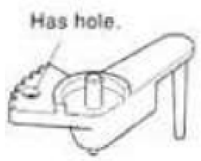
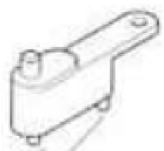


Figure 3.4: New simplified mechanism of robot arm

3.3 Structure of gripper

The gripper is made up of several spare parts such as finger link, finger base, rack gear, clutch gear ang spacer. Table 3.2 shows the spare parts used to assemble the gripper.

Table 3.2: Main parts of gripper

Main parts of gripper	Name	Quantity
	Finger Base A	1 pcs
	Finger Base B	1 pcs
	Upper Finger Base A	1 pcs
	Upper Finger Base B	1 pcs
	Finger Link X	1 pcs
	Finger Link Y	1 pcs

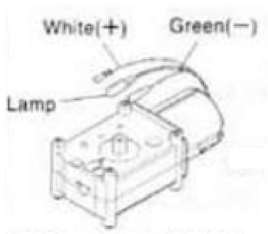
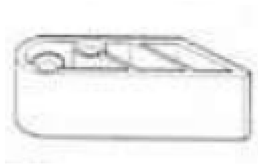
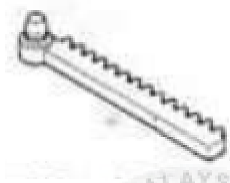
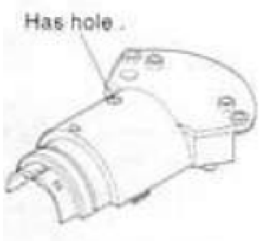
	Power Unit	1 pcs
	Finger	2 pcs
	Rack Gear	1 pcs
	Clutch Gear	1 pcs
	Spacer	1 pcs
	Gripper Cover 1	1 pcs
	Gripper Cover 2	1 pcs

Figure 3.5 shows the illustration of assembly of the gripper. The power unit is fixed into the gripper. The finger base and finger link of one side are assembled well and stick to the rack gear. The rack gear is connected to the clutch gear on power unit. The power unit consists of motor is used to generate power to open and close the gripper. Figure 3.6 shows the structure of assembled gripper which disassembled from the robot arm trainer.

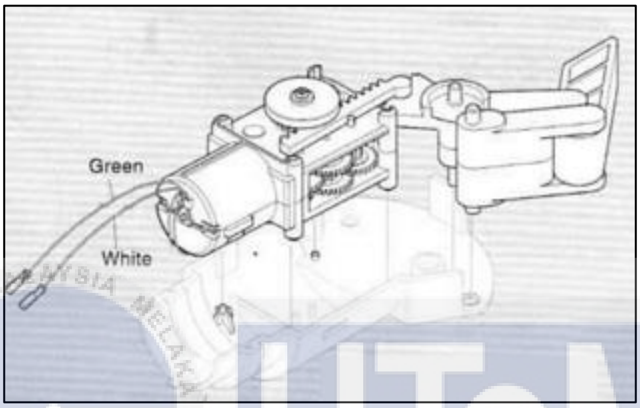


Figure 3.5: Illustration of assembly of the gripper

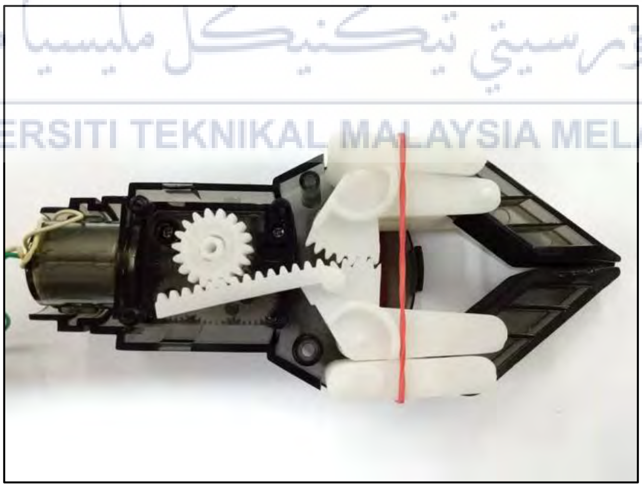


Figure 3.6: Structure of assembled gripper

3.4 Operation of gripper

For opening and closing operations of fingers, a device called “rack and pinion” is used. The gear in a straight-line called the rack gear and the pinion gear are engaged so that they can convert a rotational movement into a straight-line movement, or operate this inversely. The application of this mechanism are used to the car steering structure and the mountain railway which can go up to steep slope. For the gripper structure, the power is transmitted to the fingers through the clutch gear engaging the rack gear at the Power Unit. In this process, the rotational movement is converted into a reciprocating movement of opening and closing of the fingers. Figure 3.7 show the movement of pinion gear can cause the rack gear move upwards or downwards.

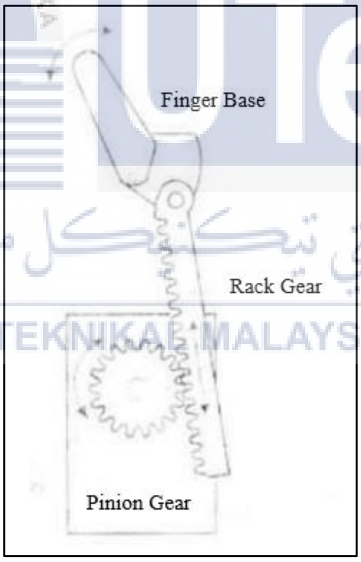


Figure 3.7: Gear movement

However, under this condition, the fingers’ opening or closing motion remains a movement of a fan contour, which makes it difficult to grasp. To secure the grasping, it is desirable for the finger tips to open or close in parallel. This parallel motion is also created by a mechanism called a parallel crank, a kind of crank (link) mechanism as shown in Figure 3.8.

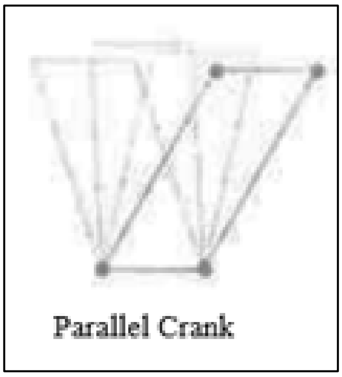


Figure 3.8: Parallel Crank

The mechanism of a parallel crank is based on a parallelogram. It is so constructed that the opposite side always makes a parallel movement when one of its sides make a motion. For gripper structure, one of its sides functions as a finger base and its opposite sites functions as a finger link as shown in Figure 3.9.

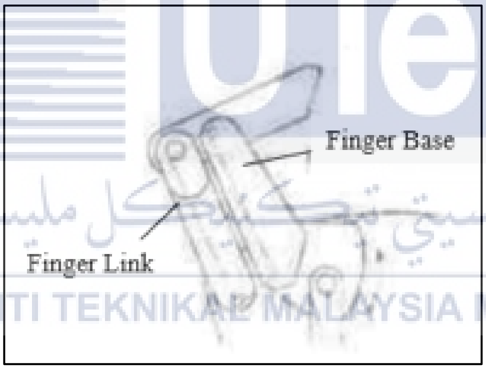


Figure 3.9: Structure of finger

Incidentally, the parts functioning as a parallel crank will not move when the fingers open and close fully. This happens as excessive force may ruin the mechanism if the gear Box continues to run. Therefore, the drive axle of Power Unit and the clutch gear slip and the drive axle run idle when excessive force is applied. It can be adjusted by the proportion of tightening the screws when the drive axle start to run idle. Thus, the mechanism which disables transmission of more force than limited to prevent excessive force is called a torque limited.

3.5 Kinematic analysis of gripper

Kinematics analysis for multi degree of freedom of manipulator is the studies that related to the relationship between each link and connectivity which involve the value of motion angle, workspace and to define the end-effector for certain configuration of manipulator arm without considering any contributing force. This kinematics analysis applies the concept of trigonometry equation in order to determine the parameters between each point in connected link which form the certain value of angle.

There are two methods of kinematics analysis which are forward kinematics and inverse kinematics. Forward kinematics is the methods in kinematics analysis which using an equation to define the end-effector of the manipulator arm. For inverse kinematics, the joint parameters are defined to provide a desired position of the end-effector by using related formulas or equations which also analyzed a constrained system of rigid bodies. Thus, inverse kinematics is the most suitable methods in kinematics analysis for this robot arm with 4 DOF since the manipulator arm is comprised of rigid bodies. Figure 3.10 shows the free body diagram for each link of robot arm

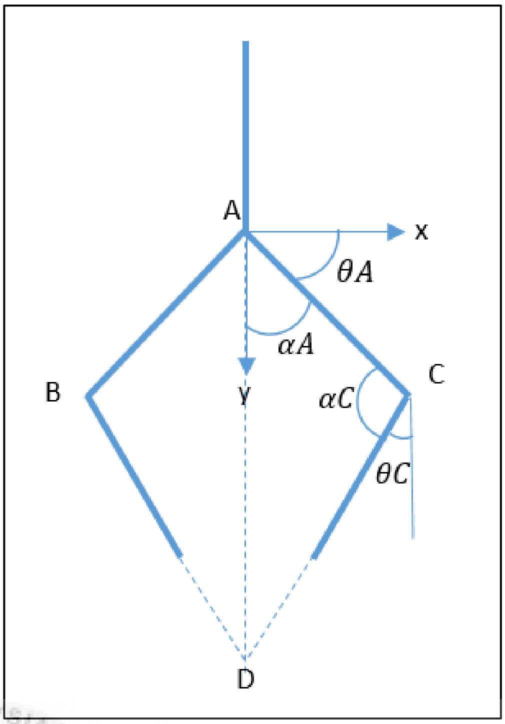


Figure 3.10: Free body diagram of gripper

$$\alpha A = cos^{-1}\left(\frac{(AC)^2 + (AD)^2 - (CD)^2}{2(AC \times AD)}\right)$$

$$\theta A = 90 - \alpha A$$

$$\alpha C = cos^{-1}\left(\frac{(AC)^2 + (CD)^2 - (AD)^2}{2(AC \times CD)}\right)$$

$$\theta C = 90 - (\alpha C - \theta A) \qquad (3.3)$$

Where,

αA = degree of angle CD

αC = degree of angle AD

θA = degree of angle against y axis

θC = degree of angle against x axis

3.6 Development of new manipulator

3.6.1 The manipulator design considerations

In designing the new manipulator, there are some concerns to be considered. The new manipulator should have the characteristics of lightweight to minimize the dynamic coupling between both subsystems. For balancing purpose, the gripper should be attached as close as possible to the center. This would vertically align the center of buoyancy and the center of gravity. The new manipulator should be placed as low as possible to maximize the distance between the buoyancy and gravity center thus improve the stability.

When the gripper is not working, the gripper should adopt a position that reduce the water resistance while the vehicle navigate through the water. Furthermore, the manipulator should be designed out of the vehicle workspace to prevent any damages to ROV. It is not recommended that the gripper has a high payload. The weight of size of payload depends on the size and maximum rated load. In this study, a small payload is used as the maximum rated load is 130 gram only. The usage of small payload is able to reduce battery and power consumption.

3.6.2 Product Design Specification (PDS)

PDS is acting like a mantle enveloping the whole core activity. Product design and development involves a number of processes in order to increase the chances of success once in the market. The process of product design is initiated with the creation of a product design specification or PDS. The PDS documents all of the necessary requirements and constraints the new design must adhere to. Solutions or concept designs should be generated with reference to the PDS. In this design, the PDS involved are material, weight, dimensions and size. Material is a very important aspect for a product's design. It is convenient to have a high strength and low weight of material because it can enhance the period of use and at the same time fulfill the requirement of easy to carry and use. The product is designed based on the dimension of payload skid and underwater vehicle BLUEROV2 which are stated clearly under the technical specification in Table 3.3.

Table 3.3: Product design specification

Material	• Material selected should be light and durable. • Material selected should be waterproof. • Material selected should be able to withstand water pressure.
Size	• The device should be able to fit into payload skid. • The size of the load should not exceed project requirement standard.
Weight	• The maximum weight of load is set to 130 gram. • The battery compartment must be light, easy to carry and able to withstand the weight of battery.
Ergonomics	• The gripper should be easy to operate by user. • The device should be portable and easy to carry.
Efficiency	• The manpower required to use the gripper should not more than 2 people. • The time taken to grasp the load should be as less as possible.
Reliability	• Device must be able to operate underwater constantly for 1-2 years, without failure or deterioration.
Manufacturing process	• Manufacturing process does not involving expensive machining process that can affect the fabrication cost.

Assembly	• The device will be assembled and installed on site at destination of use. • Simple fixings used to allow ease of assembly.
Finish	• The connection part of the device should be sealed with hot glue to prevent any leaking of water.
Testing	• Before device's first use, it will be tested for functional capabilities and safety compliance on land. • The testing should be conducted based on different object.
Safety	• The gripper device should be designed, fabricated, tested, installed and maintained in such a way to reduce and minimise risks to humans, the environment and material assets.
Maintenance	• The product must be easily cleanable using widely used cleaning methods, i.e. hand washing etc. • All mechanisms must be accessible for repair and replacement with ease.
Product life span	• The condition of the device that not safe to use for operation need to be stated.
Hazards	• Care must also be taken when disassembling the entire installation, electric and electronic components could cause potential dropping hazards.

3.6.3 Gantt chart

The use of Gantt Chart is very much popular method to be used in project management. It helps in illustrate the tasks need to do in each week to complete this project. By following the schedule on the Gantt Chart, the project is managed to be completed in the estimated time. The Gantt Chart for final year project 1 and final year project 2 are attached as Appendix A and Appendix B respectively.

3.6.4 Design using CATIA software

In designing the new manipulator, a design software called computer-aided three-dimensional interactive application (CATIA) is used. CATIA software is a multi-platform software suite for computer aided design (CAD), computer-aided manufacturing (CAM), computer aided engineering (CAE), PLM and 3D, developed by the French company Dassault Systemes. It is a complete 3D software tools which been used to design, simulate, analyze and manufacture products in a variety of industries including aerospace, automotive, consumer goods and industries machinery. In this project, the CATIA V5 software is used in designing four different type of manipulator.

3.6.5 Conceptual design generation

Concept development is the phase of creation and exploration of new ideas. The conceptual design's idea are generated from existing designs and from other studies. It is a detailed description of the design to avoid misinterpreting information based on the designs. It also consists of rough sketches and brief descriptions. This is also the phase where the best concept design is chosen.

3.6.5.1 Conceptual Design

The design A as shown in Figure 3.11 consists of a battery compartment with rectangular shape. The gripper of robot arm is connected to cylinder and the cylinder is connected to rectangular battery compartment. The four batteries will be arranged in parallel and stored in the rectangular box.

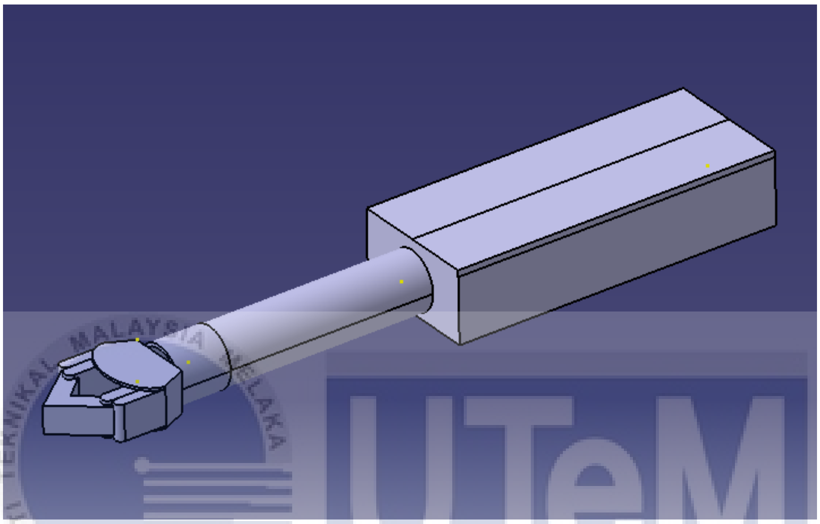


Figure 3.11: Design A

Figure 3.12 shows design B consists of a battery compartment with cylindrical shape. The gripper of robot arm is connected to cylinder and the cylinder is connected to larger cylindrical battery compartment. The four batteries will be arranged in parallel and stored in the large cylindrical battery compartment.

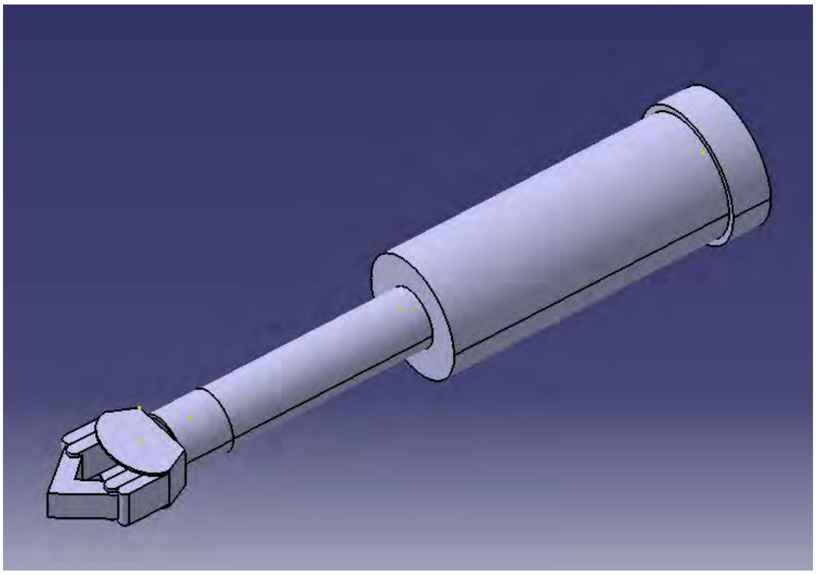


Figure 3.12: Design B

The design C as shown in Figure 3.13 consists of a long cylinder which acts as battery storage area. The batteries used in this design are arranged in series. The gripper of robot arm is connected directly to the cylindrical battery compartment.

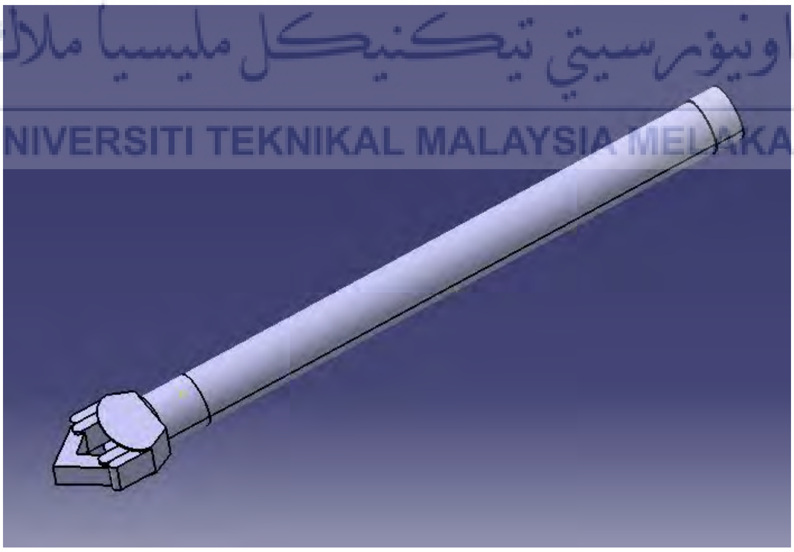


Figure 3.13: Design C

Figure 3.14 show the conceptual design D. The batteries will be stored in cylindrical shape compartment. The gripper of robot arm is attached to the bottom of cylinder.

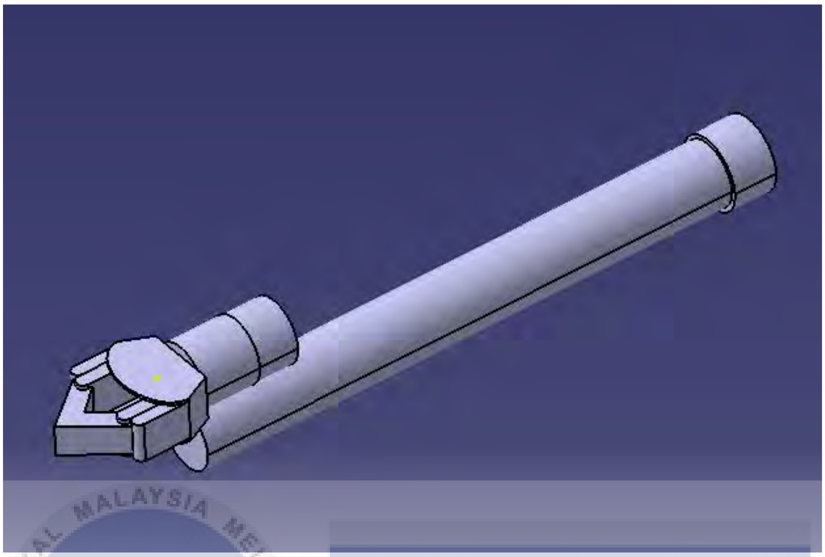


Figure 3.14: Design D

3.6.6 Pugh matrix selection method

The Pugh matrix selection method is used to select the best concept design. This method consists of main important criteria which is needed to be considered for fabrication process. Rating will be given to each design according to different aspect and criteria. The decision of rating will be: "++" represents very high; "+" represents high; "0" represents average; "-"represents low and "--" represents very low. After giving rating, the sum of "+", "-" and "0" is calculated. Net score will be obtained by using the sum of "+" to deduct the sum of "-". The highest net score will be selected as the best design and proceed to other process. The Pugh Matrix Selection method is as shown as Table 3.4.

Table 3.4: Pugh Matrix Selection Method

CRITERIA	DESIGN A	DESIGN B	DESIGN C	DESIGN D
LOW COST	0	+	+	++
LOW COMPLEXITY OF STURCTURE	+	+	+	0
LOW WEIGHT	--	0	+	+
HIGH PORTABILITY	-	+	++	--
HIGH DURABILITY	-	0	+	-
EASE OF USE	++	++	+	+
EASE OF HANDLING	0	++	++	0
LARGE BATTERY'S STORAGE AREA	++	+	0	0
EASE OF MAINTENANCE	++	-	-	-
EASE TO MANUFACTURE	+	+	++	0
SUM '+' s	8	9	11	3
SUM '0' s	2	3	1	4
SUM '-' s	4	1	1	4
NET SCORE	4	8	10	0
RANK	3	2	1	4

Note: Decision rating

“++” = very high; “+” = high; “0” = average; “-“ = low; “—“ = very low

3.6.6.1 Pugh matrix selection method analysis

Based on the selection analysis from Table, the final design chosen for the new manipulator is design C. The net score of Pugh matrix selection for design C is the highest among all of the 4 designs. The characteristics of this design is low cost, low complexity of structure, high portability, ease of handling and ease to manufacture. However, the weakness of this design is not easy to perform maintenance.

The weight of design A is the highest among the 4 designs. It consists of rectangular box which weighed a lot and occupied space. The design A is weak from the aspect of portability and durability. However, its rectangular box contributes to the large storage area of batteries and ease of maintenance as the batteries can be removed easily from the compartment.

It is not easy for design D to be carried everywhere due to its design. The gripper which attached to the bottom of cylinder can cause difficulty in carrying the manipulator. The durability for design D is weak. The strength of gripper which is attached to the bottom of cylindrical compartment is not strong when the gripper is grasping the load. This can cause gripper lose and drop off from the compartment after several uses.

The design B is ease to use and ease of handling. The durability is high in design B as the compartment with cylindrical shape is used. In cylinder, there is no sharp corners or edges like rectangular which can cause stress concentration when it is put underwater. However, it is not easy to perform maintenance for cylindrical compartment such as design B, design C and design D. This is due to the removal of the battery from the cylinder compartment is not as easy as in rectangular box. For cylinder, the batteries must be removal from one side of cylinder. If the compartment is rectangular shape, the batteries can be removed from the top of compartment and the condition inside the compartment is obvious at a glance.

In conclusion, design C is better than design A, design B and design D in the aspect of portability and easy to manufacture. Thus, design C is chosen to be fabricated through Pugh matrix selection method.

3.6.7 Modification of design

By using Pugh matrix selection method, design C is chosen. However, the design of current gripper consists of open end. If design C is applied, the water will enter the battery compartment easily. Thus, the design is modified so that the battery compartment is watertight. The new design of manipulator is sealed tightly by two end caps. The big PVC straight adapter and PVC reducing adapter are used to connect the gripper and the PVC pipe. The screws with size 3/8" are used to join the gripper with connector. All of the separate parts are screwed to ease the removal of separate parts. Figure 3.15 shows the different parts which are used to fabricate the manipulator. Figure 3.16 shows the well assembled manipulator.

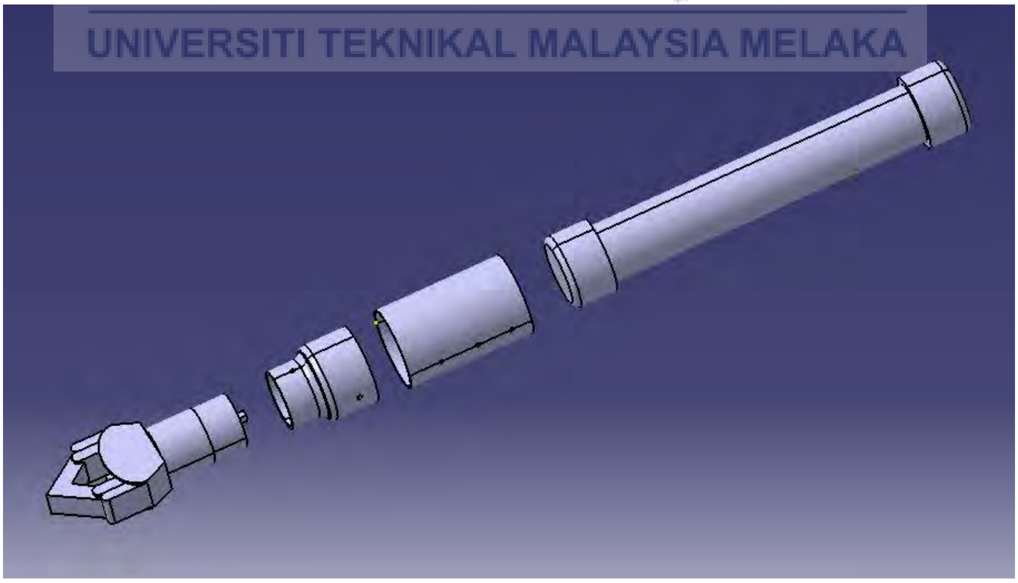


Figure 3.15: Different parts of manipulator

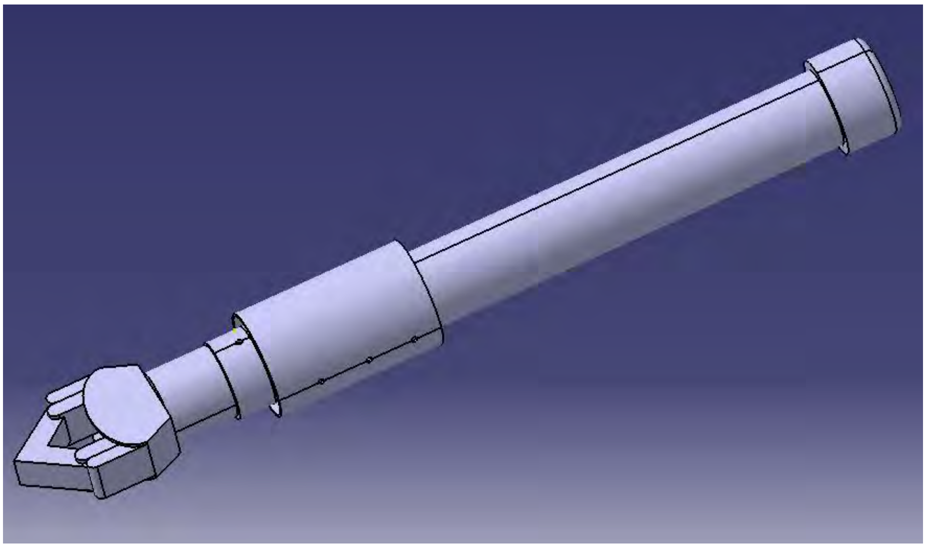


Figure 3.16: Assembled manipulator

3.6.8 Materials selection

The material should be selected by referring many aspects such as strength and waterproof ability. The material must be high strength and able to withstand high water pressure. The material used should be waterproof to ensure electric and electronic components in this project is secured. The selection of materials is important to ensure long life span of project. Table 3.5 shows the bill of materials of this project.

Table 3.5: Bill of Materials

No.	Name of Materials	Quantity
1	PVC Pipe (400mm x 40mm)	1
2	End Cap	2
3	PVC Straight Adapter	1
4	PVC Reducing Adapter	1
5	D size of Batteries	4
6	Motor	1
7	Payload Skid	1
8	Four core wire (2m)	1
9	Small container	1

3.6.8.1 PVC pipes with end cap

The materials chosen for battery compartment is PVC pipe with the diameter of 45 mm. The length of PVC pipe includes the end cap is 410 mm. The end cap is well fixed to the pipe to secure an enclosed compartment. PVC pipes consists of the advantages such as lightweight, waterproofing and low cost. There are two type of PVC pipes: Schedule 40 and Schedule 80. Both type of pipes consists of same inner diameter but different outside diameter. Schedule 40 have thinner wall than Schedule 80 PVC.

In this project, the PVC pipe with Schedule 40 are used. Collapse pressure is the amount of outside pressure that a pipe can withstand before it start collapsing inwards. For the Schedule 40 pipe with diameter of 45 mm, the collapse pressure it can withstand is 270 psi. PVC Schedule 40 can used in the water at the depth of 624 meters. Figure 3.18 shows that two end caps are well fixed to the pipe to secure an enclosed compartment

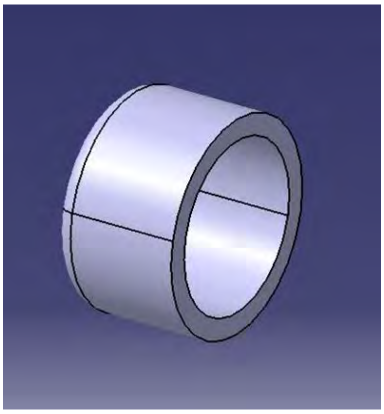


Figure 3.17: End cap

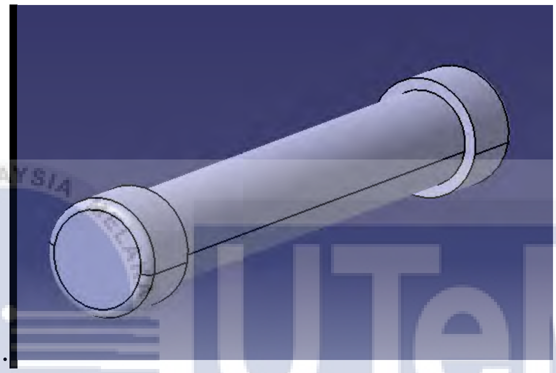


Figure 3.18: PVC pipe with end cap

3.6.8.2 PVC straight adapter

The PVC adapter is used to adapt the reducing adapter and end cap of cylinder. Six of the small holes are drilled on the body of straight adapter. The screws with size 3/8" are used to fix the reducing adapter and end cap to the straight adapter.

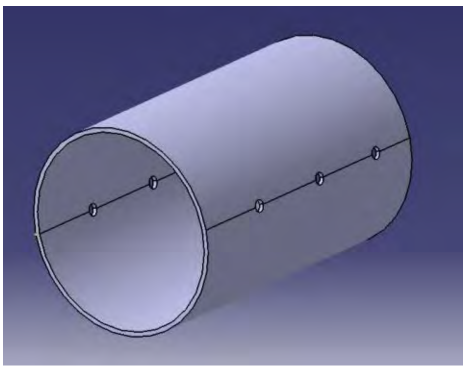


Figure 3.19: PVC straight adapter

3.6.8.3 PVC reducing adapter

The PVC reducing adapter is fixed into straight adapter. The small end is used to fix the gripper with screw. The large end is inserted into straight adapter and screwed tightly.

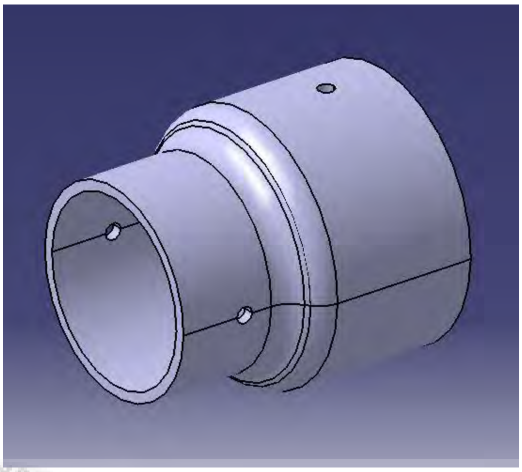


Figure 3.20: PVC reducing adapter

3.6.8.4 Small container

The small container as shown in Figure 3.21 acts as additional storage of electronic components other from the PVC pipe. In this project, the small container is used as the compartment for a circuit board called Terminal Connector Unit as shown in Figure 3.22. The small container is located between four core wire and the controller.

Figure 3.21: Small container

Figure 3.22: Terminal Connector Unit

3.6.8.5 Four core wire

A four core wire consists of four copper conductor cores. The inner diameter of gray PVC sheath is 3mm. In this project, four copper conductor cores from one side of wire is used to connect 4 individual wires of batteries and gripper. For another side of the four core wire, it is used to connect to the circuit board. Its PVC sheath secures the copper conductor cores from water and enhances the waterproofing ability of entire manipulator.

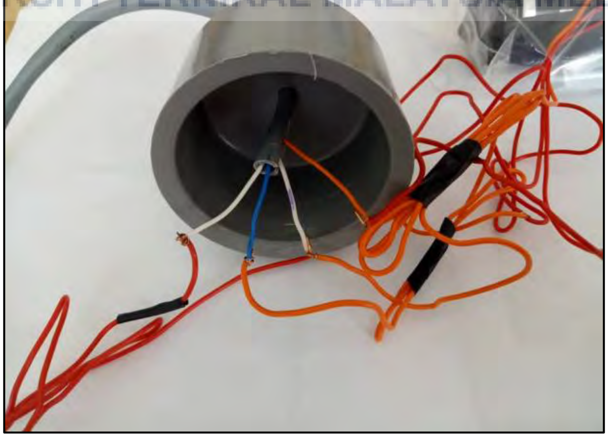


Figure 3.23: 4 core wire

3.6.8.6 Battery

In this design, four piece of “D” size batteries will be used to generate power for gripper. The diameter of the battery is 34.20 mm and its length is 61.50mm. Each battery weigh up to 90 grams. Each batteries consists of voltage value: 1.5 V. The batteries will be arranged in series and the voltage of batteries will become to 6 V. Four of the batteries are stored in the cylindrical compartment which is PVC pipe with end cap.

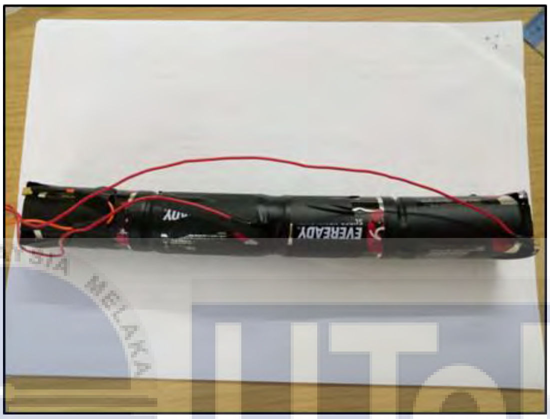


Figure 3.24: Batteries in series

3.6.8.7 Motor

Motor as shown in figure is used to generate rotating force to operate the gripper. The weight of the motor is 19 g. The output power is 0.16 to 3.0 W. The diameter of motor is 21 mm and its length is 25 mm. The technical specifications of motor is as shown as Table 3.6.

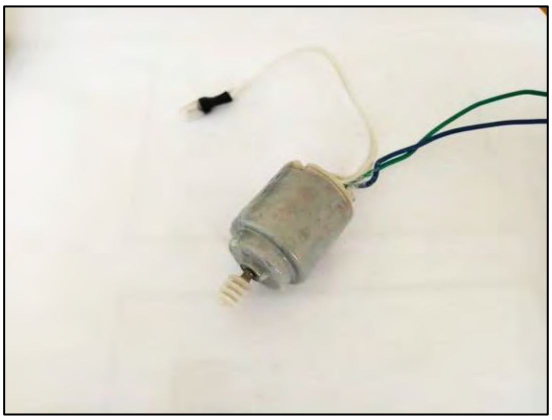


Figure 3.25: Motor

Table 3.6: Technical specification of motor

VOLTAGE		NO LOAD		AT MAXIMUM EFFICIENCY					STALL		
OPERATING RANGE	NOMINAL	SPEED	CURRENT	SPEED	CURRENT	TORQUE		OUTPUT	TORQUE		CURRENT
	V	r/min	A	r/min	A	mN.m	g.cm	W	mN.m	gcm	A
1.5-3.0	1.5	8100	0.21	6150	0.66	0.66	6.7	0.42	2.74	28	2.10

3.6.8.8 Power unit

Figure 3.26 shows the motor, worm gears and flat gears arranged in power unit. The tip of motor is stick to worm gears. The worm gear is connected to flat gears. The power generated in the motor is transmitted to gears. The gears act as speed reducing devices to allow small motor to provide greater power to be able to move heavy load. The transmission of power by gears is able to decrease the rotational speed and increase the torque. Figure 3.27 shows the concept of worm gears which is generated by motor to rotate the flat gears. When the worm gear is generated by motor in clockwise, the flat gear should make a counter-clockwise rotation. The rotation of flat gear will move the rack gear which connected to finger base.

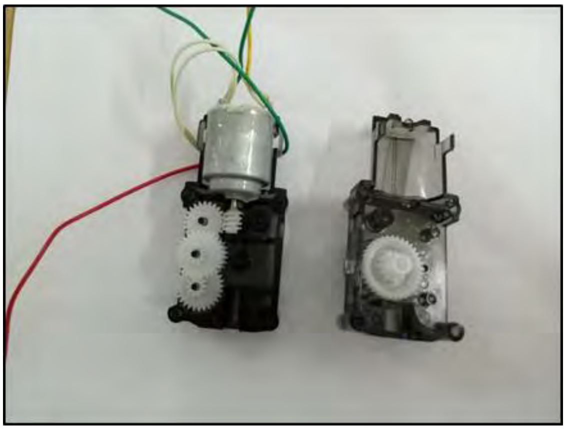


Figure 3.26: Power Unit

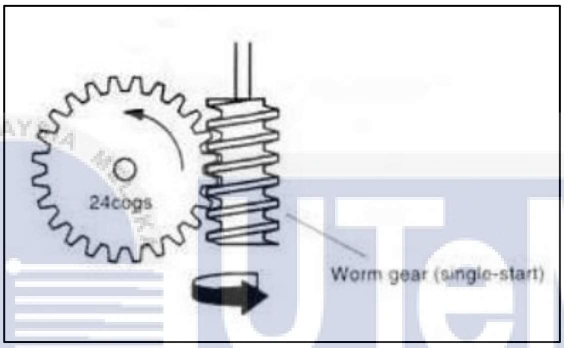


Figure 3.27: Worm gear and pinion gear

3.6.8.9 Payload Skip

The ROV components should be designed out of the robot arm workspace to prevent any damages on failure of its control. Thus, an equipment called Payload Skid as shown in Figure 3.28 is used to increase additional workspace.

Figure 3.28: Payload Skid

The Payload Skid is a modular frame for the BlueROV2 with mounting points for additional watertight enclosures and lights. By using the Payload Skid, the additional large instruments and other equipment can be added BlueROV2. It is designed to be fit tightly to the bottom of the ROV as shown in the Figure. The physical specification of Payload Skid is as shown in the Table 3.7. The 2-Dimensional drawing of Payload Skid is attached in Appendix A1.

Table 3.7: Physical specification of Payload Skid

Parameter	Value (mm)	Value (in / Ibs)
Length	475 mm	18 in
Width	338 mm	13.3 in
Height	197mm	7.7in
Weight (in air)	1200g	2.65lbs

It also can host up to an additional two Lumen subsea lights, twelve Ballast Weights, and a 4' Watertight Enclosure or three 3' Watertight Enclosures. In this study, Payload Skid is used to host the manipulator and its battery compartment. It can ensure the manipulator to perform tasks smoothly without damaged to BlueROV2 components. Figure 3.29 shows the Payload Skid fit to the bottom of BlueROV2.

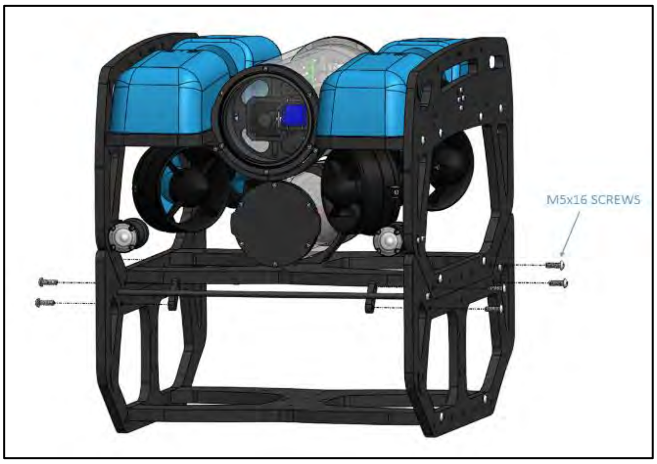


Figure 3.29: Payload Skid fit to the bottom of BlueROV2

3.6.9 Waterproof protection

There are some materials used to improve the waterproofing ability of manipulator. In this project, the waterproof materials used are: nail enamel, hot glue gun and tape. The transparent nail enamel is used to coat the motor and electric circuit board. The hot glue gun is used to seal the gap between gripper and PVC pipe. It is also used to seal the small box which is used to store electric circuit board. The tape is used to seal the gap between gripper and PVC pipe too. In this project, the electric components and motor will be housed in PVC with rubber end caps which sealed with hot glue.

3.7 Implementation of new design of manipulator to BlueROV2

3.7.1 Three options for positioning of manipulator on BlueROV2

After designing the new manipulator by using CATIA software, the position of manipulator on the vehicle is to be determined. There are three options for the position of manipulator on BlueROV2 as shown in the Table 3.8. The advantages and disadvantages are stated in the Table 3.9. The watertight battery compartment which store the electric components and the manipulator are fixed within the area of Payload Skid. The position and movement of manipulator will not interfere the area where BlueROV2 located.

Table 3.8: Three options for position of robot arm

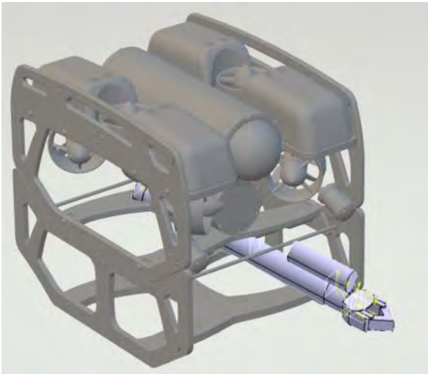
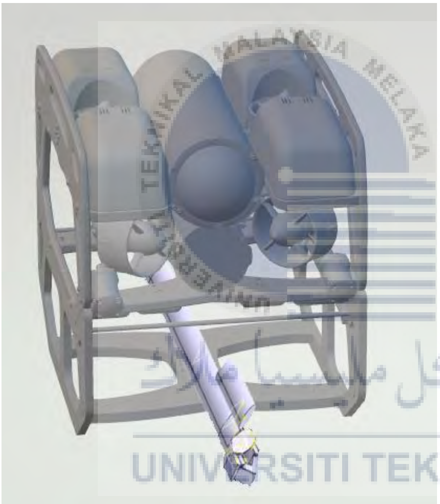
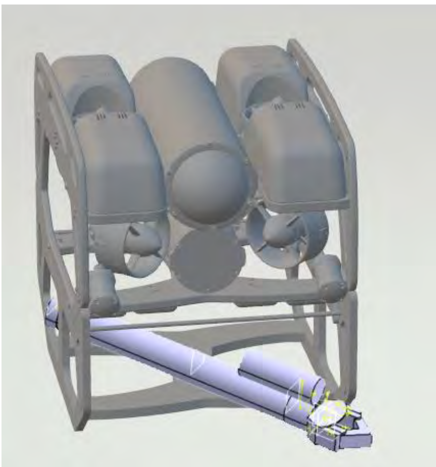
Figure	Options
	The manipulator is placed at the left side of the payload skid.
	The manipulator is placed at the center that under the vehicle.
	The manipulator is placed in an inclined position and faced toward the left corner of payload skid.

Table 3.9: Advantages and disadvantages of robot arm

Options	Advantages	Disadvantages
The manipulator is placed at the left side of the payload skid.	• It is good for manipulating objects when manipulator is at the left side of the vehicle. -This position enables manipulator to grasp object at left side corner easier.	• The manipulator is positioned far from the center of the vehicle. This position will cause the vehicle become imbalance. The weight of battery compartment will cause the ROV to incline to left side and affect the balancing of vehicle. • It requires the additional camera to monitor the action of manipulator. The movement of manipulator cannot be viewed by using the camera on ROV.
The manipulator is placed at the center that under the vehicle (inside of Payload Skid).	• The manipulator is positioned just about at the center of the vehicle. This would vertically align the center of buoyancy and the center of gravity thus balance the vehicle. • It doesn't requires any additional camera to monitor the action of robot arm. The movement of robot arm can be viewed by using the camera on ROV.	• The manipulator is hard to reach the object at corner since it is positioned in the middle of payload skid.

The manipulator is placed in an inclined position and faced toward the left corner of payload skid.	• It is good for manipulating objects when manipulator is placed in inclined position. This position enables manipulator to grasp object at corner easier.	• This position cause the distribution of weight of battery compartment within the payload skid imbalance. • It requires the additional camera to monitor the action of manipulator. The movement of manipulator cannot be viewed by using the camera on ROV.

In a nutshell, the position where the manipulator is placed at the center that under the vehicle (inside of Payload Skid) is chosen. It consists of the advantage which is the center location would vertically align the center of buoyancy and the center of gravity thus balance the vehicle. It also doesn’t requires any additional camera to monitor the action of gripper. The grasping process by gripper can be viewed by using the camera on ROV.

3.8 Determination of gripping force

There are some steps to determine the gripping force by using different mass of load. The object grasping process is conducted on land. The weight set as shown in the Figure 3.30 is used in this experiment. Each of the load is weighed 10 gram. The weight set are stacked and fixed together by tape.

Figure 3.30: Weight set

The mass of load used in this study are 20g, 40g, 60g, 80g, 100g, 120g, 140g and 160g. The object grasping process can be expressed into following steps:

1. The manipulator is positioned nearby the load with mass of 20 g.
2. The gripper is controlled to grasp the load. This force increment of gripper should be within certain limits such that the load neither gets damaged nor slips out of the jaws.
3. The load is being grasped and raised up to certain height.
4. The gripper is controlled to release the load.
5. The steps are repeated by increasing the mass of load. The mass of load is increased by 20 gram per times.
6. The increment of loads of 20 g is added until failure occurred due to slippage.

Figure 3.31 and Figure 3.2 shows the load grasped by gripper. The weight set are stacked and fixed together by tape.

Figure 3.31: The load grasped by gripper (top view)

Figure 3.32: The load grasped by gripper (side view)

3.3.6 Testing of manipulator

3.3.6.1 Testing the gripper in water

The first stage testing is done on the gripper of robot arm. This testing is to check the functionality of the gripper in water. By manipulating the controller, the gripper of robot arm will open and close as normal. The problem will be identified and tackled if any parts of gripper not functioning. The testing will be conducted in a water tank as shown in the Figure 3.33. This testing is to check whether the motor of the gripper is waterproof.

Figure 3.33: Small water tank

3.3.6.2 Testing the manipulator in water

The second stage testing is done on the new design of manipulator. This testing is carried out to test the functionality of manipulator in water. The testing includes: testing of the ability of open and close in water and testing of ability to grasp the load in water. By manipulating the controller, the testing is conducted. This is also to test the waterproof performance of manipulator. The problem will be identified and fixed if manipulator not functioning in water.

CHAPTER 4

RESULTS AND DISCUSSION

4.0 Introduction

This chapter presents the results of fabrication of manipulator. This chapter also shows the new design of manipulator developed by using CATIA software. In this study, the testing result based on functionality of gripper in water is presented. The manipulator is tested in water after fabrication is completed. The results of testing the gripping force of the gripper by using different mass of load is also presented in this chapter.

4.1 Results

4.1.1 Drawing of new design of manipulator

Figure 4.1 shows the gripper of robot arm generated by using CATIA software. Figure 4.2 shows the drawing of manipulator which consists of gripper and its battery compartment. The gripper is connected to the PVC pipe which acts as battery compartment in this project.

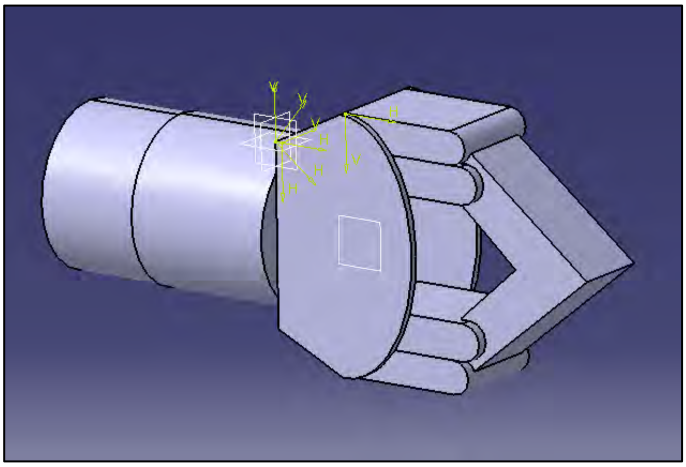


Figure 4.1: Gripper

Figure 4.2: Manipulator

Figure 4.3 shows the manipulator is fixed to the Payload Skid. The position of the manipulator is placed at the center of Payload Skid. The cable tie will be used to fix the manipulator onto Payload Skid. Payload Skid is used to host the manipulator and its battery compartment. Figure 4.4 shows the Payload Skid is assembled to the BlueROV2. The use of Payload Skid is to provide additional space for manipulator to perform tasks smoothly without damaged to BlueROV2 components. Appendix B17 shows the 2-dimensional drawing of full assembly of manipulator on BlueROV2.

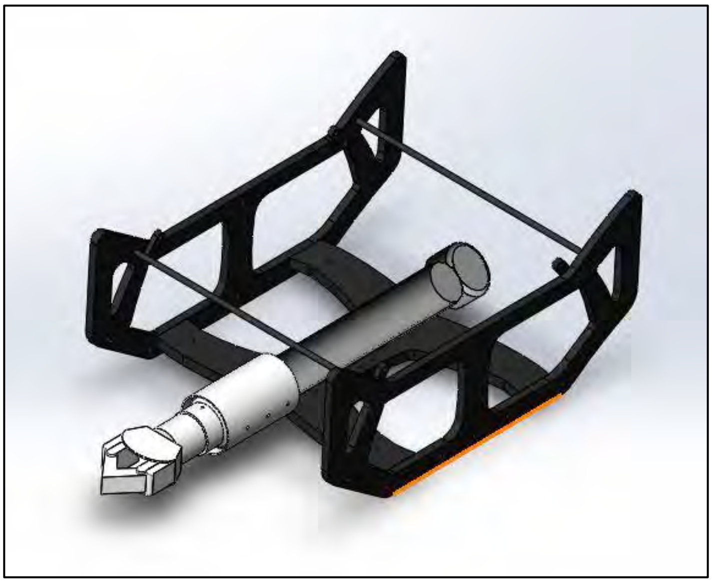


Figure 4.3: Manipulator on Payload Skid

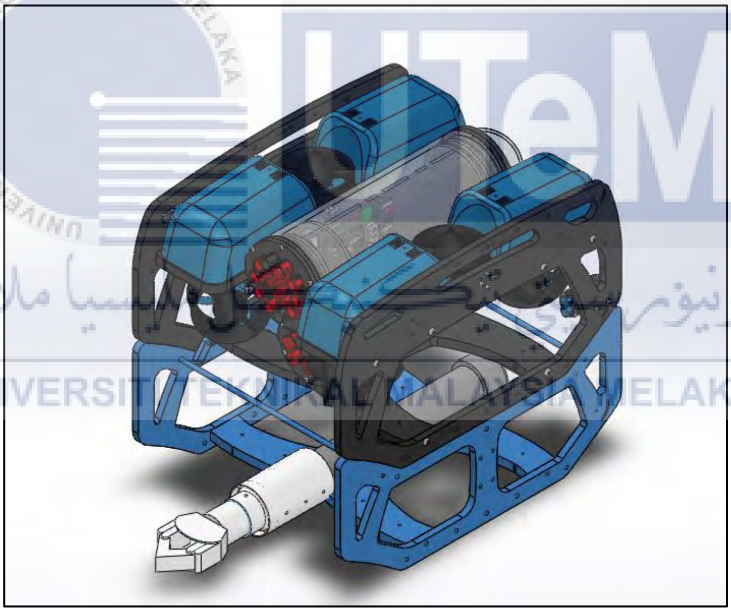


Figure 4.4: Payload Skid is attached to BlueROV2

Figure 4.5 shows the full assembly of the manipulator which consists of 4 core wire, small container, cable wire and controller. Figure 4.6 shows the separate parts of the manipulator. Table 4.1 shows the name of separate parts of the manipulator and their dimension respectively. Table 4.2 shows the specification of the manipulator. The details drawing for main parts of the manipulator is presented as appendices at the end of the thesis.

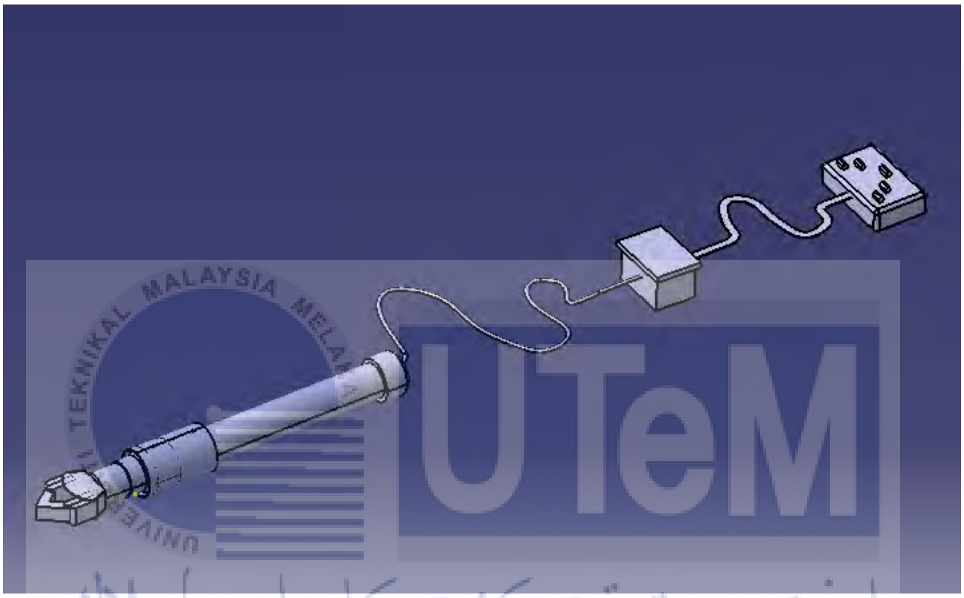


Figure 4.5: Fully assembled manipulator

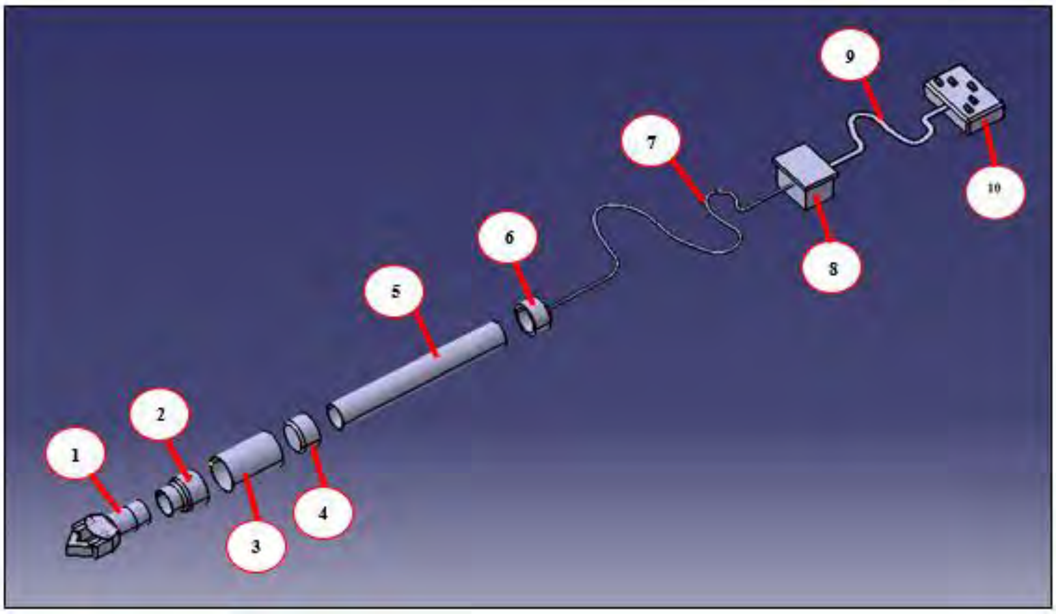


Figure 4.6: The main parts of manipulator

Table 4.1: The main parts of manipulator

Item. No	Part	Dimension	Quantity
1	Gripper	Open and close: 0-50 mm	1
2	PVC Reducing Adapter	Length: 70 mm Smaller diameter : 50 mm Larger diameter: 63 mm Inner diameter: 44 mm	1
3	PVC Straight Adapter	Length: 105 mm Outer diameter : 66 mm Inner diameter: 63 mm	1
4	End Cap	Length: 36 mm Outer diameter : 60 mm Inner diameter: 48 mm	1
5	PVC Pipe	Length: 341 mm Outer diameter : 48 mm Inner diameter: 45 mm	1
6	End Cap	Length: 36 mm Outer diameter : 60 mm Inner diameter: 48 mm	1
7	4 Core Wire	Length: 2 m Diameter: 5 mm	1
8	Small Container	83 mm x 5.9 mm x 57 mm	1
9	Cable Wire	0.9 m	1
10	Controller	130 mm x 80 mm x 34 mm	1

Table 4.2: Specification of the manipulator

Parameter	Value
Length	570 mm
Diameter	60 mm
Depth	3 m
Weight of manipulator (in air)	9.663 N
Weight of manipulator (in water)	2.613 N
Cable diameter	5 mm
Cable length	3 m
Supply voltage	6 V
Maximum torque	0.66 mN. m
Maximum grip force	1.5696 N
Finger opening	50 mm
Time to open/ close	4.8 s

4.1.2 Electrical circuit of the manipulator

The electric circuit of the manipulator is as shown in the figure. The new design of manipulator is equipped with one motor. The motor and the batteries are connected to the terminal connector unit. The connector unit is connected to the switch of the controller. In the direct current motor, the rotational direction can be changed by reversing the polarity (positive + and negative -) on the battery (connected to the terminals). In this design of circuit, the batteries are arranged in series. Figure 4.7 shows a posture of setting the switch to one side. This makes the electric current flow from plus side of the batteries and return to the minus side. When the switch is turned to another side, the direction of the currents flowing in the motor is reverse.

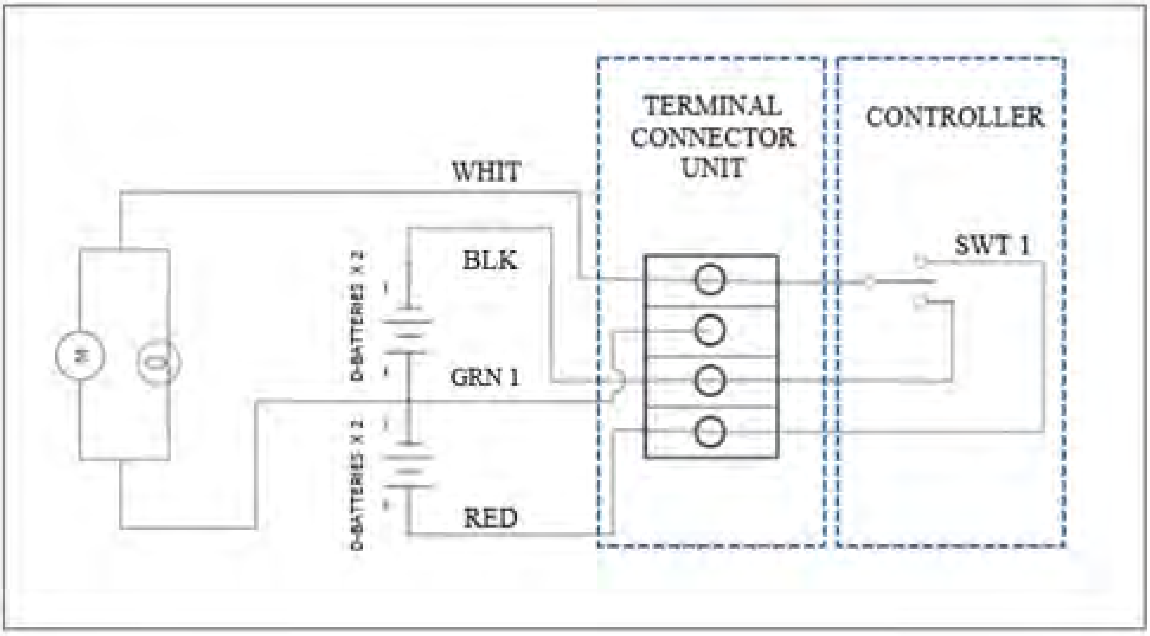


Figure 4.7: Electric circuit of the manipulator

4.1.3 Assembly of main parts

The manipulator is made up of main components which are batteries, terminal connector unit and controller. The power unit is connected to batteries while the batteries is connected to 4 core wire. The other side of 4 core wire is connected to terminal connector unit which is stored inside the small container. The terminal connector unit inside small container is connected to the controller.

Figure 4.8 show the power unit is connected to the batteries and the controller. The power unit is tested whether it is able to rotate in clockwise and anticlockwise. When the power unit is functioning as normal, the power unit is placed inside the gripper. Figure 4.9 shows the gripper is connected to the batteries.

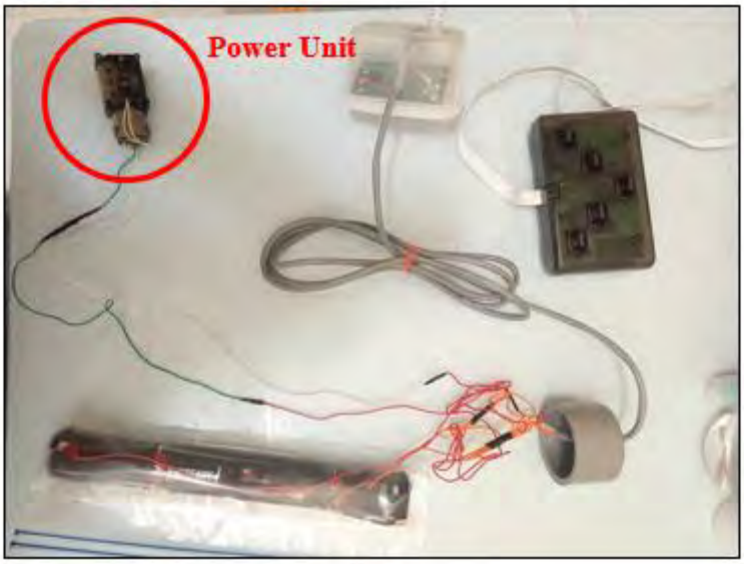


Figure 4.8: Assembly of power unit with batteries

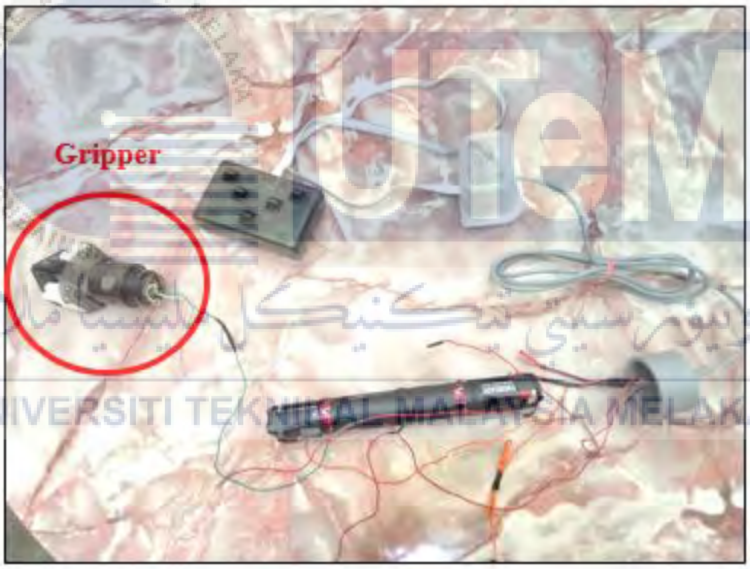


Figure 4.9: Assembly of gripper with batteries

Figure 4.10 shows the full assembly of manipulator which consists of gripper and its battery compartment. The batteries are stored inside the PVC pipe and closed with end cap. The gripper is connected to PVC pipe (battery compartment). The 4 core wire (2meters) is used to connect end cap and small container. The battery compartment is connected to 4 core wire while the other side of 4 core wire is connected to terminal connector unit which is stored inside the small container. The terminal connector unit inside small container is connected to the controller.

Figure 4.10: Assembly of manipulator

4.1.4 Modification of the wire connections

Although the manipulator is assembled and function well, the challenge presents on the wiring system when the manipulator is disassembled into separate parts. The wire is connected from gripper to the controller. The connection of wire is throughout the model as shown in Figure 4.11.

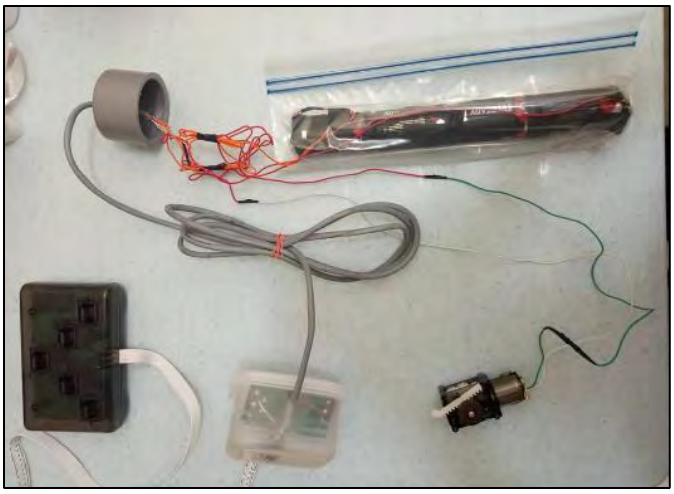


Figure 4.11: Wiring throughout the model

Figure 4.12 shows the twisting method is used to connect two wires. If there is error exist in gripper, the removal of gripper from the body will be difficult. The wire must be separated to take out any parts of gripper model. The wire connection part must be opened again by twisting.

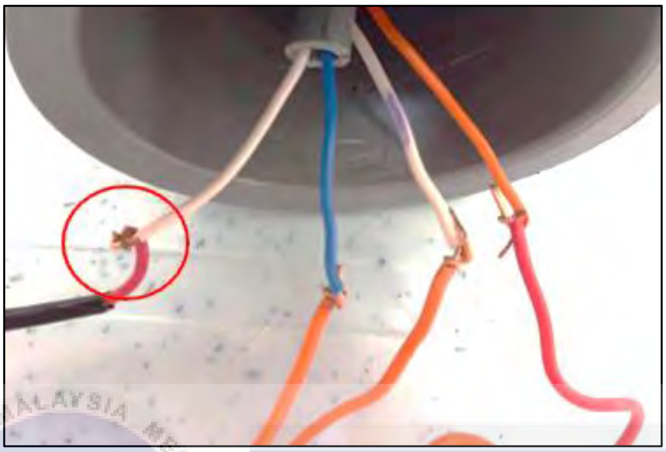


Figure 4.12: Joining of two wires

The connection parts are modified so that the removal of any wire or any part will be easier for user. The multi-pin connectors as shown in the Figure 4.13 are used for the connection of two wires. In this project, the multi-pin connectors are used for the connection of gripper wires and batteries wires and also the connection of 4 core wire and the batteries wires.

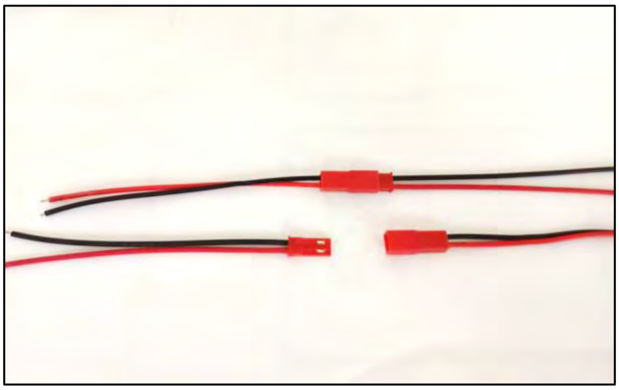


Figure 4.13: Multi-pin connectors

Figure 4.14 and Figure 4.15 show the connectors used in this project. The functionality of gripper is tested when the multi-pin connectors is fully assembled in this project. The testing result shows the circuit is completed and the gripper is able to open and close. By applying the connectors in the project, the separation and removal of wires becomes more easy and convenient.

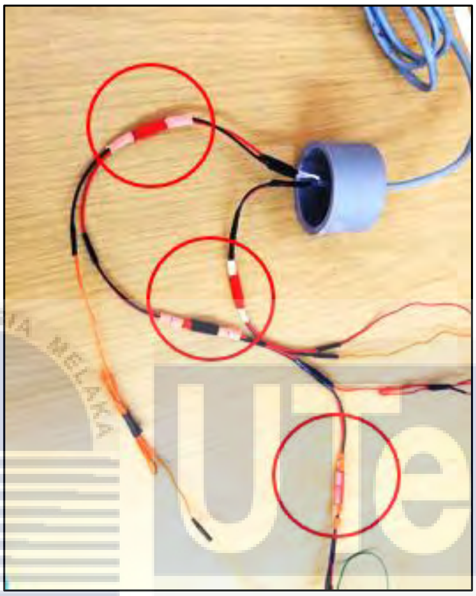


Figure 4.14: The connectors used in project

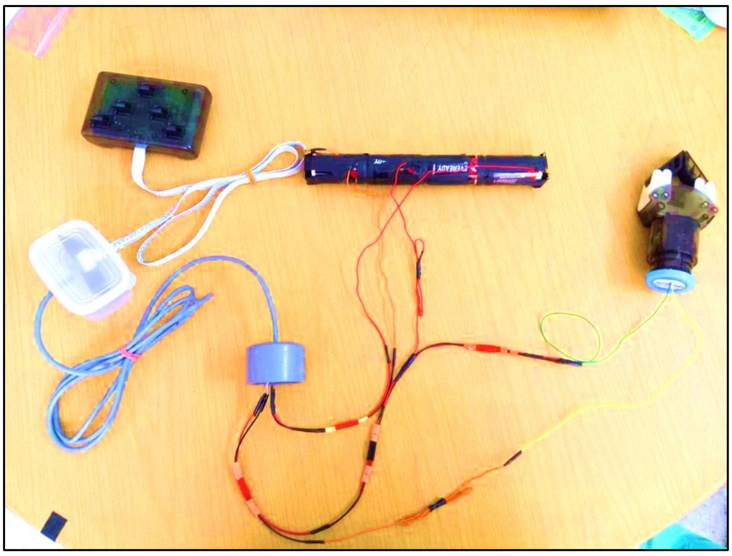


Figure 4.15: The connectors used in project

4.2 Calculations

4.2.1 Weight of manipulator in water

The pressure exerts on an object in the fluid is applied in all directions. In a static fluid, the pressure exerted in every direction depends on the depth of the fluid. The deeper the object in the fluid, the more pressure is exerted on the object that is submerged (Jonathan, 1996). The density of fluid can affect the pressure exerted on object. The denser the fluid above it, the more pressure it experiences. This is due to the weight of the fluid above the object. The Eq. (4.1) below is used to calculate the pressure exerted on an object submerged in a fluid:

$$P = \rho .\ g.\ H \tag{4.1}$$

Where

- ρ is the density of the fluid
- g is the acceleration of gravity
- h is the height of the fluid above the object

There are additional pressure exerted on object in water when the container is open to atmosphere. The additional pressure is called atmosphere pressure. To find the total pressure, the pressure exerted on object in water is added with atmosphere pressure as shown as Eq. (4.2). The atmospheric pressure is 1.01 x 10^5 N/m^2.

$$Ptotal = Pfluid + Patmosphere \tag{4.2}$$

$$Ptotal = \rho.g.h + Patm$$

In this project, the manipulator is designed to be submerged in water at the depth of 3 meter. The density of water is 1.00 x 10^3 kg/m^3. The magnitude of the acceleration due to gravity is 9.81 m/s^2.

$P = \rho .\ g.\ H$

$= 1.00 \times 10^3\ kg/m^3 \times 9.81\ m/s^2 \times 3\ m$

$= 29{,}430\ N/m^2$

$= 0.2943 \times 10^5\ N/m^2$

$P_{total} = \rho.g.h + P_{atm}$

$= 0.2943 \times 10^5\ N/m^2 + 1.01 \times 10^5\ N/m^2$

$= 1.3043 \times 10^5\ N/m^2$

$= 130.43\ kPa$

When an object submerged in water, it will experience a buoyant force. The buoyant force is the fluid exerts an upward force on an object. According to Archimedes' principle, the buoyant force on an object immersed in a fluid is equal to the weight of the fluid displaced as shown as in Eq. (4.3) (Michael et al., 2003).

$$\text{Buoyant force} = \text{weight of fluid displaced by object} \tag{4.3}$$

$$F_b = W_f$$

When an object is completely or partially immersed in a fluid, an upward force exerted by fluid on the object is equal to the weight of the water that is being displaced by the submersion. When the object is submerged in water, the submerged surface of the object is stroked by the fluid molecules. These impact forces are combined into a single force that is buoyant force as shown as in Eq. (4.4).

$$F_b = \rho g V = \rho g h A \tag{4.4}$$

Where

F_b = buoyant force of a liquid acting on an object (N)

ρ = density of the liquid (kg/m^3)

g = gravitational acceleration (9.80 m/s^2)

V = volume of liquid displaced (m^3)

h = height of water displaced by a floating object (m)

A = surface area of a floating object (m^2)

In addition, the buoyant force created from the pressure exerted on the object by the fluid. As the depth of object increases, the fluid pressure increases (Richard and Rusty, 2006). Thus, the pressure on the bottom of an object is always greater than the force on the top. The buoyant force is present whether the object floats or sinks. Figure 4.16 shows the pressure is exerted on an object.

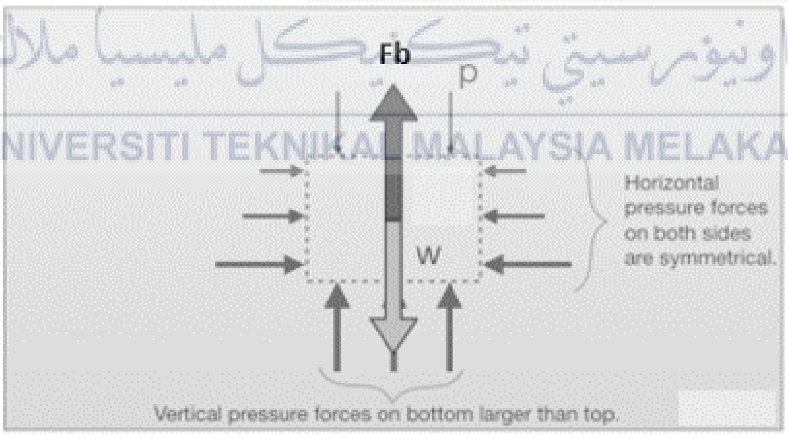


Figure 4.16: Pressure exerted on object

The displacement method is used to determine the volume displaced by fluid (Chris, 2018). In order to measure the volume of manipulator in this project, a container is filled up with water. The initial water level without the manipulator is record. The manipulator is immersed into the water and the water level rises. The change in the water level is measured and the volume change is calculated by using the dimensions of the container.

Mass of assembled manipulator in air $= 0.985$ kg

Weight of assembled manipulator in air, $F_{mair} = 0.985 \text{ kg} \times 9.81 \text{ m/s}^2$

$= 9.663$ N

Initial volume of tank (without manipulator) $= 545 \text{ mm} \times 440 \text{ mm} \times 130 \text{ mm}$

$= 31.174 \times 10^6 \text{ mm}^3$

Final volume of tank (with manipulator) $= 545 \text{ mm} \times 440 \text{ mm} \times 133 \text{ mm}$

$= 31.893 \times 10^6 \text{ mm}^3$

Volume of water displaced, $V_f = 31.893 \times 10^6 \text{ mm}^3 - 31.174 \times 10^6 \text{ mm}^3$

$= 0.719 \times 10^6 \text{ mm}^3$

$= 7.19 \times 10^{-4} \text{ m}^3$

Weight of water displaced, $W_f = \rho.g.V$

$= 1000 \text{ kg/m}^3 \times 9.81 \text{ m/s}^2 \times 7.19 \times 10^{-4} \text{ m}^3$

$= 7.05$ N

Buoyant force = Weight of water displaced

$F_b = W_f$

Buoyant force, $F_b = 7.05$ N

Since the manipulator is fully submerged,

Volume of manipulator, $V_m = V_f = F_b / \rho_f.g$

$= 7.05\ N / (1000kg /m^3 \times 9.81\ m/s^2)$

$= 7.19 \times 10^{-4}\ m^3$

Density of the manipulator, $\rho_m = m_m/V_m$ = Fmair / (g.Vm)

$= (9.663\ N) / (9.81\ m/s^2 \times 7.187 \times 10^{-4}\ m^{3)}$

$= 1370.55\ kg/m^3$

Weight of manipulator in water = weight of manipulator in air – weight of displaced water

Weight of manipulator in water = 9.663 N – 7.05 N

= 2.613 N

The calculations show that the weight of manipulator in air is more than the weight of fluid displaced by manipulator. The volume of displaced water is equal to volume of manipulator. Therefore, the manipulator is sink in the container. The weight of manipulator in water is recorded.

4.2.2 Gripping force of gripper

The gripper mechanism is used to convert input power into the required force to grasp and hold the object (Jaafar and Yusoff, 2008). There are two important parameters in grasping the load which are mass of an object and coefficient frictional force. Figure 4.17 shows the basic idea of gripper enclosing object. W is represents weight of object and F_g is represents gripping force of gripper. Figure 4.18 shows the free body diagram of the gripper and the load.

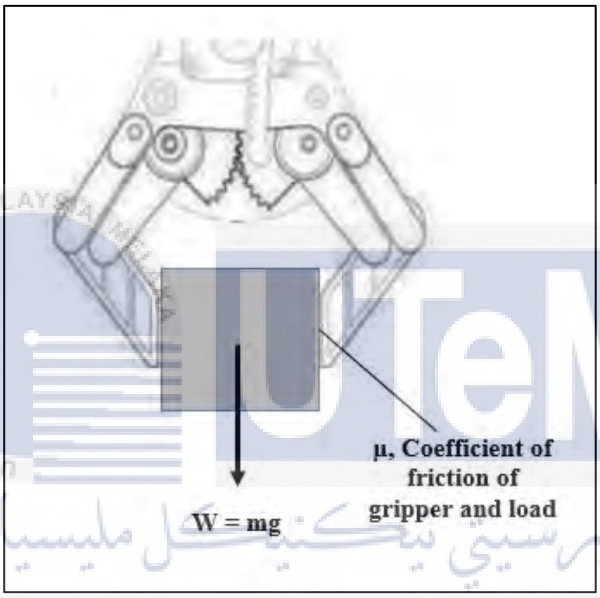


Figure 4.17: Basic idea of gripper enclosing object

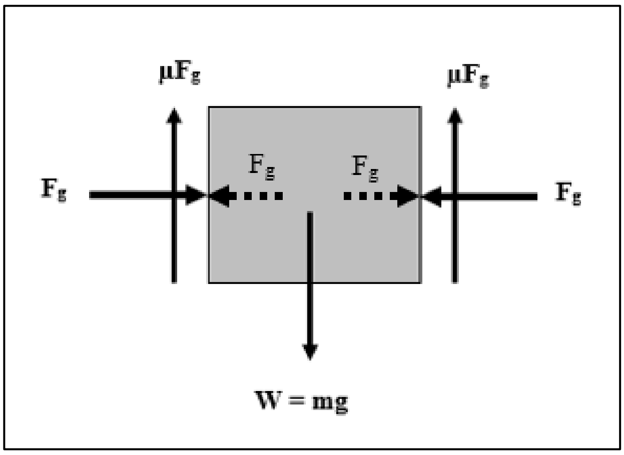


Figure 4.18: Free body diagram of the gripper and the load

There are two ways which constraining the object in gripper. The object is enclosed partly by the finger of gripper which constraining its motion. Thus, the contact surface of finger can be designed to be in approximate shape of part geometry. In addition, the friction is used to hold the object between fingers and the object. The finger must apply sufficient force for friction to maintain the object against gravity or other force that might arise during holding operation. The force exerted by gripper to resist the slippage depends on the weight of the load and coefficient of friction.

In this project, the gripper is simple design which may grasp different size of objects as long as the length not more than 50 mm. It is designed to perform contraction (grasp) and expansion (release) operations with less amount of power. The gear and rack method is used to actuate the opening and closing of gripper. The gripping force can be calculated by using the Eq. (4.5):

$$F_g = \frac{mg}{\mu n} \tag{4.5}$$

Where

F_g = gripping force of gripper, N

m = mass of the object, kg

g = gravity acceleration, m/s^2

μ = coefficient of friction

n = number of pairs of contact surface

For the gripper used in this project, the data are computed as follows:

Mass of load = 0.02 kg

Gravity acceleration = 9.81 m/s^2

Coefficient of friction between gripper finger (plastic) and load (steel), μ= 0.5

Number of pair, n = 2

Thus, the gripping force of the gripper for load of 0.02 kg is:

$$F_g = \frac{mg}{\mu n}$$

$$F_g = \frac{0.02kg \; x \; 9.81m/s^2}{0.5 \; x \; 2}$$

$$F_g = 0.1962 \text{ N}$$

Table 4.3 shows the gripping force based on different mass of load. The value of coefficient of friction between gripper finger (plastic) and load (steel), is remained as μ= 0.5 for every increment of mass of load. The graph of gripping force versus different mass of load is plotted as shown as in Figure 4.19.

Table 4.3: Gripping force based on different mass of load

Mass of load (kg)	Gripping force (N)
0.02	0.1962
0.04	0.3924
0.06	0.5886
0.08	0.7848
0.10	0.9810
0.12	1.1772
0.14	1.3734
0.16	1.5696

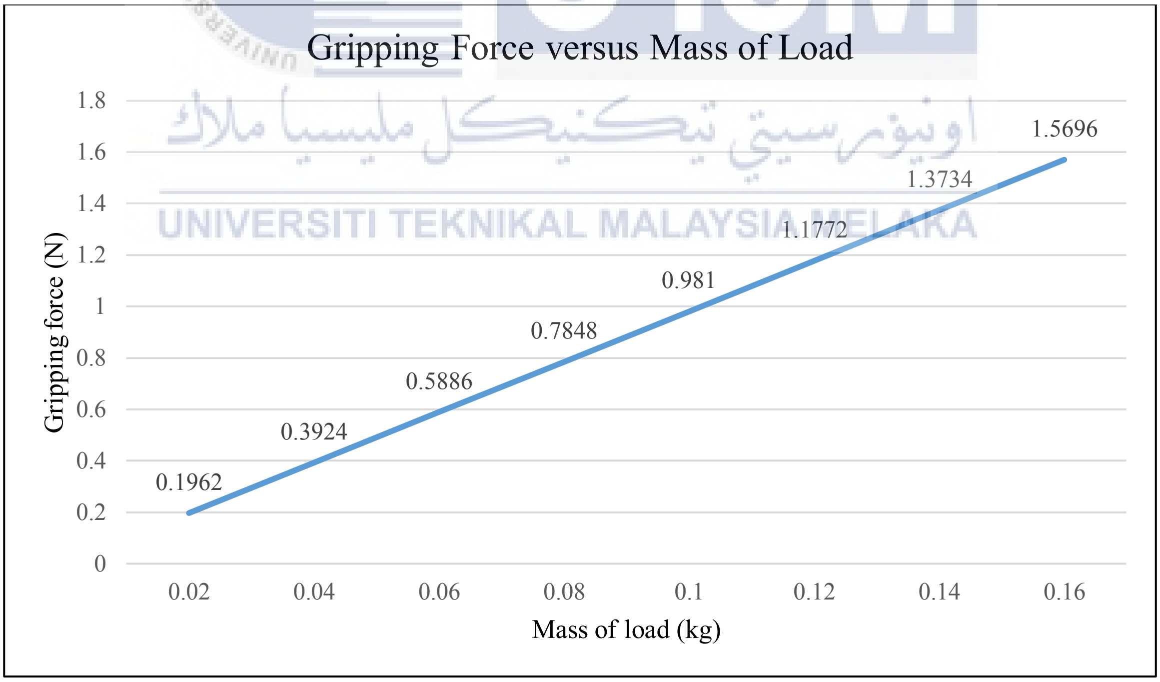


Figure 4.19: Gripping force versus mass of load

The coefficient of friction is varied by different material's surface. By changing the coefficient of friction, the gripping force is varied. Table 4.4 shows the gripping force based on different value of coefficient of friction. The mass of load is remains constant as 0.02 kg for different value of coefficient. The graph of gripping force versus different coefficient of friction is plotted as shown as in Figure 4.20.

Table 4.4: Gripping force based on coefficient of friction

Coefficient of friction	Gripping force (N)
0.1	0.9810
0.2	0.4905
0.3	0.3270
0.4	0.2453
0.5	0.1962
0.6	0.1635
0.7	0.1401

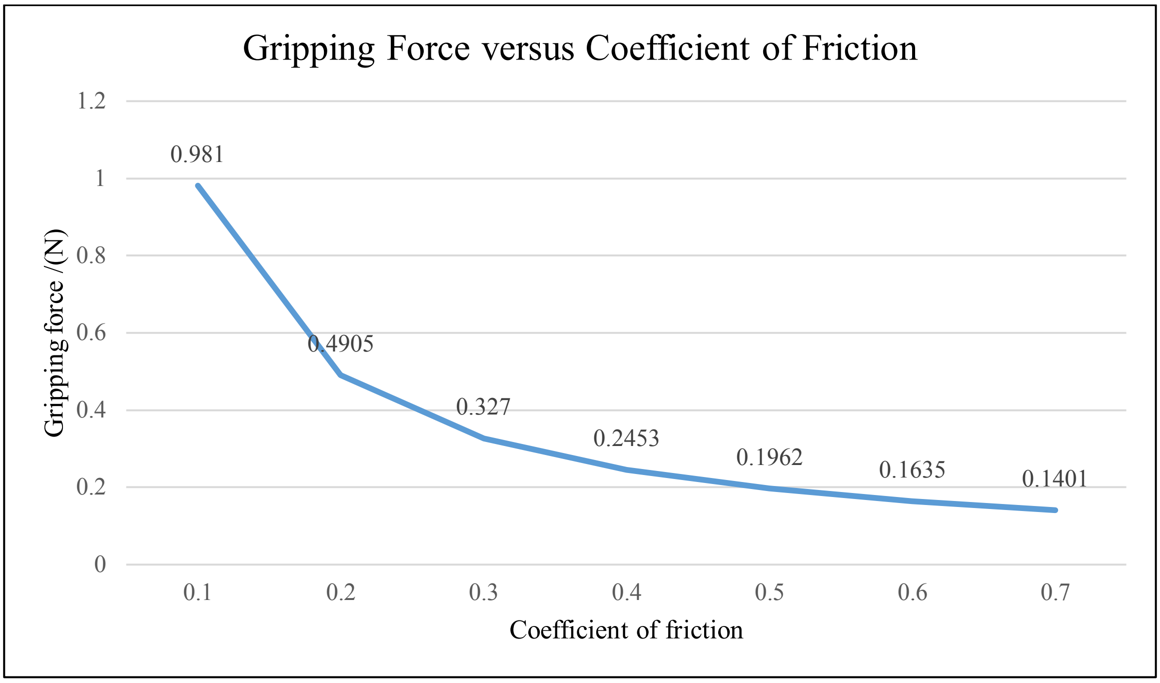


Figure 4.20: Gripping force versus coefficient of friction

4.2.2.1 Analysis of results

In this project, the relationship between the gripping force and the mass of load are investigated. The experiment is conducted by increasing the mass of load from 20g, 40g, 60g, 80g, 100g, 120g, 140g and 160g. The ability of finger of gripper to grasp and hold the load are investigated. Table shows the results of mass of load and the gripping force. The gripping force is directly proportional to mass of load. As the mass of load increasing, the gripping force is also increasing. This is due to the greater force is required to overcome the gravity acceleration of the load and hold the object.

The maximum mass of load that can be grasped by gripper is 0.16 kg. There is a failure due to slippage occurs when the mass of load is more than 0.16 kg. When the mass of load is 0.18 kg, the gripper is unable to grasp it well. The load dropped when the manipulator is being raised up. To obtain the high accurate value of maximum mass of load, the procedure are repeated by using load at 0.17 kg. However, the load is dropped when the manipulator is being raised up. Therefore, the maximum allowable mass for gripper is 0.16 kg and the maximum gripping force is 1.5696 N.

The coefficient of friction means the ratio of the force acting between the material surfaces to the pulling force. There are two type of coefficients: static and kinetic. The kinetic coefficient of friction is applies to objects that are in motion. While, the static coefficient of friction are used for objects without relative motion. (William, 2010). The gripping force of the gripper may varies with different coefficient of friction. The coefficient of friction is depends on the type of materials of object grasped by the gripper.

The graph in Figure 4.20 shows the relationship between coefficient of friction and the gripping force. As the coefficient of friction increase, the gripping force decrease. This means if the surface of materials is very smooth, the coefficient of friction may be very low. The gripping force required is higher with the decrease of coefficient of friction. Low coefficient of friction require higher grip forces for gripper to grasp the object. Thus, the low coefficients of friction is not appropriate for grasping object.

4.3 Testing

4.3.1 Testing the gripper in water

The gripper is tested in water before assembled to the battery compartment. Before testing the gripper in water, the motor is coated with three layers of nail enamel. Testing is conducted to the gripper and its motor in the water. Figure 4.21 shows the batteries, terminal connector unit and the controller are placed on land. The wires of gripper are immersed in the water. Figure 4.22 shows the water level is higher than gripper that is water immerse the body of gripper fully.

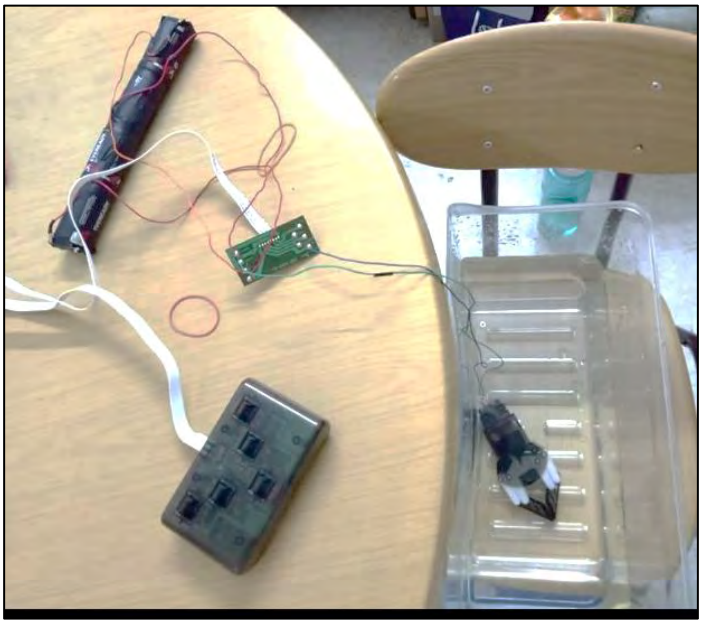


Figure 4.21: Testing of gripper in water

Figure 4.22: The gripper fully immersed in water

The testing results show that the movement of gripper is controlled by using controller, it is able to open and close as on land. Figure 4.23 shows the gripper is opening its finger and Figure 4.24 shows the gripper is closing its finger. The testing of gripper is successful as the gripper can function well underwater.

Figure 4.23: Gripper Opening (top view)

Figure 4.24: Gripper closing (top view)

The gripper is placed in water for 3 hours. After 3 hours, the functionality of gripper is tested again. The testing of the gripper is successfully as the gripper is able to open and close in water after 3 hours. After it, the gripper is assembled into manipulator.

4.3.2 Testing the manipulator in water

The well assembled manipulator is placed in the water at the depth of 133 mm. The manipulator is tested from the aspect of functionality and waterproof ability. The manipulator is sealed with hot glue gun and tape to prevent the water from entering the battery compartment. The testing is conducted to open and close the finger of gripper by using controller. Figure 4.25 shows the manipulator is able to open its finger in water. Figure 4.26 shows the manipulator is closing its finger.

Figure 4.25: Gripper opening

Figure 4.26: Gripper closing

The testing results shows the manipulator is function well in water. The manipulator is tested from the aspect of perform task. The manipulator is positioned nearby the load. The load is composed of 16 pieces of weight set. The 16 pieces of weight set with total weight of 0.16 kg are stacked, fixed together and placed in water tank. The controller is controlled so that the gripper can open or close its finger to perform grasping tasks. Table 4.5 shows the procedure of task performing of the gripper in water.

Table 4.5: The gripper grasping the cylindrical load

Figure	Descriptions
	• The weight set are stacked into cylindrical shape. • Gripper is approaching with the load. • The gripper's finger is opened to grasp the load slowly as shown in the figure.
	• Gripper close its finger to grasp the load.
	• The load is being grasped and raised up from water. • The gripper is able to grasp and hold the load tightly. The load does not slip from the finger of gripper during the grasping and raising up process.

The testing is carried out by using the load with circular shape. The 16 pieces of weight set are put into the circular container. The mass of load is maintained as 0.16 kg. This is to test whether the gripper is able to grasp and hold the circular object. Table 4.6 shows the steps of gripper grasping the object at the corner.

Table 4.6: The gripper grasping the circular load

Figure	Descriptions
	• The 16 pieces of weight set are put into the circular container. • The circular load is put into the water tank.
	• Gripper is approaching with the load. • The gripper's finger is opened.

	• Gripper close its finger to grasp the load.
	• The load is being grasped and raised up from water. • The gripper is able to grasp and hold the load tightly. The load does not slip from the finger of gripper during the grasping and raising up process.

Next, the 16 pieces of weight set with total weight of 0.16 kg are stacked and fixed together. The load is placed at the corner of water tank. The mass of load is maintained as 0.16 kg. This is to test the movement of gripper whether it is able to reach the load at corner and grasp it successfully. Table 4.7 shows the steps of gripper grasping the object at the corner.

Table 4.7: The gripper grasping the object at corner

Figure	Descriptions
	• The gripper is approaching the load at corner.
	• The finger is opened to grasp the load at corner. • The design of the finger enable it to reach the load at corner.
	• The load is being grasped and raised up from water. • The gripper is able to grasp and hold the load tightly. The load does not slip from the finger of gripper during the grasping and raising up process. • The testing is successful as the failure due to slippage does not occur.

After the testing in water, the manipulator is removed from water and placed on land for one days. After one days, the motor of the gripper is tested on land. The results show that the motor is still able to rotate in two direction as normal. In addition, the battery compartment is opened to check whether it is waterproof. The body of the manipulator is wiped by wiping cloth after testing the functionality of gripper in water. The result shows that the batteries and the cable wires inside the PVC pipe is secured from water. The compartment has achieved waterproof condition.

The testing results show that the manipulator is able to perform grasping tasks in water. The gripper is able to open and close its finger successfully in the water to grasp the load with two different shapes. The design of finger also enable it to reach the load which placed at the corner of the water tank. When the gripper grasp the load in water, there is no continuous force required to hold the object. The load can stay between the fingers of gripper statically when there is no continuous force generated by motor. This shows the gripping force of gripper is strong enough to hold the object in same position without receiving continuous force. When the manipulator is being raised up from water, the finger of gripper is able to grasp and hold the load. Since the manipulator is able to function well and perform grasping tasks in water, the testing of manipulator underwater is successful.

CHAPTER 5

CONCLUSIONS

5.1 Summary

In this study, the underwater manipulator for BlueROV2 application is designed and fabricated. By using Pugh matrix selection method, the design C is chosen and modified to be fabricated. The details design of manipulator are generated by using CATIA software. The manipulator is placed at the center that under the vehicle (inside of Payload Skid) as this position ensure the balancing of the vehicle. Based on the results obtained, as the mass of load increase, the gripping force is also increase. The results clearly shows the maximum mass of load that can be grasped by gripper is 0.16 kg. When the mass of load is increased further, the gripper is unable to grasp the load well. The results is proven by showing that when the mass of load is increased to 0.17 kg and 0.18 kg, there is a failure due to slippage. The load dropped when the manipulator is being raised up. Therefore, the maximum gripping force of gripper is 1.5696 N. The gripping force is also affected by the coefficient of friction. When the coefficient of friction is 0.1, the force required to grasp the load is 0.9810 N. As the coefficient of friction increase, the gripping force is also increase.

The testing is conducted to the well assembled manipulator. By manipulating the controller, the manipulator is able to grasp and hold the load in water. The shape of load tested included cylindrical shape and circular shape. When the manipulator is being raised up from the water, the cylindrical load and circular load are still resists in position between the fingers of gripper. The manipulator is tested by grasping the load which is placed at the corner of water tank. The design of finger enable manipulator to reach the load at the corner and perform the grasping task successfully. From the testing results, the load does not slip off from gripper when there is no continuous force generated by motor. Thus, the gripping force of gripper is strong enough to grasp and hold the load between two fingers of gripper.

5.2 Recommendations

There are some recommendations for the upcoming research which is related to underwater manipulator. One of the recommendations is the underwater manipulator can be integrated with more fingers. For example, the gripper with three fingers can be designed to increase the gripping forces so that it can grasp more objects of different sizes and shapes. The design of manipulator also can be more sophisticated so that it is able to perform multiple tasks in water. The additional equipment such as force sensor can be added to the fingers of gripper. This is to ensure the gripper can automatically detect and grasp the object in the water without any human manipulation.

In addition, the electrical and control system of the underwater manipulator can be improved by removing the cable connection between the manipulator and operator. This can ensure better movement for manipulator in the water without limitation. For the future research, the improvement can be done from the aspect of mobility and navigation. The future manipulator will be mobile and able to move in the water under their own power and navigation systems. Therefore, the future mobility and navigation of manipulator will not depends on the underwater vehicle only.

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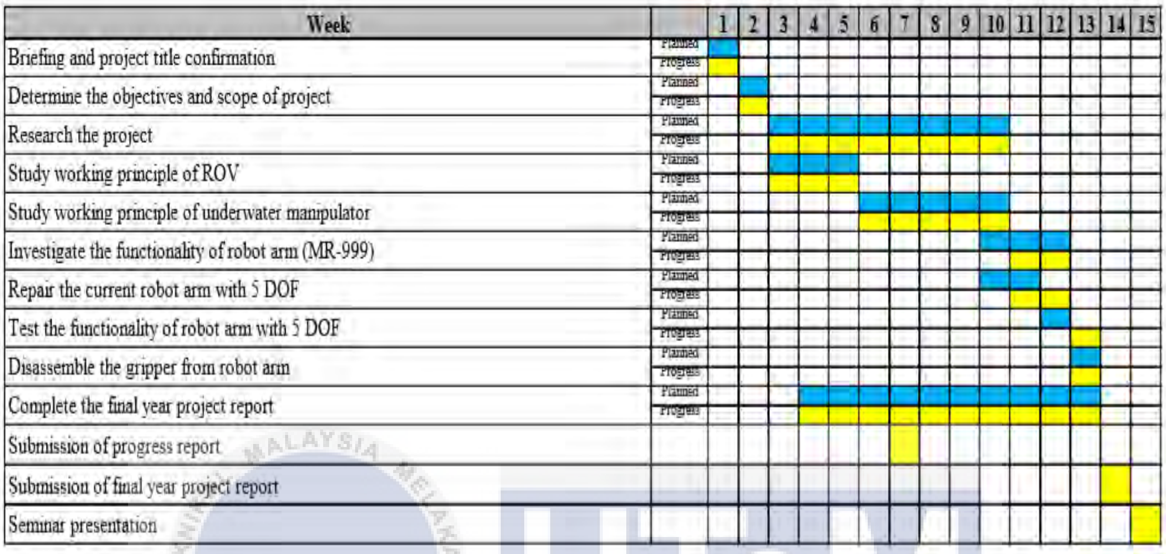
APPENDICES

APPENDIX A1



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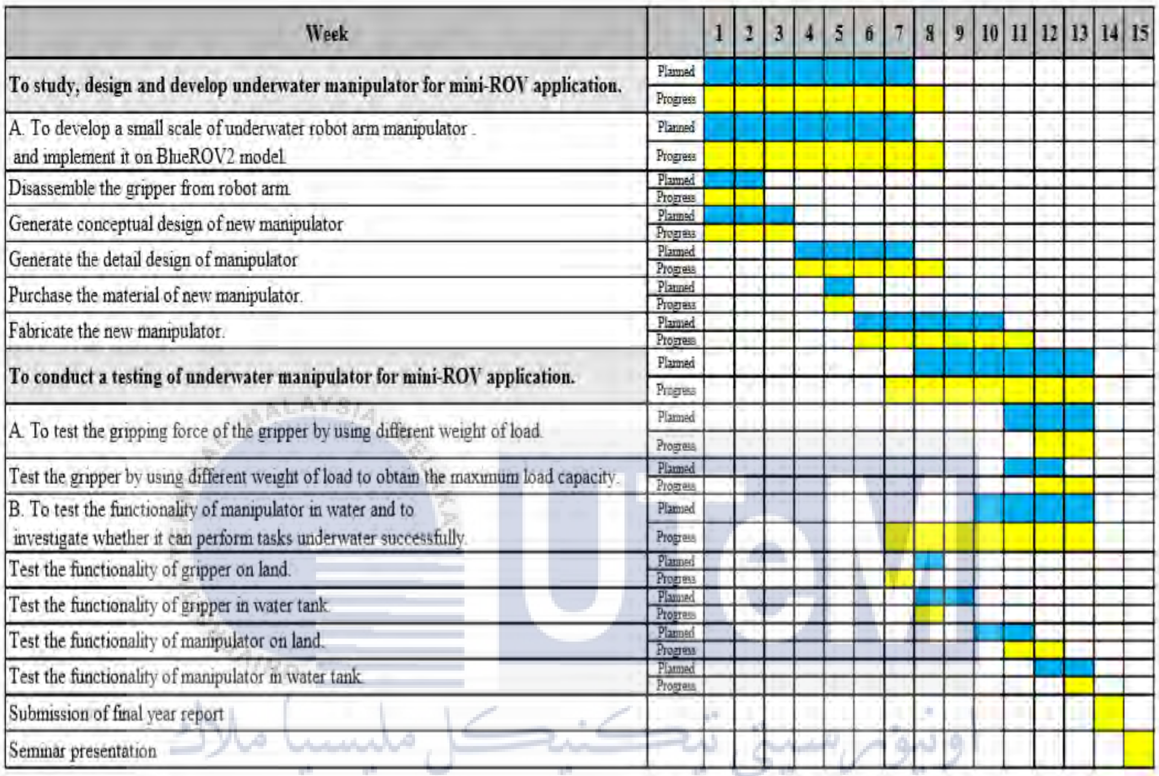

Week
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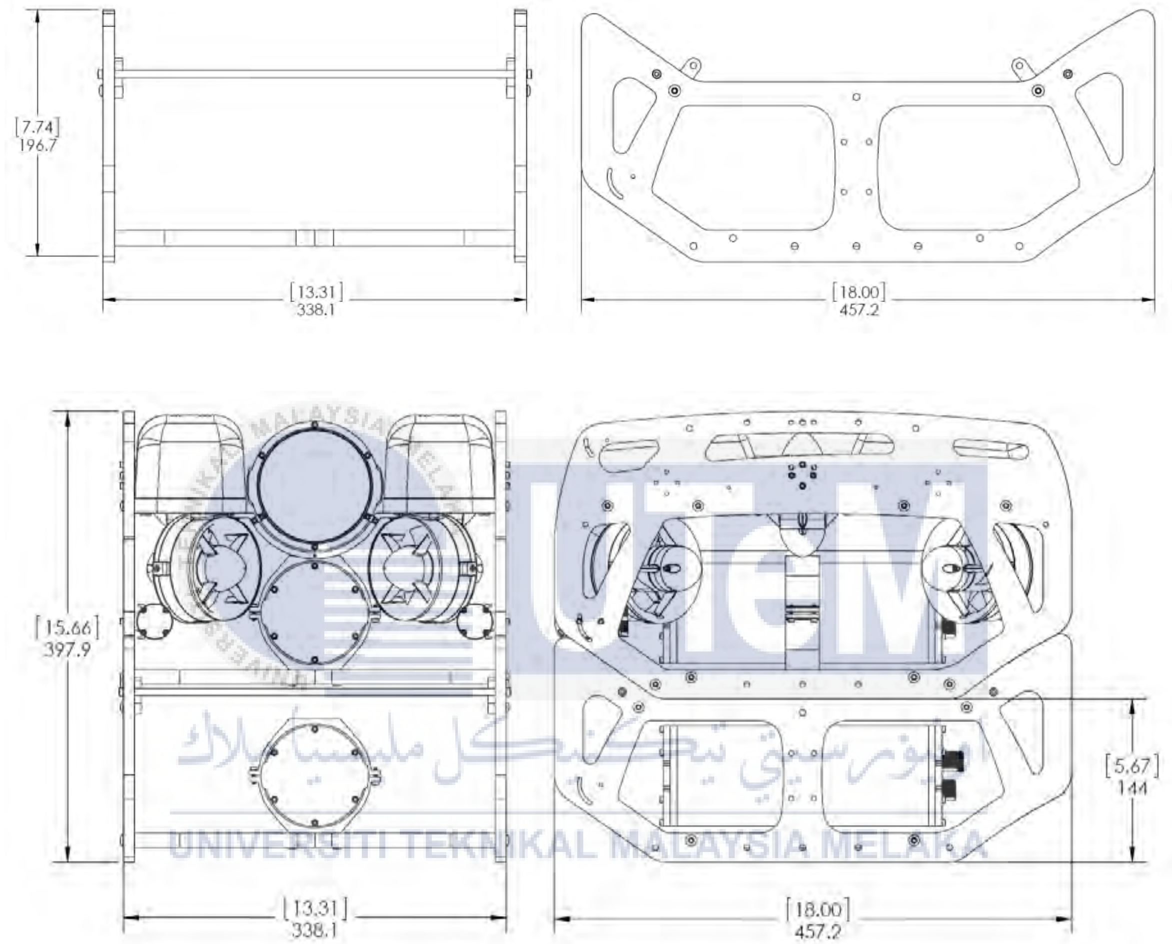
15
To study, design and develop underwater manipulator for mini-ROV application.
A. To develop a small scale of underwater robot arm manipulator and implement it on BlueROV2 model.
Disassemble the gripper from robot arm.
Generate conceptual design of new manipulator
Generate the detail design of manipulator
Purchase the material of new manipulator.
Fabricate the new manipulator.
To conduct a testing of underwater manipulator for mini-ROV application.
A. To test the gripping force of the gripper by using different weight of load.
Test the gripper by using different weight of load to obtain the maximum load capacity.
B. To test the functionality of manipulator in water and to investigate whether it can perform tasks underwater successfully.
Test the functionality of gripper on land.
Test the functionality of gripper in water tank.
Test the functionality of manipulator on land.
Test the functionality of manipulator in water tank.
Submission of final year report
Seminar presentation
Planned
Progress

APPENDIX B1



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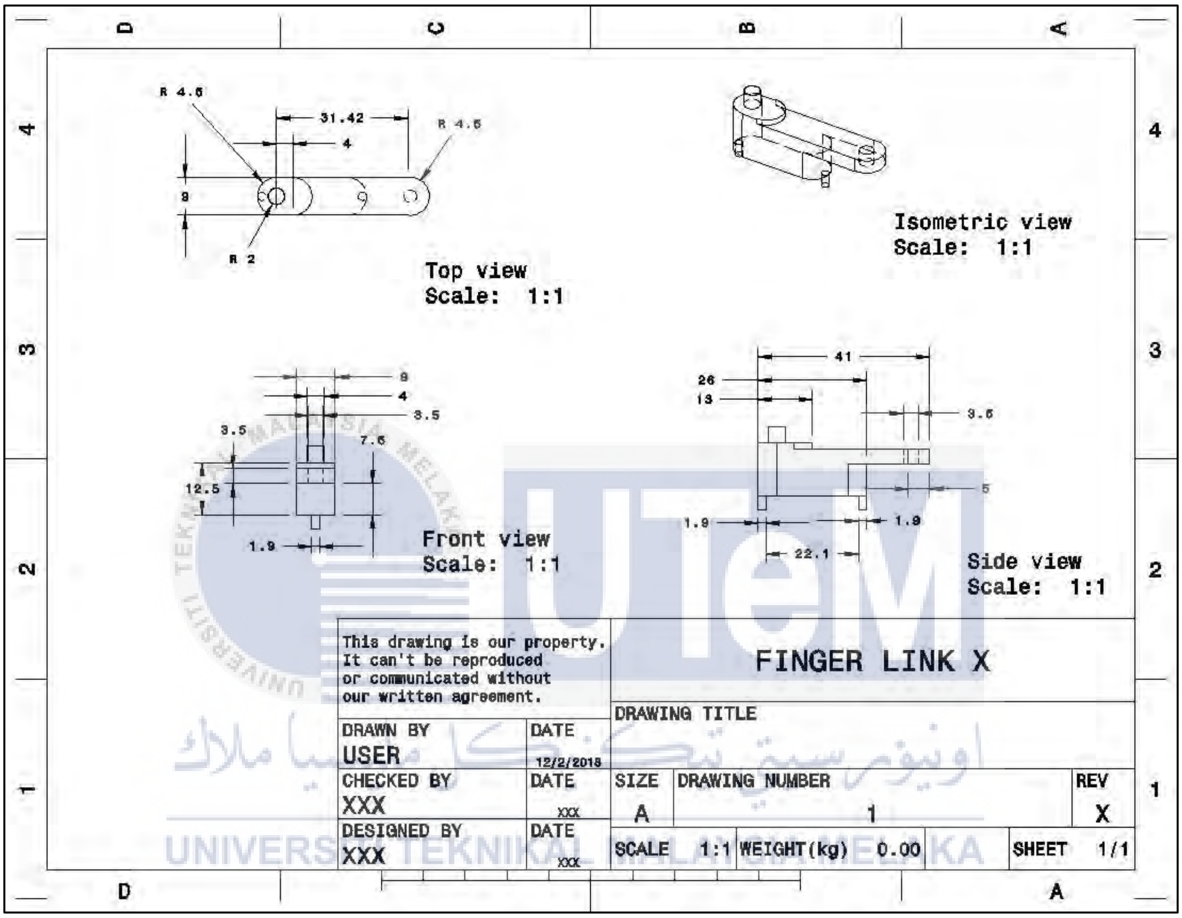
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our written agreement.
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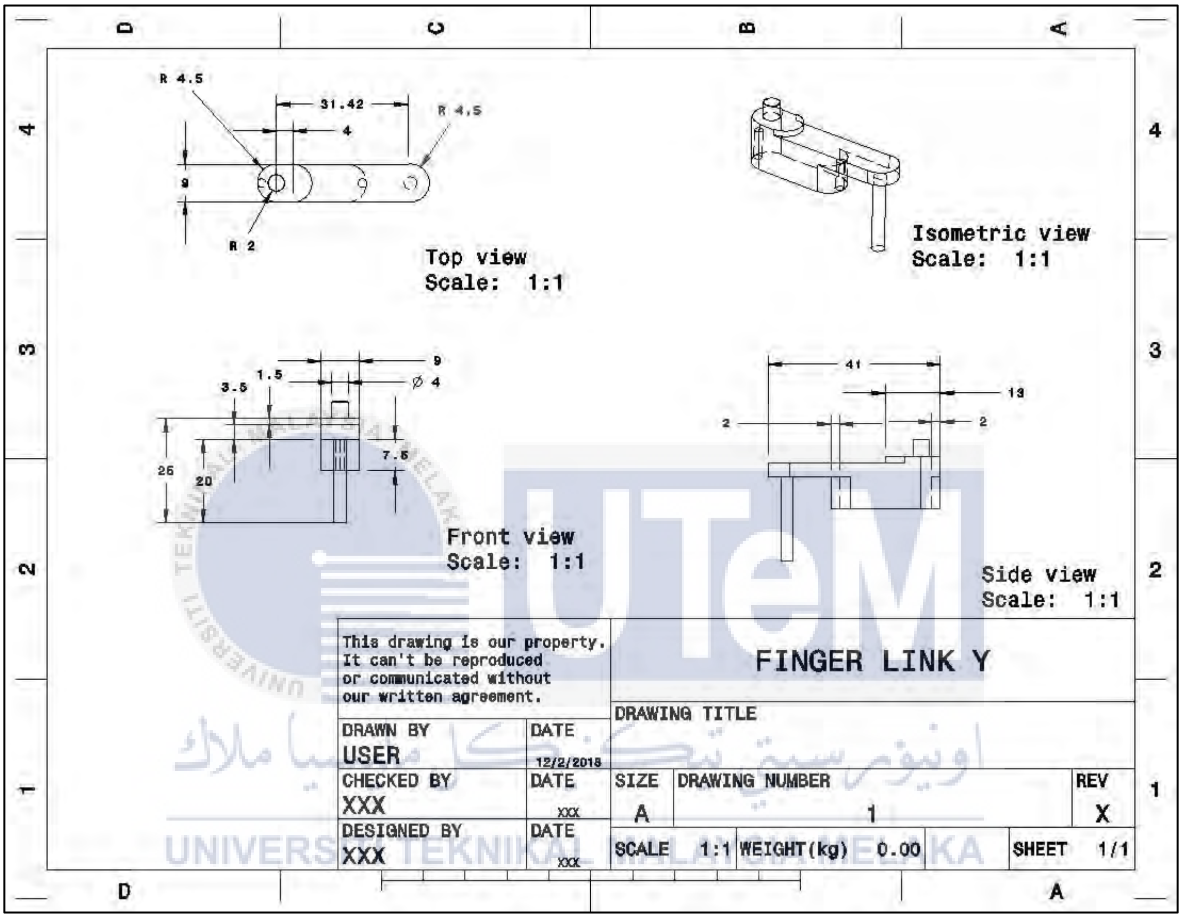

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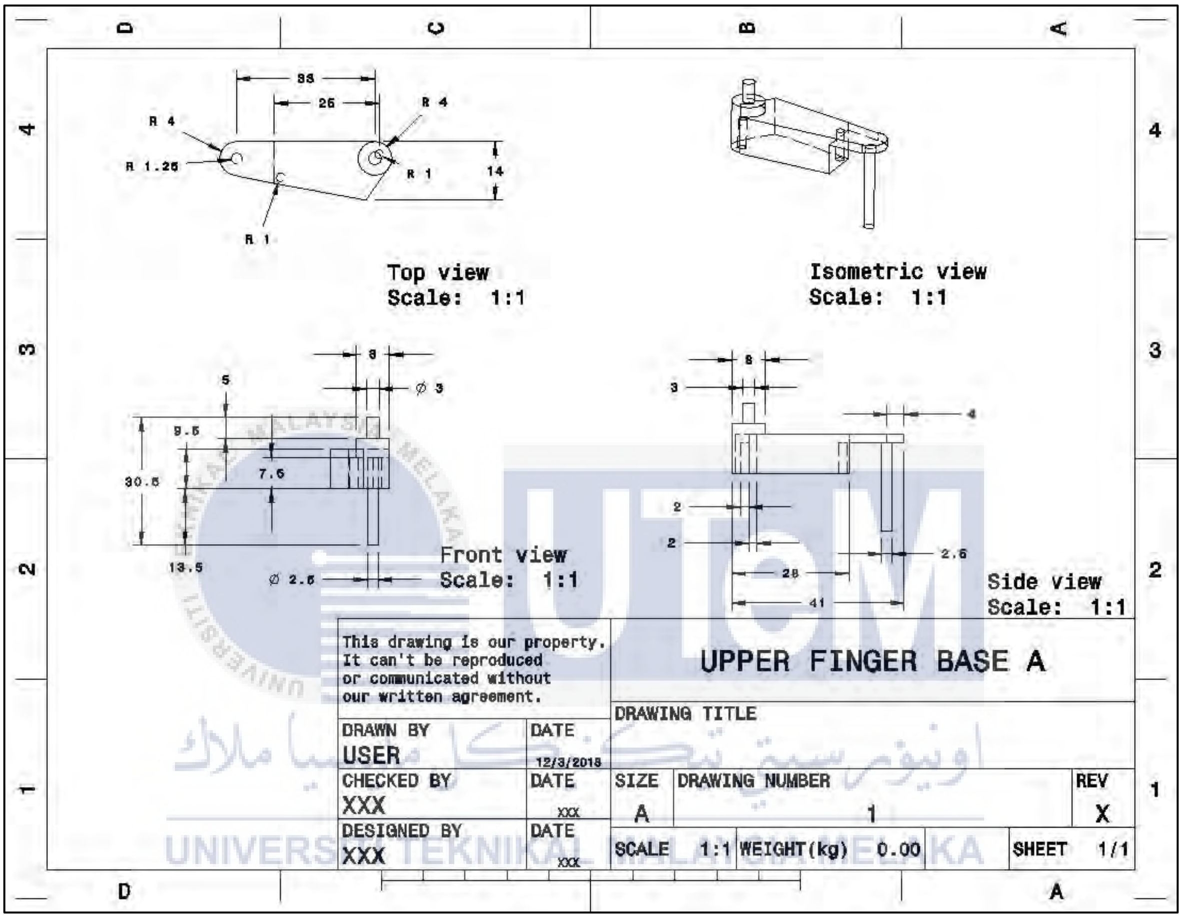

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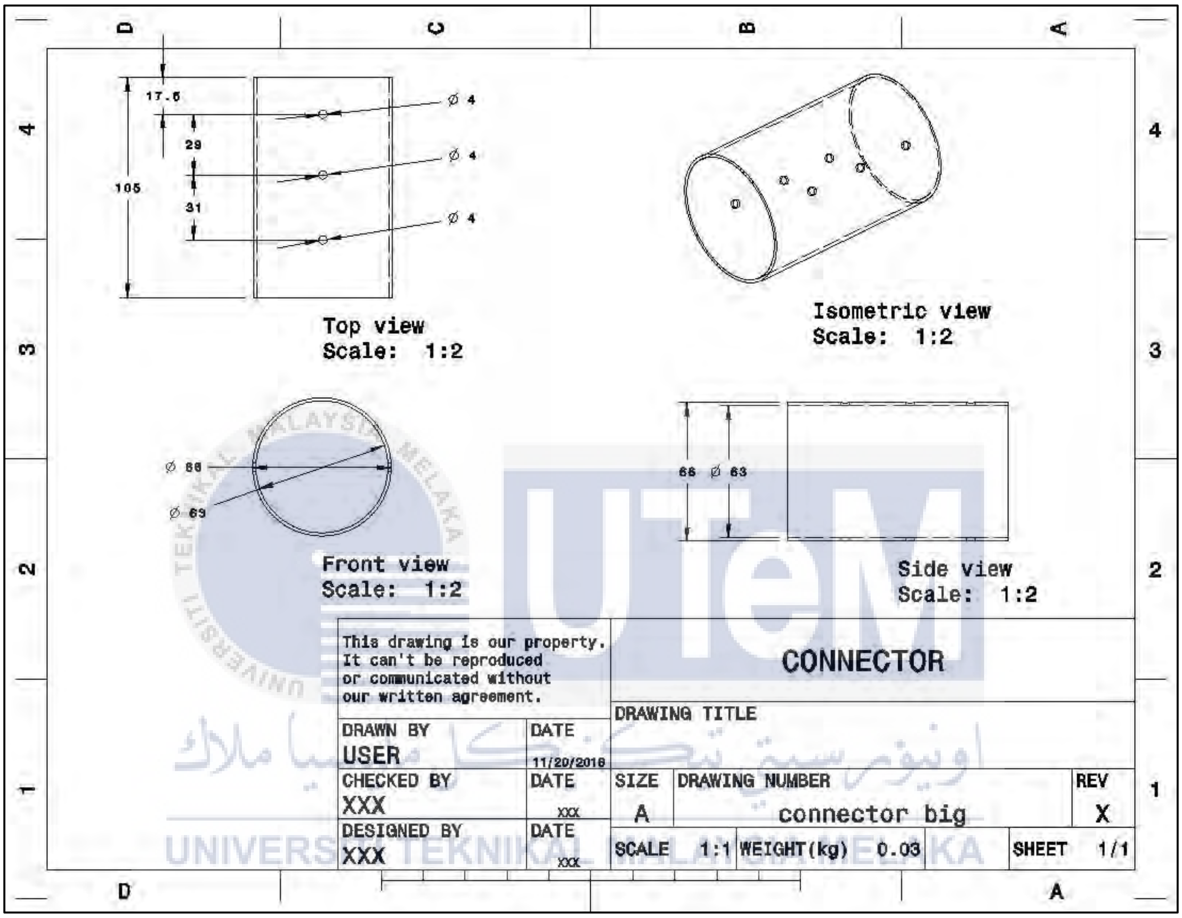

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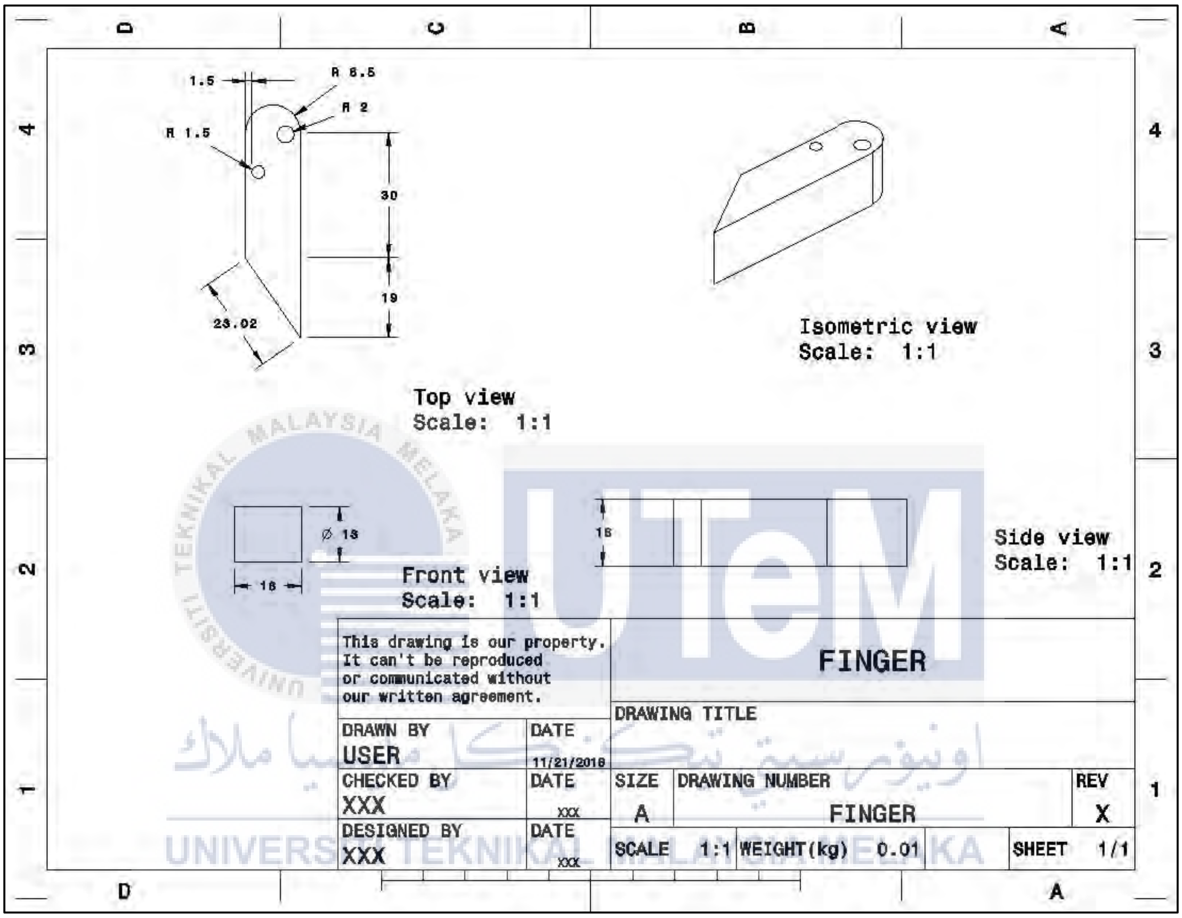

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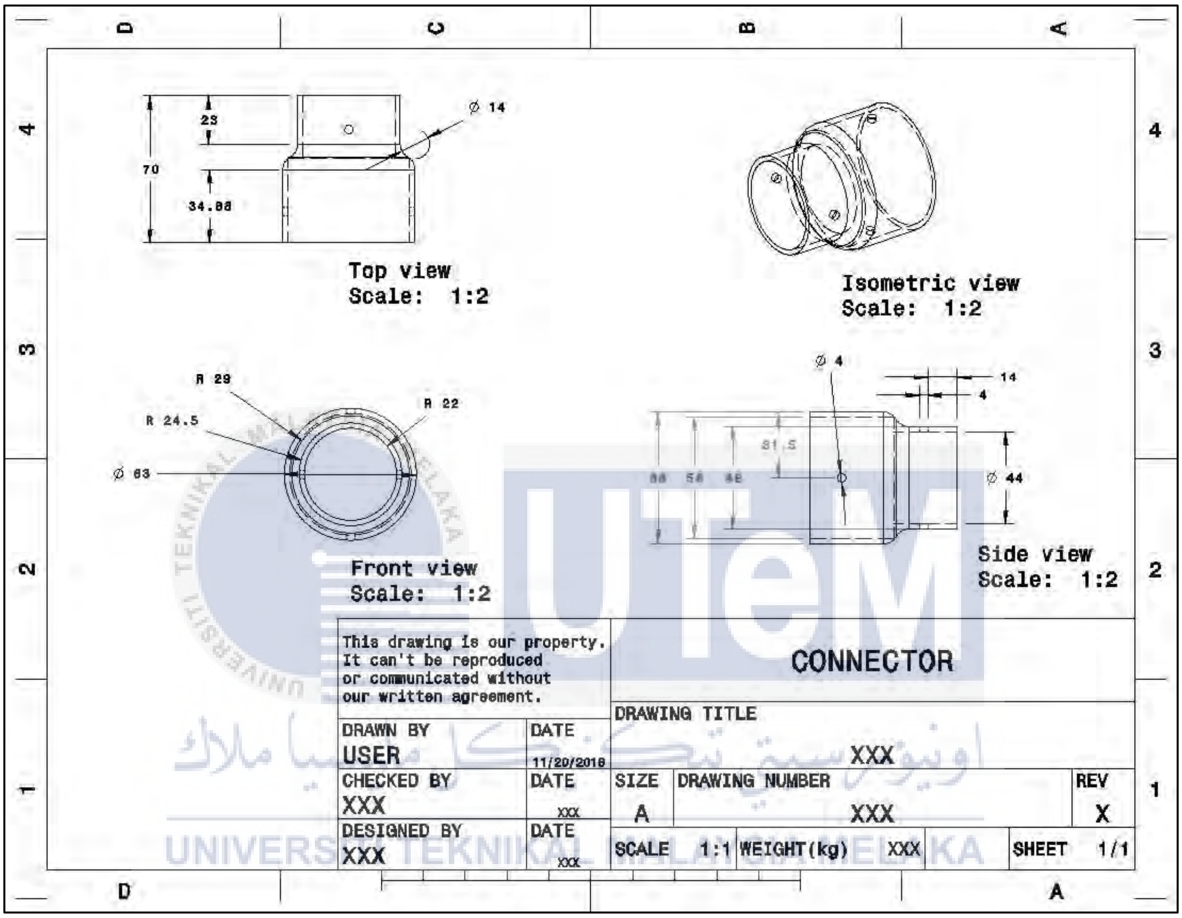

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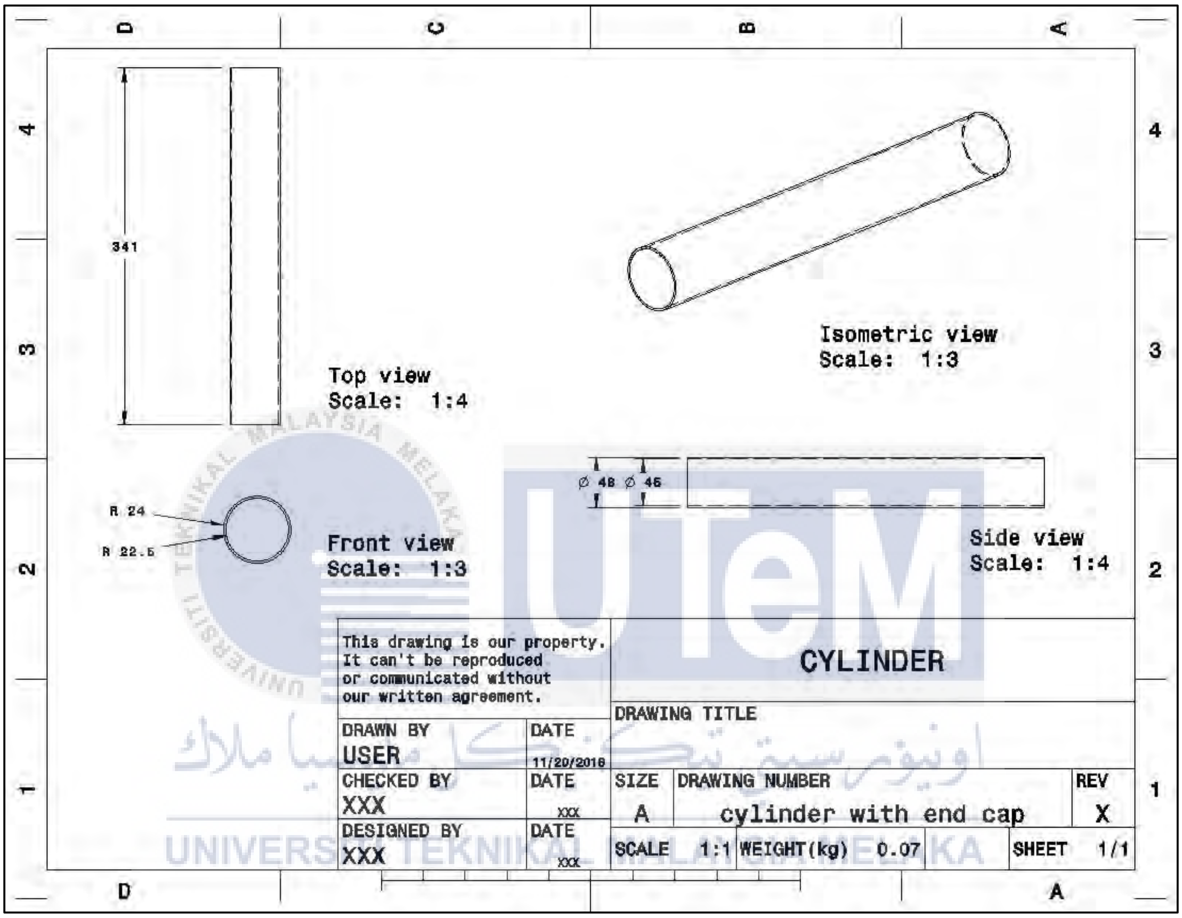
APPENDIX B8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Isometric view
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Front view
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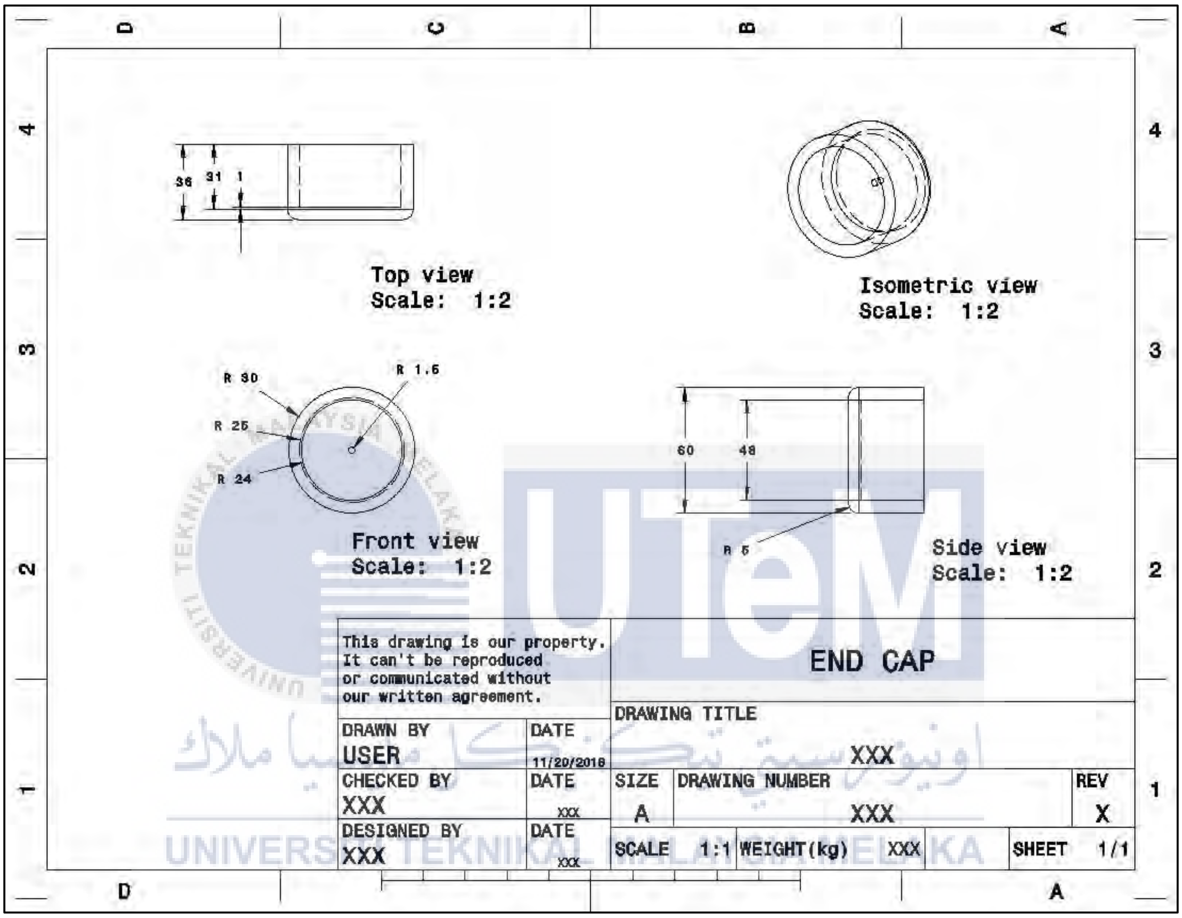
APPENDIX B9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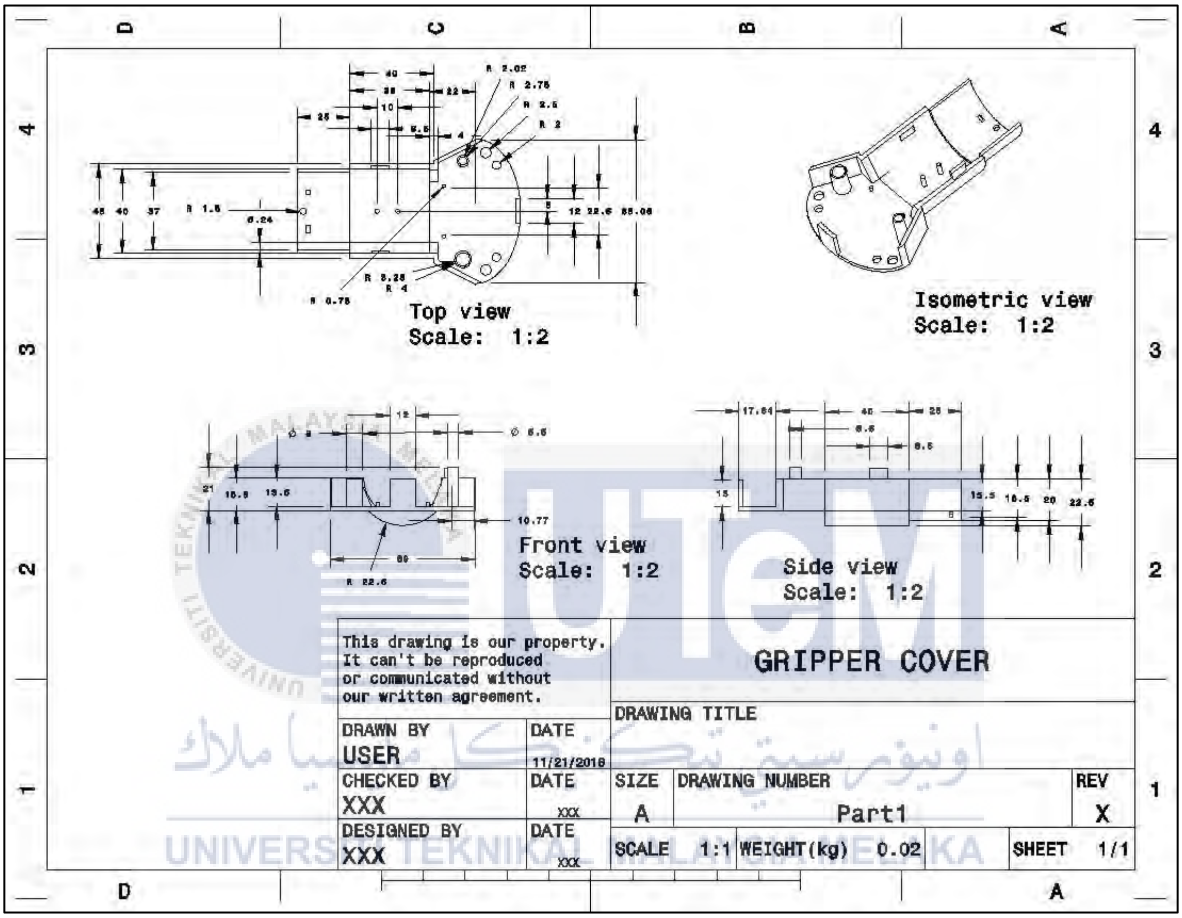
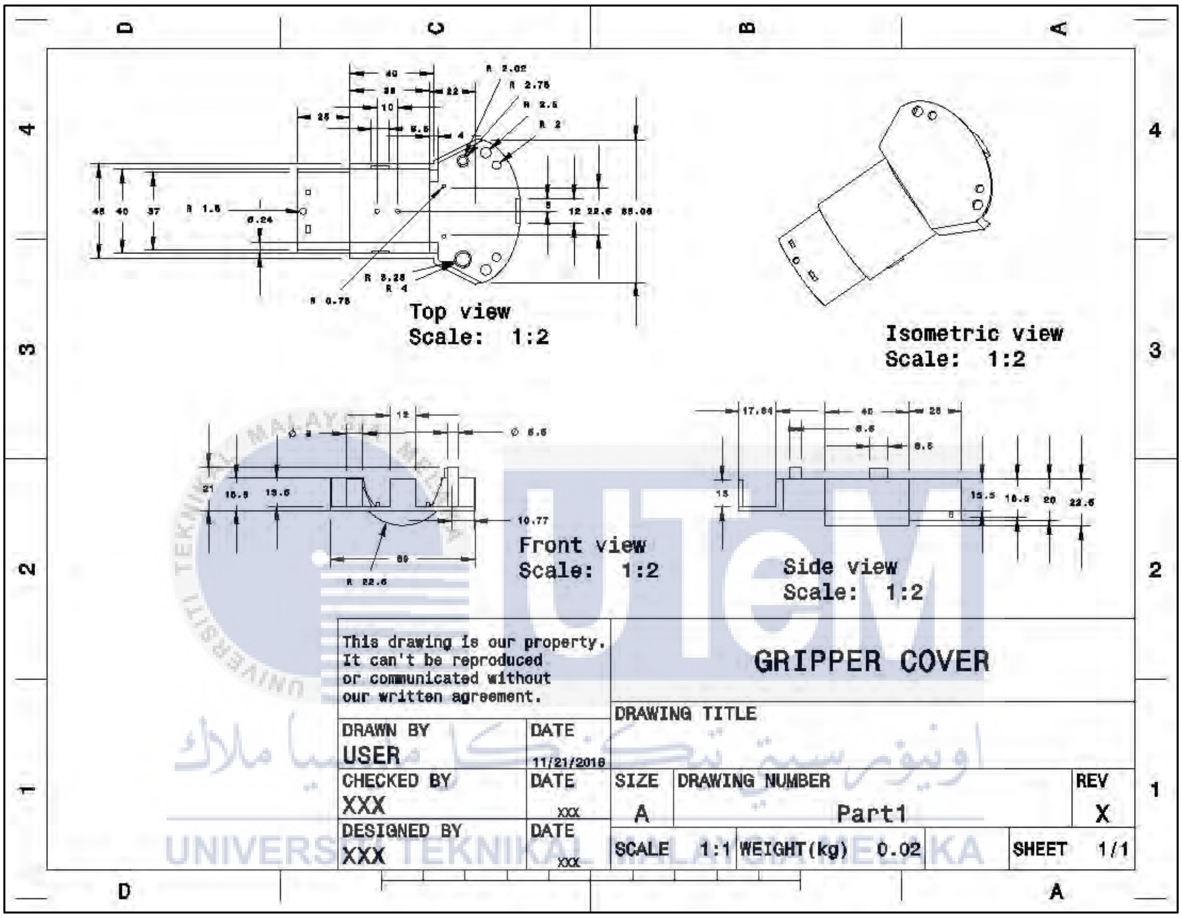
USER
DATE
11/20/2018
CHECKED BY
XXX
DATE
XXX
DESIGNED BY
XXX
DATE
XXX
SIZE
A
DRAWING NUMBER
XXX
REV
X
SCALE 1:1
WEIGHT(kg) XXX
SHEET 1/1

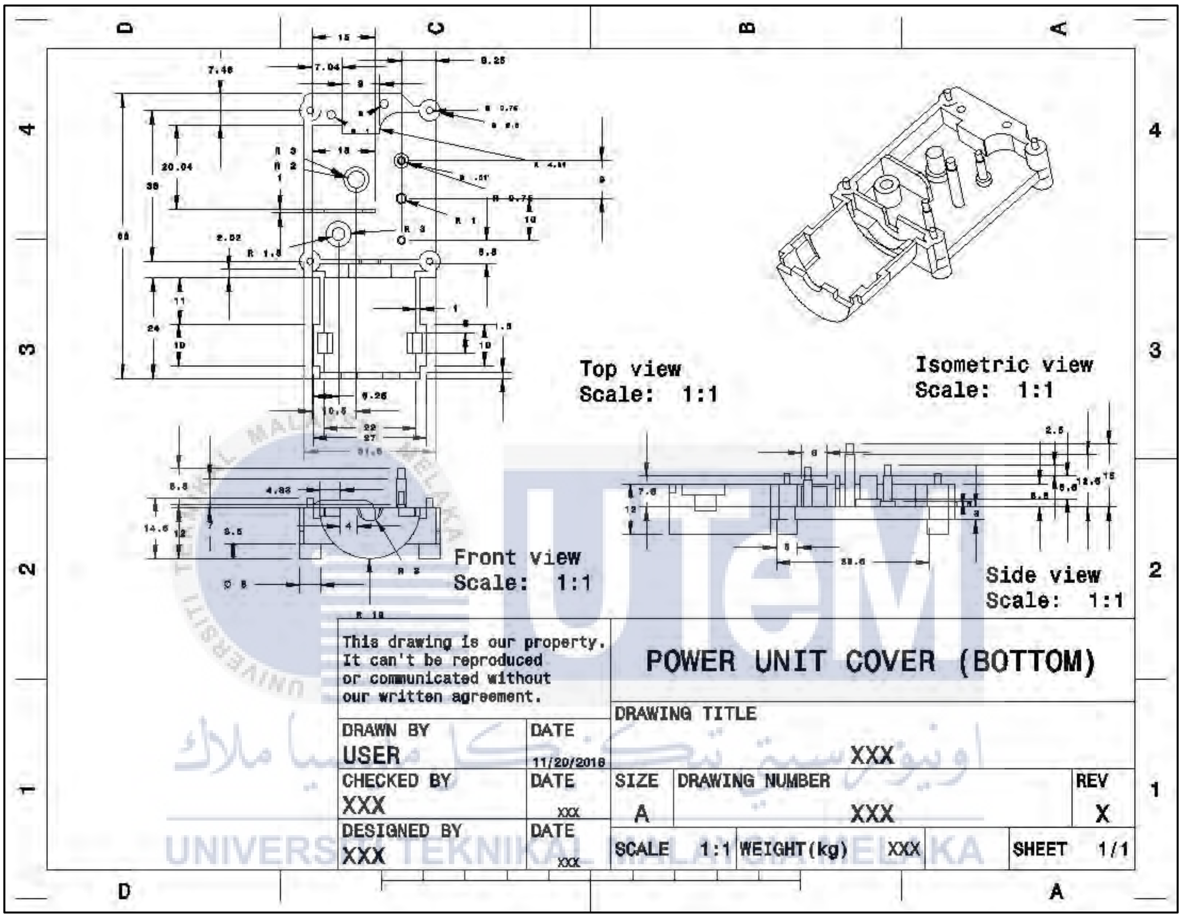
APPENDIX B10



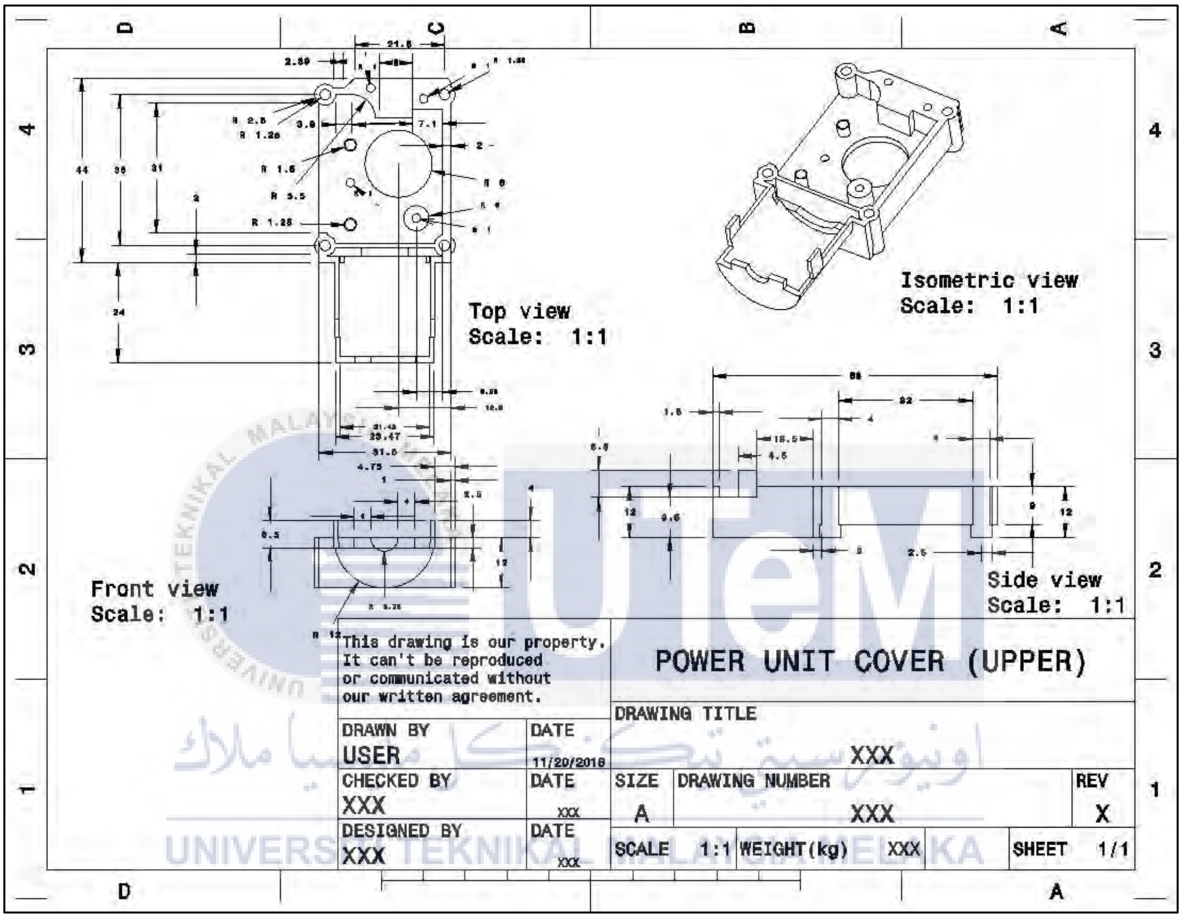
APPENDIX B11



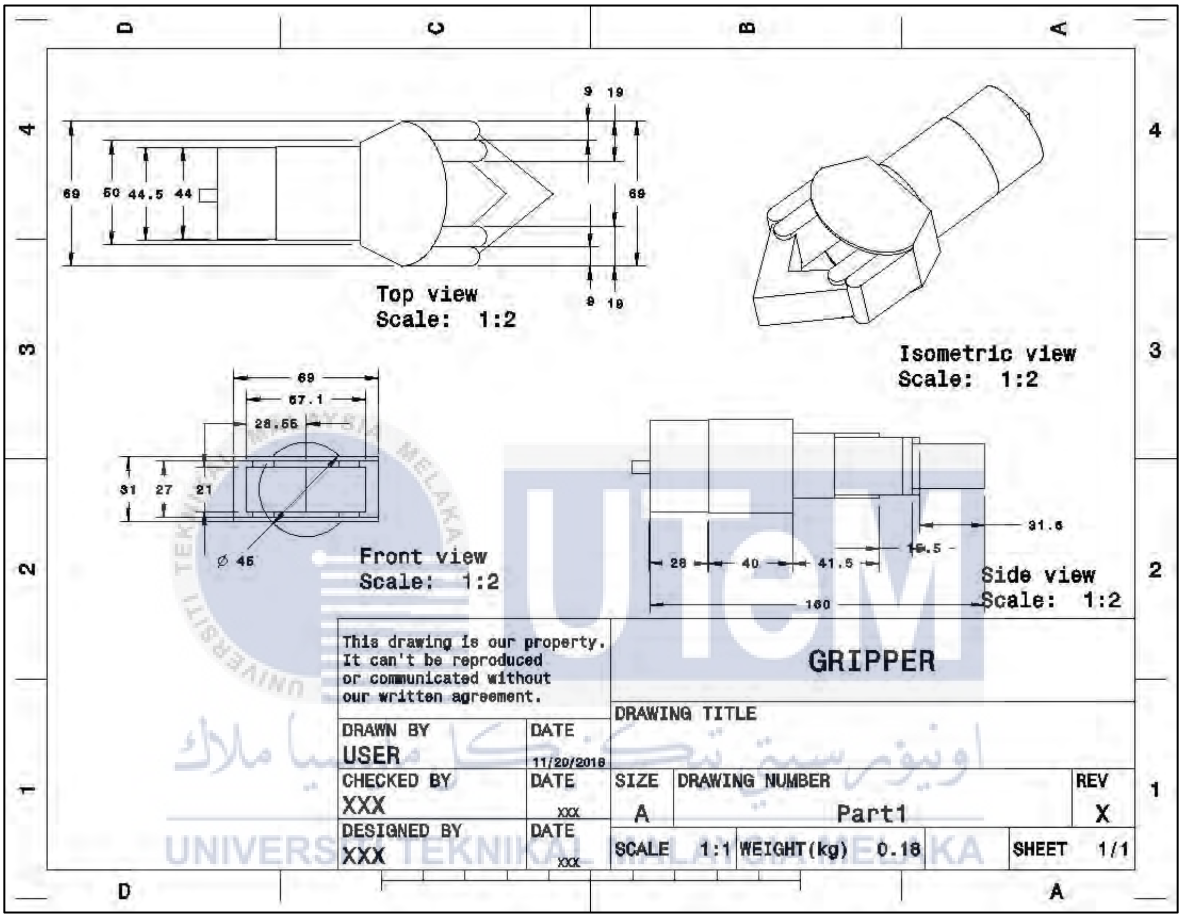
APPENDIX B12



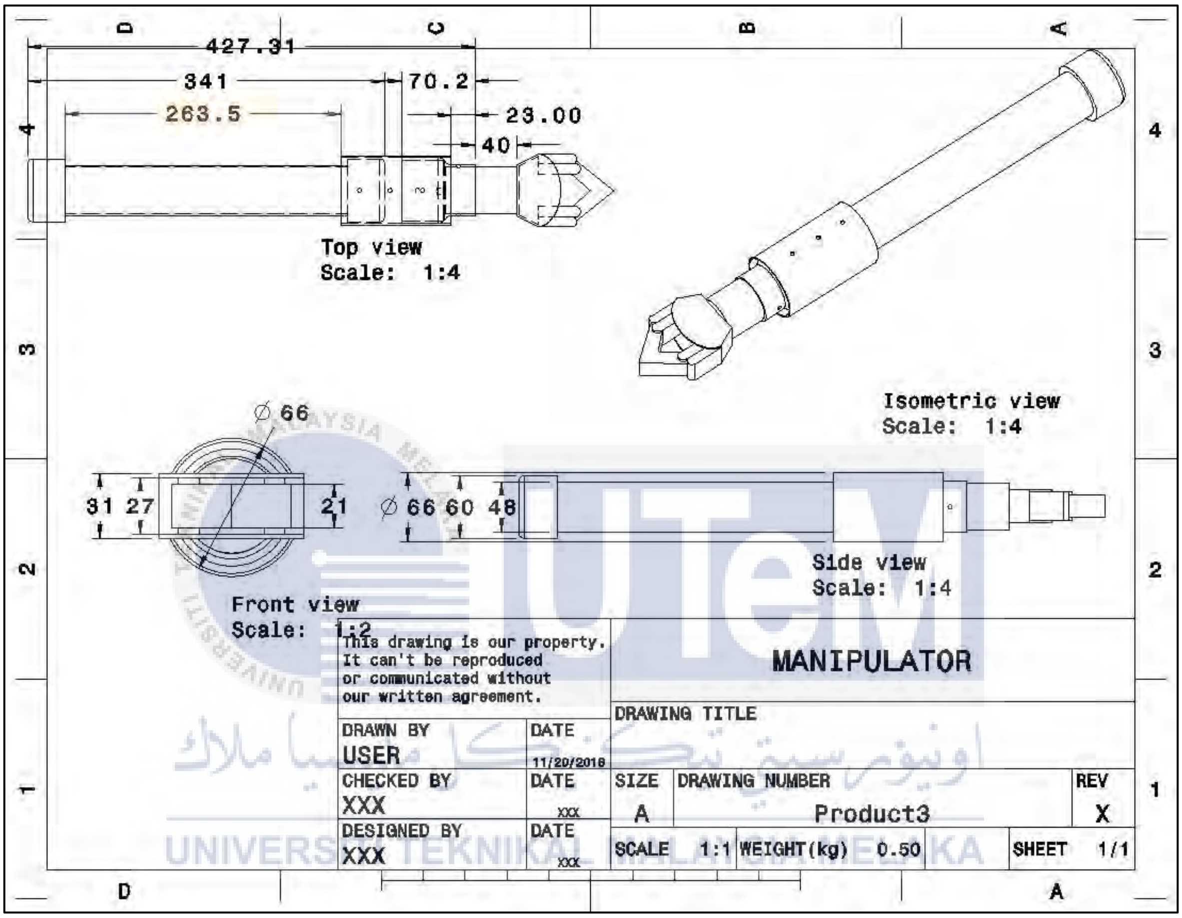
APPENDIX B13



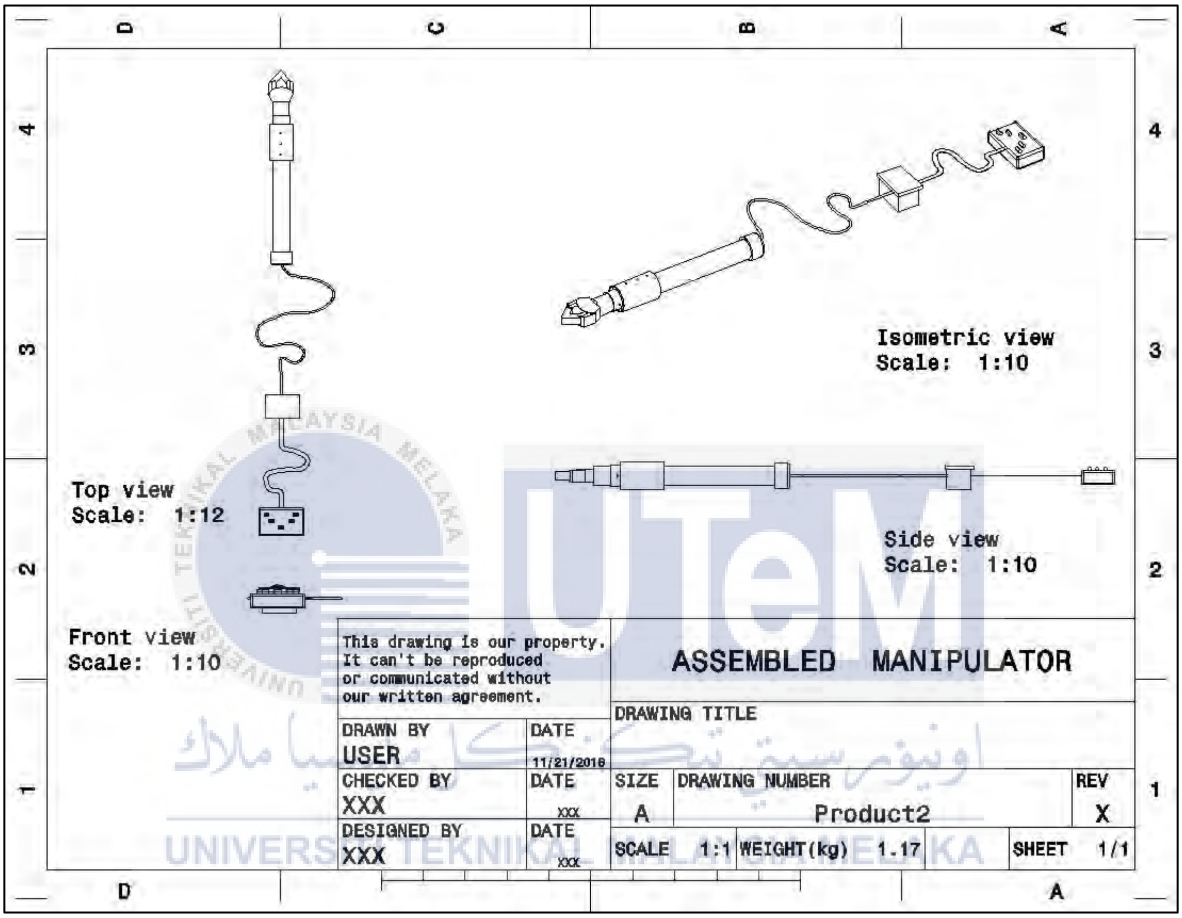
APPENDIX B14



APPENDIX B15



APPENDIX B16



APPENDIX B17