" I hereby declare that I have read through this report entitle "Development of an Unmanned Underwater Remotely Operated Crawler based on wheel mechanism design" and found that it has comply the partial fulfillment for awarding the degree of Bachelor of Mechatronic Engineering"

Signature :

Supervisor's Name : EN. MOHD SHAHRIEEL BIN MOHD ARAS

Date :

DEVELOPMENT OF AN UNMANNED UNDERWATER REMOTELY OPERATED CRAWLER BASED ON WHEEL MECHANISM DESIGN

RASHIDAH BINTI OMAR

A report submitted in partial fulfillment of the requirements for the degree of

Bachelor of Mechatronic Engineering

Faculty of Electrical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2015

“I declare that this report entitle “Development of an Unmanned Underwater Remotely Operated Crawler based on Wheel Mechanism design” is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.”

Signature :

Name : RASHIDAH BINTI OMAR

Date :

DEDICATION

To my beloved mother and father,

My supervisor,

And to all my friends

ACKNOWLEDGEMENT

First and foremost, I would like to express my sincere and gratitude to my supervisor En. Mohd Shahrieel Bin Mohd Aras for guidance throughout the progress of this project, for his germinal ideas, invaluable guidance, continuous encouragement and constant support. This thesis would not have been possible without her guidance. I really appreciate his consistent support from the first day. Furthermore, I would also like to acknowledge with much appreciation the crucial role of the staff of Faculty of Electrical Engineering, who gave the permission to use all required equipment and the necessary materials to complete the task "Development of an unmanned underwater remotely operated crawler based on wheel mechanism design". Also special thanks go to my friends, who help me to assemble the parts and gave suggestion about the task. Last but not least, many thanks to Pn. Fadilah Binti Abd Azis whose have invested their full effort in guiding me in achieving the goal. I acknowledge my sincere and my great appreciation goes to all my family members who have been so patient and support me all these years. Without their encouragement and love, I would not be able to undergo the pressure due to this project.

ABSTRACT

Underwater Remotely Operated Crawler (ROC) is one of the unmanned underwater robots. The development of an unmanned underwater ROC based on wheel mechanism design for monitoring application. To reduce the risk to human life when divers searching artifacts, underwater vehicles have more benefit which is they are able to operate at greater depths, possess less human liability and have longer working hours than any commercial divers. Besides that, the major problem with this kind of application crawler is travelling across uneven surface. While vehicle move uneven surface the crawler may be unstable so it affected the system progress. So the wheel of ROC is considered to be able travel on uneven surface. Other than that, the tethered underwater robot control manually by user using joystick. The ROC combines a standard 134mm high, 350mm wide and 400mm long remotely operated vehicle crawler. The Peripheral Interface Controller (PIC) is used to control the movement of this ROC. The ROC was design based in 3 goals maneuverability, performance and future industrial implementation. This method to make the robot function as well regarding to the objective and scope. As a result, the movement of the ROC will running in water by means of crawler system. A stable running is represented for the center of gravity and the center of buoyancy. Furthermore, this project also will give much benefit for related underwater industries and the range of applications where this ROC concept is best suited and outperforms others.

ABSTRAK

Kenderaan kawalan di dalam air adalah salah satu robot dalam air tanpa pemandu. Tujuan projek ini untuk membangunkan kenderaan tanpa pemandu dalam air berdasarkan reka bentuk mekanisme roda untuk aplikasi permantauan. Untuk mengurangkan risiko kepada nyawa manusia apabila penyelam mencari artifak, kenderaan dalam air mempunyai banyak faedah untuk beroperasi pada kedalaman lebih besar, memiliki kelebihan dari kekurangan manusia dan mempunyai lebih lama kerja daripada mana-mana penyelam yang komersial. Selain itu, salah satu masalah dalam aplikasi kenderaan dalam air adalah di permukaan yang tidak rata. Apabila kenderaan bergerak di permukaan yang tidak rata, kemungkinan kenderaan kawalan di dalam air tidak stabil yang akan mengakibatkan kemajuan pergerakkan sistem kenderaan. Oleh itu, roda kenderaan kawalan akan di pertimbangkan untuk bergerak di atas permukaan yang tidak rata. Selain itu, tali akan digunakan untuk kenderaan kawalan di dalam air secara manual oleh pengguna dengan menggunakan joysticks. Kenderaan kawalan di dalam air menggabungkan kenderaan biasanya 134mm tinggi, 350mm lebar dan 400mm panjang untuk aktiviti penyelidikan berganda dengan memilih bahan yang sesuai diperlukan untuk mengelakkan kenderaan terapung di dalam air itu. Peripheral Interface Controller (PIC) digunakan untuk mengawal pergerakan kenderaan ini. Kenderaan kawalan ini dicipta berdasarkan matlamat untuk pengandalian, prestasi dan perlaksanaan industri untuk masa depan. Kaedah ini untuk membuat robot berfungsi dan sehubungan dengan penyampaian objektif dan skop. Hasilnya, pergerakan kenderaan akan berjalan dalam air melalui sistem kenderaan kawalan. Kenderaan kawalan akan stabil apabila kenderaan itu ada pusat graviti dan pusat keampungan . Selain itu, dengan harapan projek ini juga akan memberikan banyak manfaat bagi industri yang berkaitan di bawah air dan pelbagai aplikasi di mana konsep kenderaan kawalan di dalam air adalah paling sesuai dan melebihi yang lain.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Unmanned underwater vehicles (UUV) are any vehicles that are able to operate underwater without a person on board. UUV are widely used around the world, both in military applications such as mine hunting and mine disposal. There are different kinds of UUV which are mainly divided into two categories which is Remotely and Autonomous Underwater Vehicles (AUV). These two categories can come in all sizes and shapes depending on the application. AUV which are operate independently of direct human input and AUV also often just move forward and steer the heading and depth with rudder like a torpedo, and country. There are several types of unmanned underwater remotely vehicles such as Remotely Operated Vehicle (ROV) and Remotely Operated Crawler (ROC). ROV can be steer in many directions since they usually have a motor act as thruster. ROV also are controlled by a human operator and it’s tethered either to a submarine, a surface vessel or a used in harbor and is thereby controlled by an operator [6]. While ROC are specialized vehicles that allow for underwater intervention by staying in direct contact with the seafloor.

1.2 Research Background

This project is about the development and design of an unmanned underwater Remotely Operated Crawler (ROC) based on the wheel mechanism. An underwater vehicle with crawler is a robot which running on land and sea without requiring input from a user. So it use wheels to running on water. These wheel of crawler are self-sufficient, capable of making on-the-fly decisions, remove the human element, thereby, overcoming the disadvantages of ROV [7]. Besides that, the performance that led to the choice of 4 wheel architecture of the crawler because of the generally ROC running stably when the ROC had an adequate weight in water and adequate center of gravity as well as center of buoyancy. Thus, the wheel depends on the weight and the discrimination line is obtained with the weight and the buoyancy of ROC, the water residence, the point of its application and the dimension of crawlers. So it's necessary to research the influence of the weight on the movability characteristic of crawler system in order to possess adequate movability on sea floor. It is controlled and powered from the surface by using remote control [8]. It is because the user can easily handle the underwater crawler to travel from its current location to another location specified with latitude and longitude coordinates. The crawler offers a very stable platform for manipulating object or for taking measurements. Additionally, crawlers lend themselves to long term work. The vehicle is controlled by a remote control cable from the boat and it's equipped with cameras. This cable transfer the control signals and power between the surface unit and the ROC.

1.3 Motivation

Shipwrecks are the remains of a ship that has wrecked, which are found either beached on land or sunken to the seafloor. From research, the United Nation Educational, Scientific, and Cultural Organization estimates that a total of more than three million shipwrecks lie on the seafloor. The international Register of Sunken Ship also lists more than 112,000 ships as of June 2009 [9]. Back in the 1970's treasure hunting was at people start noticing the value of historic artifacts [9]. The act of treasure hunting over the last few decades lawsuits with individual states, the federal government and with other nations is beginning to flourish as technology advances with new techniques and methods of searching for and recovering artifacts deep underwater [9]. Whether it is the underwater archeologist striving to obtain information about some underwater artifact or marine salvage specialist trying to recover materials from a sunken ship.

Besides that, the international team of divers and archaeologists who are investigating the site of an ancient Greek ship that sank more than 2,000 years ago off the remote island of Antikythera, it also contains a treasure trove of artifacts. From research, at Antikythera have a cases where one of the divers died and two were paralyzed when their searching artifacts [10]. The ship is located at a depth unsafe for human divers — 55 meters (180 feet) [10]. It shows that at the Antikythera site is a treacherous one indeed. The team divers had to end their mission since there have a cases of death. It many possibility reasons such as the divers lose control in the depth sea, less breathing underwater, surrounding pressure drop and the air in lungs expands. Therefore, this motivates the project of development of an unmanned underwater remotely operated crawler.

Figure 1: The international team of divers and archaeologists who are investigating the site [10]

1.4 Problem Statement and Significant of the Research

Nowadays, robot have been widely used in environment because capability to do work that dangerous to human especially in the seafloor. So, human no need to carry own air supply (oxygen) and protect their body from pressure and temperature under the water. Therefore, crawler robot perform tasks in underwater environments that are impossible for humans to investigate the problems in the seafloor, which human cannot directly interact with damaged equipment and it have limited capabilities in making the work underwater. Depth and pressure are related which mean at a depth of 33 feet (10meters), water pressure is 29.4 pounds per square inch [11]. For every additional 33 feet descends, the water pressure increases by one atmosphere [11]. Due to pressure depth, the deeper human goes, the more pressure is exerted on the whole body. That mean the divers working at greater depths require something stronger to avoid the body pressure impact. It is harder to get to the deepest parts of our seas and it has long been acknowledged that deep sea exploration is one of the most dangerous jobs on the market. As a result the sea-beds are cluttered with much that divers cannot reach or even see. A host of shipwrecks can be counted amongst all that can no longer be reached or found in a surprisingly large number of cases. To reduce the risk to human life especially when divers searching artifacts, underwater vehicles have more benefit which is they are able to operate at greater depths, possess less human liability and have longer working hours than any commercial divers. After some research, the problem in the deepest ocean the project will come out with new idea by using Remotely Operated Crawler (ROC) with wheel mechanism. One of the significant points that choose mechanism of wheel because by using four driven wheels can propel the vehicle while on land and on water. The vehicle then begins moving in the direction of its destination. However, a major problem with this kind of application is the crawler travelling across uneven surface. While vehicle move uneven surface the crawler may be unstable so it affected the system progress. So, to overcome the stability problem at uneven surface the structure of wheel is investigated of ROC by using the rough tires, wide surface and heavy body. Other than that, for long term time travelling uneven surface the power of the motor of crawler is considered. So, the crawler will be able to travel on uneven surface in underwater. In addition, the ROC is developed with motor in order to make the crawler move by using the DC motor. Crawler can move forward, reverse, right and left. This system indirectly can help the human to overcome the problems in underwater environments.

1.5 Objective

The main objective of this project is

1) To design and develop of unmanned underwater Remotely Operated Crawler for monitoring application.

2) To study the performances of the Remotely Operated Crawler in terms of stability, maneuverability, and velocity of the crawler.

1.6 Scope and Limitation

To conduct this project, there are several scope and limitation that are needed to be followed. Firstly, the depth of the testing prototype will be less than 2 meters. Other than that, the testing environment selected is controllable for control environment at Laboratory pool. Besides that, the design of ROC can only runs on an uneven surface such as rough of the surface which is made by 100% waterproof of the DC motors. The PVC has been chosen as the part material for sealing the DC motors. Thus, this may cause the ROC to have lower characteristics in power consumption which may contribute to low speed of emerge and submerged operation. The main supply for the system is 12V battery as power source. Other than that, PSC28A is also used as a main IC for controller. Thus, ROC can only perform movement for two degree of freedom which is the maneuverability consisted forward-reverse and left-right motion. Finally, the controller of the ROC is connected by wired to the land.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter discussed about literature review. The information was taken from books, journal, conferences, thesis, articles obtained from internet and others from the previous researches in how to development of an unmanned underwater ROC and design controller. Then, to validate the result the system identification method is proposed. These strategies have different approaches and techniques. So this chapter, it covers about the principles used, review of previous related work and summary of this project.

2.2 Unmanned underwater Remotely Operated Crawler based on wheel mechanism overview.

Before we go further study about the development of the vehicle in this topic; the overview of ROC part and controller design part of the ROC will be represented to overall in advance to common knowledge of the operation of ROC system. K-Chart overview in chapter 1 shows the overview of ROC such as material, motor, tire and also the controller system. There are two kinds of robots remotely used in deep sea are ROC and ROV. Both are marvels of engineering. The vehicles can carry instruments and monitoring observation. The main difference between the two vehicles is the ROC is specialized vehicles that allow for underwater intervention by staying direct contact with the seafloor while the ROV cannot directly contact with the seafloor. The ROV can reach the seafloor by applying deep mechanism to the ROV which is thruster, ballast tank, propeller and others. The mechanism of ROC does not have to use deep mechanism but instead it uses the wheels to be running on the seafloor. Other than that, ROC is directly contact with seafloor so it have negative buoyancy while ROV have slightly positive buoyancy because it does not directly contact with the seafloor. When the crawler is positioned at the negative buoyancy, the crawler offers a very stable platform for seabed mapping while the ROV is unstable. Therefore, the ROC is a better choice to be used for monitoring application on the seafloor.

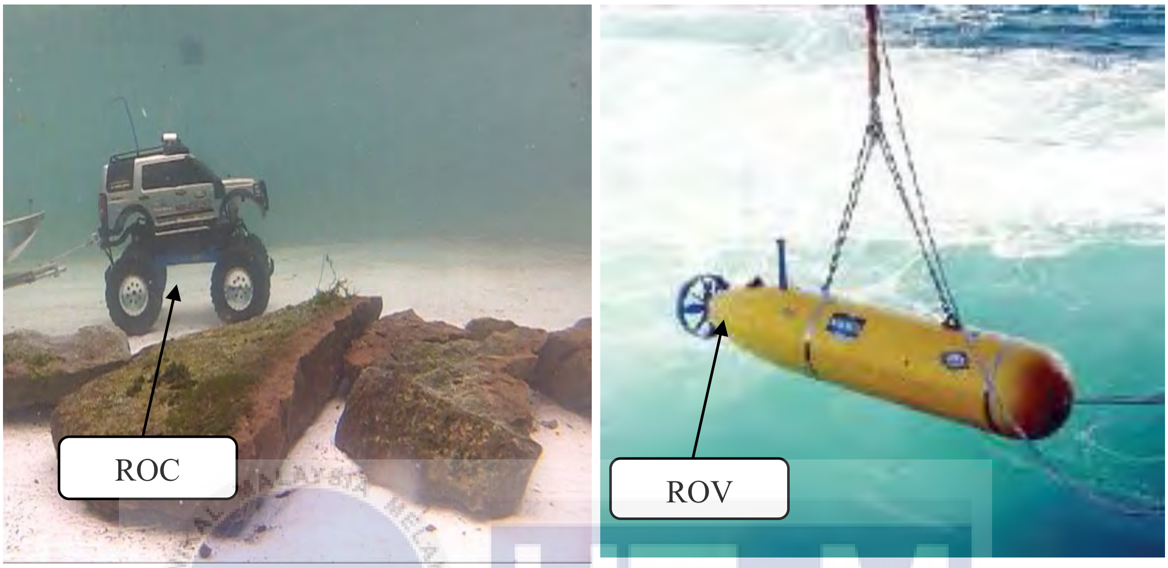


Figure 2.1: Overview of ROC and ROV

2.3 Related Journal

In the paper done by [1], the author designed a system which consists of flipper type crawler system at sea to verify running performance on sandy or irregular steep terrain seafloor. To expand the activity of research and development on the seafloor, especially survey, sampling or work on an irregular terrain seafloor, it becomes necessary to develop a function of the ROC to move and keep station. The external force acting on a crawler belt are velocity, line tension, normal reaction and external force to maintain velocity. Also, the crawler system should have the capability to move on the sandy seafloor or on the irregular terrain seafloor to search for an adequate sampling point or material. To achieve adequate mobility of the crawler systems when running on the seafloor, there is also of necessity to develop an additional advanced mechanism because the seafloor is irregular, bumpy or sloping terrain. The system could run on the rock with more than 30 degree slope. There is generally a limited height of a bump to run or climb up. The weight of the ROC in water are 191 N, revolution rate for drive motor of 1500 r/min, initial speed of 0.149 m/s and height of 65 mm. When ROC start to climb up the drive motor could be large torque because of the lack of a feedback system. Development of an advanced crawler ROV will proceed to expand the activities.

Figure 2.2: Small size flipper type crawler ROV running on the steep rock reef [1]

In the paper done by [2], the author designed a system which consists the gearmotor drive underwater ROC in crawling. One of the most innovative ROC operating under the seas today is the Little Benthic Crawler (LBC™) ROC from Seabotix. The LBC features a dual vertical thruster configuration for precise rolling movement in water and stabilization at depths down to 30 m (100 ft.). Using the lateral function on the system's joystick, the operators initiate the LBC into a roll. When the LBC attaches to a surface, it can be "driven" instead of "flown." Engaging the same controls used to fly the LBC through the water, the operator can drive the LBC with the motor-driven wheels. The drive mechanism was engineered to promote traction, straight-line tracking during inspections, and the highest possible torque for maximum operating capability with one gearmotor for each of the four wheels. By developing 360 oz.in. of torque at 40 rpm, the Pittman gear motors can drive the LBC at speeds up to 30 m/min (100 ft/min), which allows for underwater inspections to be performed quickly, especially important in situations where time may be critical. Then, a four-wheel drive system took over, enabling the LBC to drive with sufficient traction on the hull and on a steady course as directed. That vehicle have high resolution video and sonar image and provide valuable sensor and image data that connect with tether for the remotely the LBC.

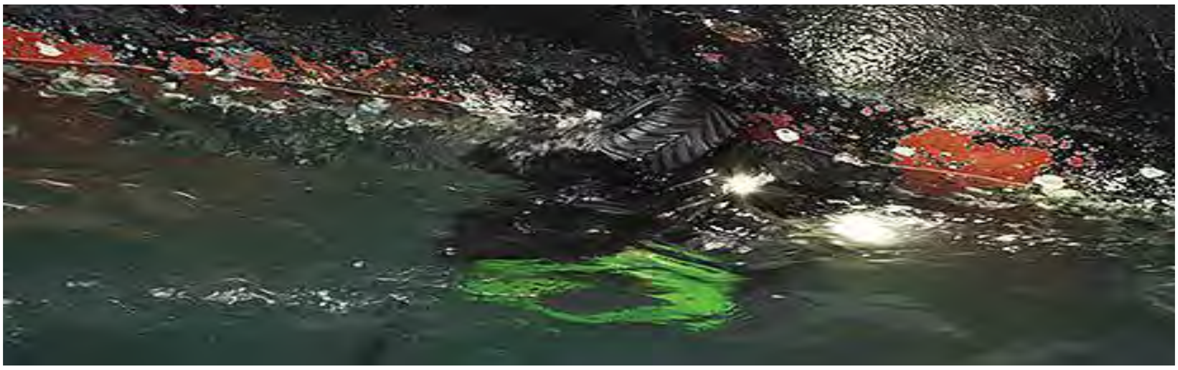


Figure 2.3: Gear motor drive underwater crawler [2]

In the paper done by [3], the author designed a system which consist of hybrid robot crawler or flyer for use in underwater archeology. At Florida Institute of Technology a hybrid remotely operated crawler has been developed for archaeological and scientific activities within coastal regions of the ocean. This hybrid vehicle combines a standard 40-cm high, 53-cm wide, 71-cm long remotely operated vehicle (ROV) flyer with a 1.0-m high, 1.52-m wide, 2.8-m long remotely operated vehicle crawler for multiple research activities such as underwater archaeology documentation and artifact removal. RG-III's underwater capabilities include the recovery of lost valuables with sensitive structures, visually examining underwater scenarios, high maneuverability at depth, and the ability to translate its position while neutrally buoyant in the mid-level depths. The control system of the crawler is split into two categories which is digital and analog. The digital system in the crawler uses Arduino micro-controllers. This acts as central controller on the crawler that delivers messages to controllers attached to each of the onboard the crawler. The tether management system introduce a larger housing for extend tether length as well guide the roller and allowing for better operation.

Figure 2.4: RG-III Crawler [3]

In the paper done by [4], the author designed a system which design of a small-scale autonomous amphibious vehicle. A detailed design of an autonomous amphibious vehicle (AAV) capable of traversing across aquatic and terrestrial environments. For a variety of reasons traversing to such places is important. Some examples include analyzing water samples in possibly contaminated environments, mapping out landmarks and the geology of an area, search and rescue, delivering items/tools from one location to another, security surveillance, and filming animals in their natural environments. To propel it underwater, two of the six wheel-legs have a propeller shape. The orientation of the wheel-legs changes to control walking direction as well as swimming direction. It describes a simple PID controller that uses as the input. The modular buoyancy attachments have used in order to allow the AAV to float on water necessary. Four paddle wheels propel the AAV across land and over water. Buoyancy attachments increase the buoyancy of the vehicle and are modular which means they can be used as needed. Ultrasonic sensors are located in front and they ensure the AAV can detect any obstacles along the way.

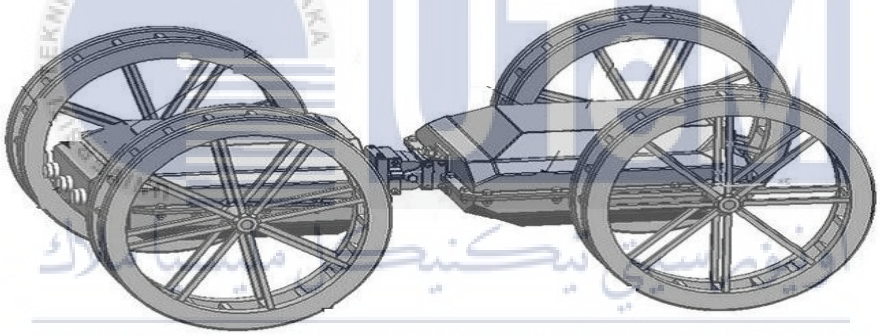


Figure 2.5: Autonomous Amphibious Vehicle

In the paper done by [5], the author designed a system which consists the traction properties of the wheel of an underwater crawler on different soils. To support choice of the mobility system and serve as a tested for traction and navigation systems, a smaller, second vehicle was developed and field-tested, referred to as the CMOVE to the choice of a 4-wheeled architecture with a rigid suspension for the chassis of the crawler. This aspect was considered advantageous from the point of view of maneuverability during operations. For actuation, each wheel is mounted to its own drive unit that attached hub and which features a pressure compensated housing surrounding a brushed DC motor, planetary gearbox and rotary encoder to indicate wheel rotation rate. The electronic part come up with a reliable and powerful controller that can handle the data flow from the vehicle and the payload sensors while at the same times is consuming as low energy as possible. The power electronics to be around 30 W when moving at 5cm/s on moderately strong sediment. This to an energy usage per meter driven of 2.0kWh for distance of 10 km. The typical required torque had been estimated as about 12 Nm. To meet the requirements it has been decides to revert to a PC104 system which runs an operating system.

Figure 2.6: View of CMOVE during development preparation [5]

2.4 Summary table from journal

Table 2.1: Comparison journals

Characteristic	Journal [1]	Journal [2]	Journal [3]	Journal [4]	Journal [5]
Material	Aluminum and metal	Stainless steel	Metal and PVC	Aluminum	Aluminum, steel alloy
Mechanism	Crawler belt	Crawler tire	Crawler belt	Wheel	Wheel
Propulsion	DC motor (4x150W)	Brushless DC motor	Brushless DC motor	Brushless DC motor	DC motor
Controller	-	-	Arduino Mega 256	PID	PC 104 central
Performance	1. Wheelie more in water than land 2. The slip will cause and affected by friction between belt and seafloor 3. Can climb over a bump	1. More efficient, easy to control and long operation 2. Highest torque for maximum operating capabilities 3. Low thermal resist	1. Stable platform for taking manipulated data 2. Buoyancy system is integrates enabling crawler to become positively buoyant in the sea	1. Two segment body connected to pitch and roll 2. More efficient	1. More energy efficiency 2. Easy to control

2.5 Summary of the crawler

Based on research in five journal above, all are using different material for the frame body of vehicle by using aluminum, steel, metal, and PVC. Design 1, 4 and 5 using aluminum while design 2 using stainless steel and material of design 3 is PVC and metal. It is also using different mechanism which is design 1 and 3 use belting type while design 2, 4 and 5 using 4 driven wheel. The length of design 3 is largest than others design. Because it's designed to analyze a large vehicle for collide with obstacles and deviating from a straight line. So it can achieve their stability and the Arduino Mega 256 controller is able to operate the vehicle safely from obstacle field even with navigation errors and limited position updates. Besides, the mechanism design 2 is using four driven wheel and small size than others design because it is easy to move and more direct to control compared others crawler. It also can achieve their stability by designing box shape frame body. The others design need additional foam to offset the stability. Most of the crawler are using DC motor as their propulsion because of the DC motor characteristic that the availability is more specialized and good performance. For every motor it have a specific torque and speed. Other than that, design 2, 4 and 5 have a same concept by using four driven wheel of crawler. It is more stable platform for taking manipulated data and their crawler system is easier to wheelie in sea than on land. All the controller is included depending on their application using.

2.6 Moving and maneuvering

2.6.1 Motor

Motor is a machine which convert electric energy into mechanical energy. The electric motor is one of the prime mover type for a mechanical system. Motor is one of the most important and need to be considering on build the ROC. Motor is used to control and necessary to achieve the movement of the ROC. Also, the motor must be able to move the ROC with excellent maneuverability. Motor come in various shapes, sizes, and technologies, each design has its own functionality. The motor drive its shaft to move the wheel and motor is selected due its ability to give out the higher torque and speed. The low power consumption also must be considered. There are several type of DC motor that commonly use in ROC.

Table 2.2: Comparison of DC motor

Type	Advantages	Disadvantages
Brushless Motor 	1. High efficiency 2. Low maintenance 3. High operated speed	1. Expensive 2. More complicated
Brushed Motor 	1. Proven technologies 2. Simple control	1. Low specific torque 2. Due to brushes there are also interference noise
Geared Motor 	1. High efficiency 2. Longer gear life at similar loads 3. High power density	1. Expensive 2. Gear must be accurate to assure load sharing

Table 2.2 shows the comparison of various DC motor that could be used as a drive for the wheels systems. Most of low cost underwater vehicle are use DC motor to operate the vehicles due is used rechargeable battery as main power source. Equation (2.1) and (2.2) for power motor.

$$P = V \, x \, I \tag{2.1}$$

$$P = T \, x \, V \tag{2.2}$$

Where

P = Power (W)

V= Voltage (V)

I= Current (A)

T = Torque (Nm)

S = speed (rpm)

2.6.2 Wheels

A wheel is a circular component that is intended to rotate on an axial bearing. The wheel is allow heavy objects to be move easily movement while transported a load. Mostly underwater crawler using 2 type wheel mechanism which is crawler belt and crawler tires.

Table 2.3: Comparison between crawler belt and crawler tires.

Type Crawler	Advantages	Disadvantages
Crawler Belt 	1. High degree of work safety 2. Easy operation of all function 3. excellent climbing	1. Turning slow 2. High cost 3. More complicated
Crawler Tire 	1. No magnet requirement 2. More efficiency 3. More intuitive to control 4. No filter	1. Poor ability to operate in tight curves.

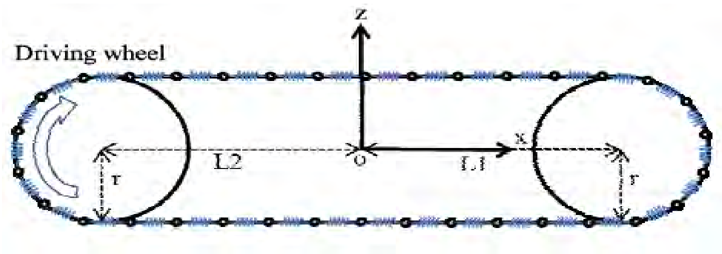


Figure 2.7: Crawler belt model [1]

Based on Figure 2.7, the external force acting on a crawler belt are gravity, line tension, normal component of reaction and external force to maintain velocity [1]. In actual operation of the crawler system, driven motors will be operated and controlled. Then the rotation speed of driven wheel, which is an element of the crawler belt on the driven wheel, is treat as an input parameter. The equation of motor are as follows:

$$m\ddot{x}_j = a_{xj}T_j + b_{xj}T_{j-1} + c_{xj}R_j + d_{xj}F_j + G_{xj} \qquad (2.3)$$

$$m\ddot{z}_j = a_{zj}T_j + b_{zj}T_{j-1} + c_{zj}R_j + d_{zj}F_j + G_{zj} \qquad (2.4)$$

Where

m	Mass of jth lump
$\ddot{x}_j$, $\ddot{z}_j$	Acceleration of jth lumped mass in x and z direction, respectively
T_j	Tension in segment between jth and (j+1)th lumped mass
R_j	Normal component of reaction in jth lumped mass
F_j	External force to keep velocity in jth lumped mass
U_j, V_j	Gravity force in jth lumped mass
$a_{xj}, b_{xj}, c_{xj} d_{xj}$	Function of x_j
$a_{zj}, b_{zj}, c_{zj} d_{zj}$	Function of z_j

The additional constraint equations, the geometric restrain condition on the wheel and the elongation rigidly of the crawler belt are as follows:

$$(x_j - L2)^2 + y_j^{\,2} = r^2 , (x \geq L2) \qquad (2.5)$$

$$(x_j - x_{j+1})^2 + (z_j - z_{j+1})^2 = dL^2 \left(1 + \frac{T_j}{AE}\right) \qquad (2.6)$$

The equation is analyzed with Houbolt's method for acceleration and velocity and with Newton-Raphson method for external forces.

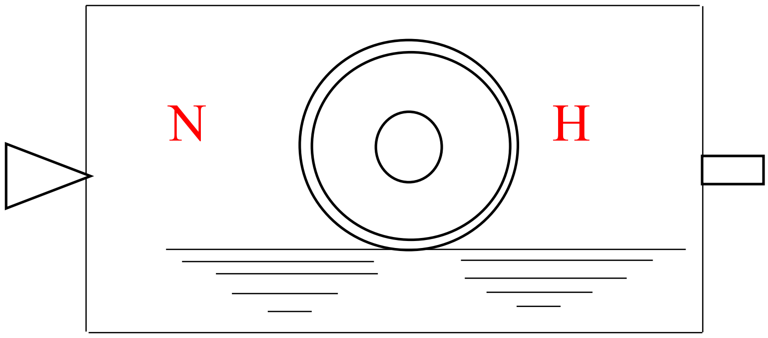


Figure 2.8: The rolling resistance crawler tire model

The crawler tires models in Figure 2.8 as shown the resistance force that acts on the wheel hub due to the rolling resistance at the road-wheel contact surface. The model can use a constant resistance coefficient or the pressure and velocity dependence of the crawler. The resistance force is zero when the normal force acting at the wheel-load surface is less than or equal to zero. The equation of constant coefficient in rolling resistance as follows:

$$F = N\mu \tag{2.7}$$

Where

F Rolling resistance force

N Normal force

μ Rolling resistance coefficient

The additional equation pressure and velocity of the crawler tires as follows:

$$F = \left(\frac{P}{P_0}\right)^{\alpha} \left(\frac{N}{N_0}\right)^{\beta} N_0 \,.\, (A + B|v_{hub}| + C{v_{hub}}^2) \tag{2.8}$$

Where

P Tire pressure

v_{hub} Hub velocity

P_0 1 Pascal (Pa)

N_0 1 Newton (N)

2.7 Tether

Underwater vehicles are normally tethers by an umbilical that supplies electrical power and fibre optics to transfer data. The umbilical tether also provides the physical link for launch and recovery of the vehicle, as well as the tracking and maneuverability of the vehicle. The performance of the vehicle can be impaired by the cable drag and weight of tether which in turn can snag or foul the tether on ocean structures. Naturally buoyant tether cables gain buoyancy with thermal rubber sheath material which are extremely flexible with good mechanical conductors also assist in reducing weight and diameter [13]. So, this type of tether is suitable for using on ROC.

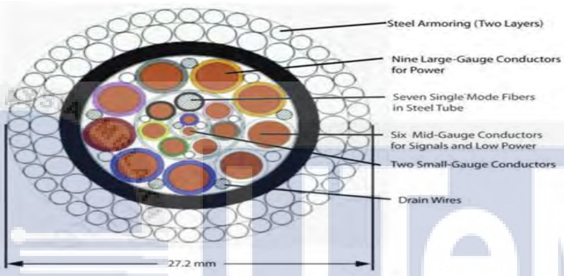


Figure 2.9: Natural buoyant tether cable [13]

2.8 Factor affecting the underwater crawler

Some factors will affect the underwater crawler in term of diving, it's physical and others. These include added mass, hydrodynamic damping, stability, environment forces and buoyancy.

2.8.1 Buoyancy

If a body is completely or partially submerged in a fluid one can call the resultant fluid force acting on it buoyant force. Since the pressure forces of the water increase with water depth, this leads to greater forces acting the lower part on the body than upper part, thus resulting in a positive net force.

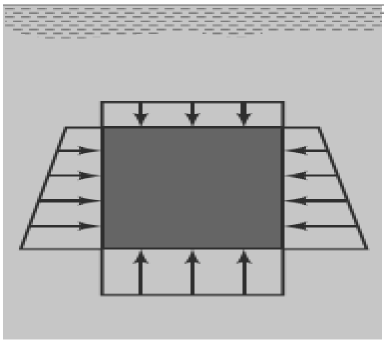


Figure 2.10: fluid pressure forces from below re larger than above thus resulting in positive vertical force [12]

If nothing the net resulting force as F one can simple Equation that describes a body's resulting net buoyant force:

$$F = F_B - W \tag{2.9}$$

Where

W = weight of body

g = gravity

$$F_B = \rho_{water} \text{ x g x } V_{body} \tag{2.10}$$

If the buoyancy force of the body and the weight force are equal, the resulting force F is zero, thus the body is neutrally buoyant and floats at an equilibrium. If the net force is negative the body sinks, and when positive the body ascends in the water column. Further simplifying yields an even simpler expression by using the specific weight of the fluid. The buoyancy has been classified intro three which is positive, neutral and negative buoyancy. So, the ROC main function is to control the buoyancy of the ROC.

$$F_B = \gamma . V_{body} \tag{2.11}$$

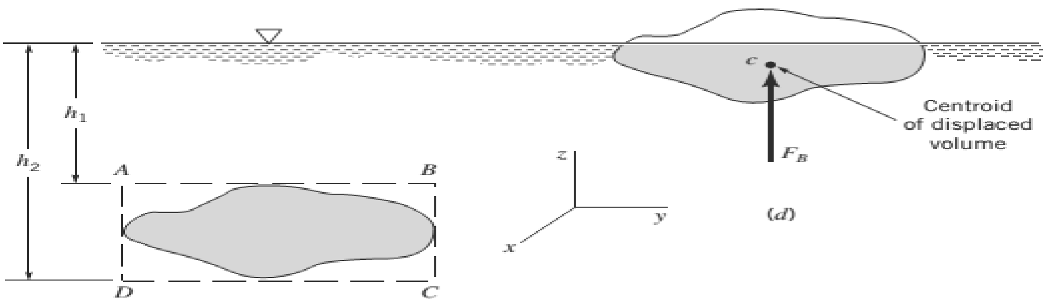


Figure 2.11: Buoyant force on submerged and floating bodies [12]

2.8.2 Positive, Neutral and Negative Buoyancy

The condition positive buoyancy where the weight and force relationship of which tend to be float on the surface of fluid. If an object weight less than the weight of water it displaces, it force will overpower its weight and the object will float. While the condition neural buoyancy where the weight and buoyancy force of the object tended to neither sink nor rise in fluid. The neutral buoyancy occurs when the object weight is equal to the fluid it displaced. Besides that, the condition of negative buoyant is weight is greater than buoyancy force of the object in which the objects will be more tend to submerge to the bottom of fluid. The ROC has negative buoyancy to immerse in the fluid and there is no air inside the crawler. The density inside of the crawler is higher compared to the water surrounding.

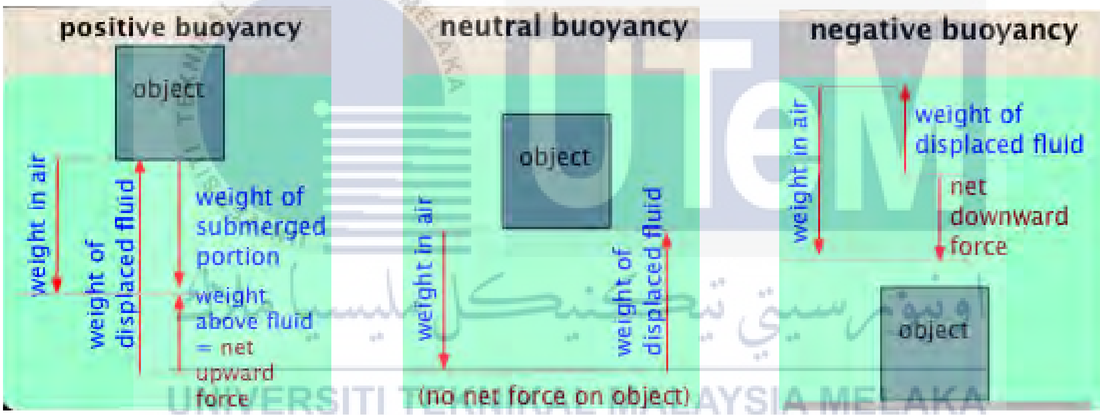


Figure 2.12: Positive, neutral and negative buoyancy [12]

2.8.3 Archimedes' Principle

The Archimedes' Principle states that the magnitude of the buoyant force acting on an object is equal to the weight of the fluid displaced by the object. Archimedes Principle tells that the buoyant force acting on a completely submerged vehicle will be equal to the weight of a vehicle size shaped of water. Since the ROV is submerged and the weight is calculated by using the force of buoyancy, buoyancy is the force that acts vertically upwards centroid of the ROV. Based on Archimedes Principle formula as: [7]

$$F_b = \gamma_f \text{ x } V_d \tag{2.12}$$

Where,

F_b =Buoyant force

γ_f = Specific weight of the fluid

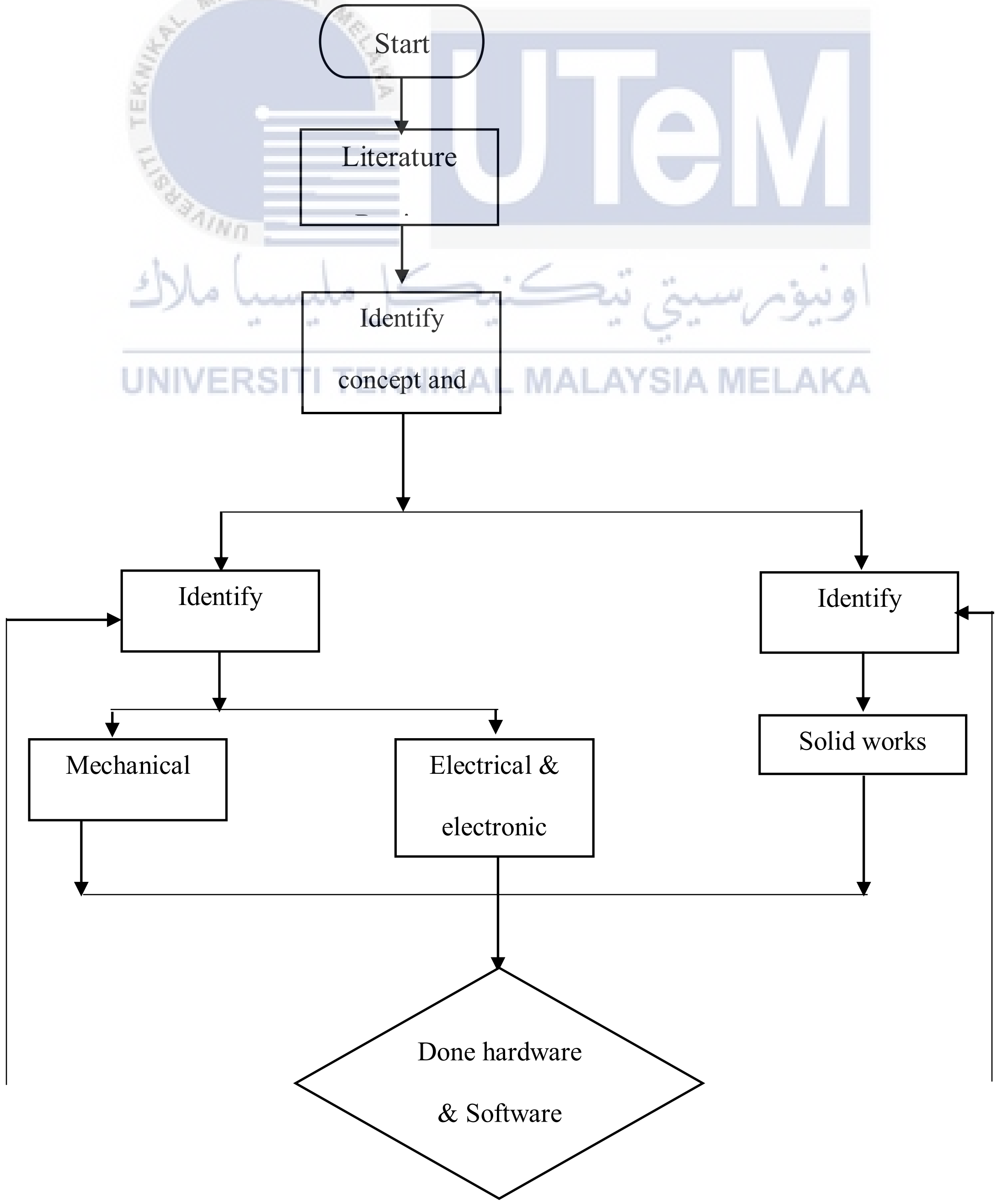
V_d =Displaced volume of the fluid

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter will discuss about methodology that will be implemented to accomplish this project. Hence, the methods that involved in project design, which are software and hardware development process will be discussed. Besides that, the material used in the design and mechanism of ROC need to be determined to ensure this project will be success on time and to fulfill all the objectives. Before starting the developing and designing stages, the most important part to generate this methodology is planning in details to accomplish this project with a good result. To ensure the project will be developed step by step according to the flow chart. The Figure 3.1 shows the flow chart of this project.



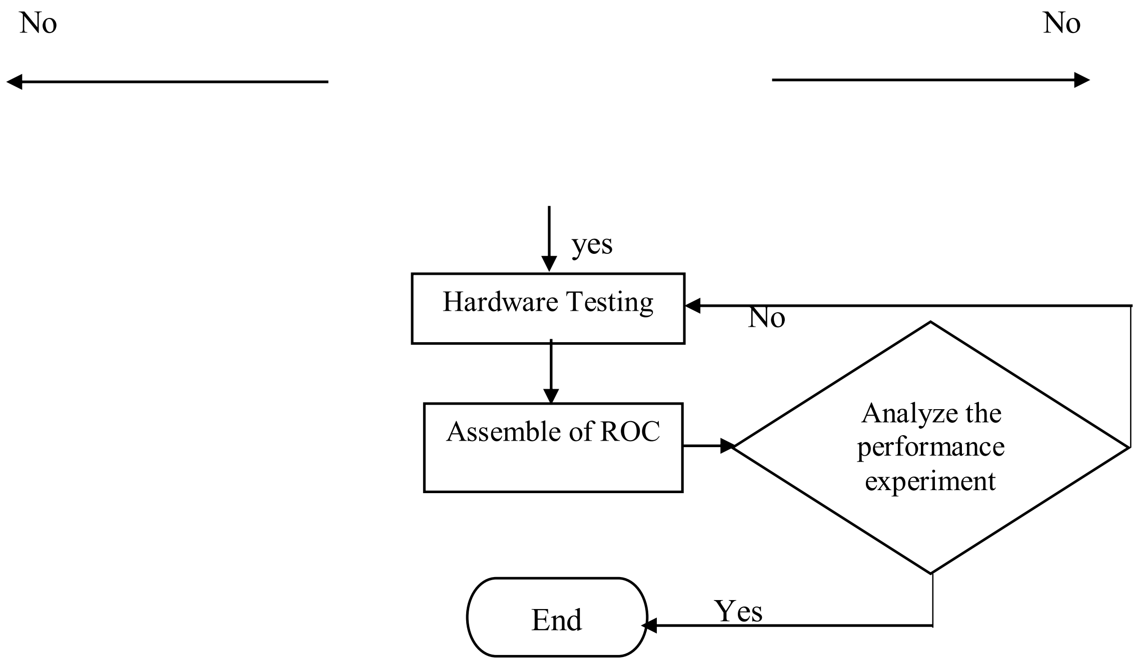


Figure 3.1 : Flow chart of project ROC

The Figure 3.1 is the flow chart of overview of this ROC project. The project started by identifying the project requirements and the problems. Therefore literature review is done by doing research about the concepts of the system. Next, the component that involves in ROC were studied. Besides that, in developing the system, the hardware and software were identified in terms of concept. The hardware development covers the design prototype of the ROC, frame of body, wheels, and structure to assemble the complete ROC. Meanwhile, the electrical and electronic element such as the light, camera, PSC28A and tether which is also constructed in hardware development. Other than that, the other stage is the software development, which is designing the ROC by using Solid Work. After that, the hardware tests are carried out and parts of ROC are assembled. Next, this ROC will be analyzed and data are taken to show the performance of the system by using several methods.

3.2 Remotely Operated Crawler Design Ideas

Figure 3.2 shows the ROC design. The design are divided into two parts which is hardware and software. Hardware includes the electronic and mechanical design.

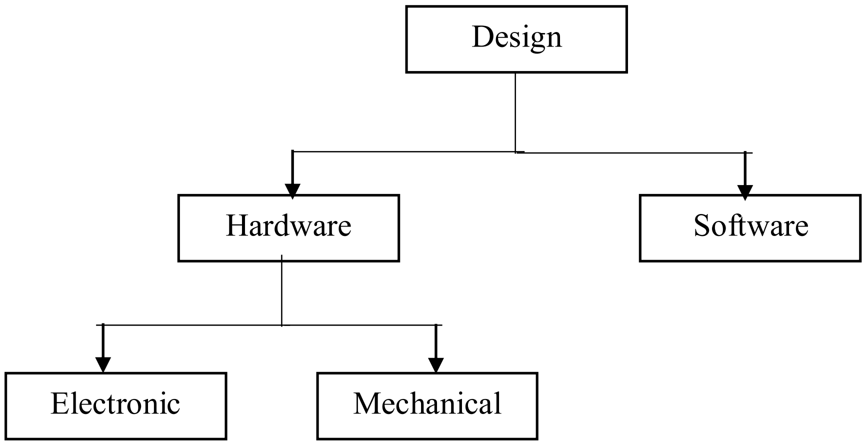


Figure 3.2: ROC design idea

3.3 Block diagram of the system

Figure 3.3 shows the block diagram of the system for this project. The controller will control the movement of wheel either it vehicle moving in the direction of its destination.

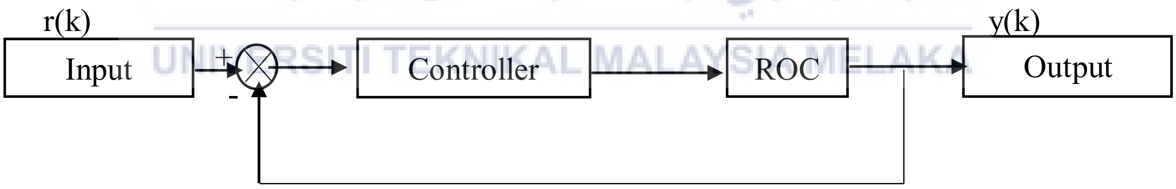


Figure 3.3 : System Overview

3.4 Design and development of unmanned ROC

In designing and development of the ROC has two part which is software and hardware. It started by designing the body structure of the ROC by using SolidWork software. After that, when the design is done, the hardware development of ROC is assembled. Besides that, the controller of the ROC is constructed to make the ROC move. The movement of this ROC can only move left, right, forward and backward. In addition, In order to control the DC motor, there is needed control box with electronic circuit that needs to install on the ROC. For this ROC, it will control by PSC28A circuit by Cytron.

3.4.1 Designing the body structure of the ROC by using Solid Work software

The first stage of implementing project is designing mechanical structure by using Solidworks software. This software allow the user to easily draw in three dimensional spaces. Besides that, it make easier to start building hardware. By using this software, it also can measure the material strength to every part of the body frame of ROC.

The Figure 3.4 shows that the project design overview based on the application and task for ROC purpose activities. Therefore, the selection of the design is important in order to increase the performance of ROC while maneuver the crawler operation in underwater condition. The crawler design is very stable platform because open frame design suitable for monitoring application and allow for underwater intervention by staying in direct contact with seafloor. With the wide surface and rough tires, the design of ROC is able to maintain its stability. Another advantages is when ROC run on the seafloor it can climb over a bump or runs on uneven surface. It because the ROC have high torque and high speed of DC motor. Other than that, the size of the ROC is 400 mm long, 350mm wide and 134mm of height is suitable for observation class of ROC.

3.4.1.1Center of Gravity

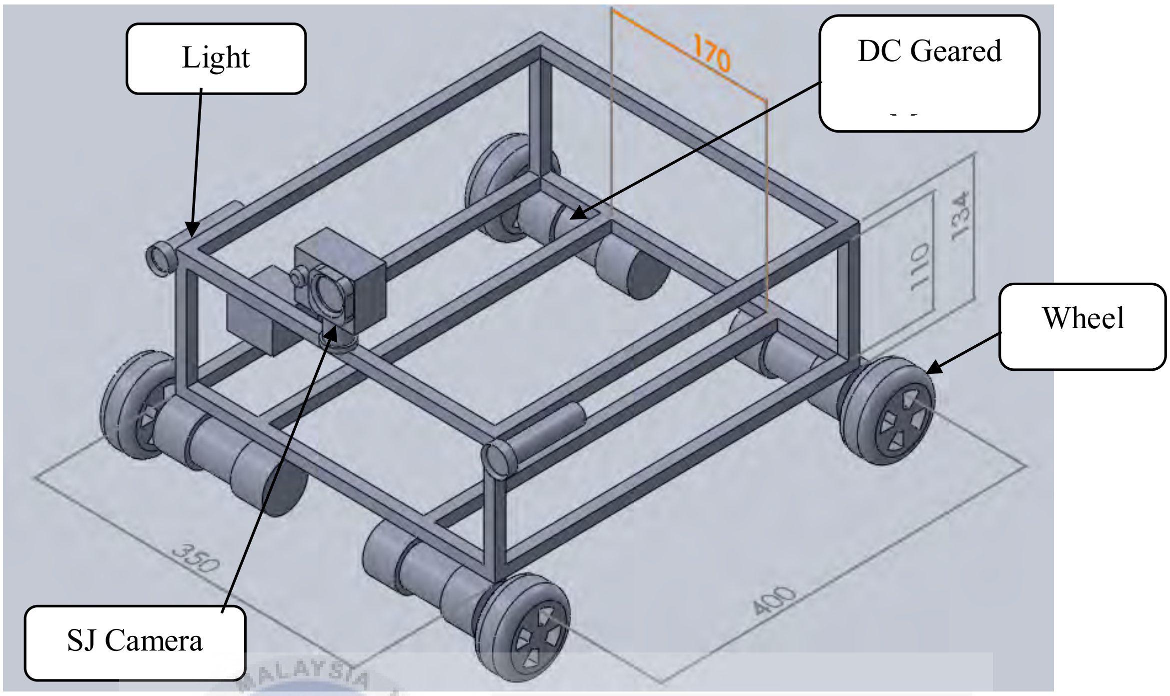


Figure 3.4 :Body structure overview

Figure 3.5 shows that the design of ROC with the centre of gravity that using two of DC geared motors to forward and reverse movement. Centre of gravity can be found using the SolidWorks. Besides that, the tendency of a ROC to return to an upright or down position is depends on center of gravity. Any completely submerged ROC with its Center of Buoyancy (CB) above its Centre of Gravity (CG) is going to be stable as long as no alters the position of CB or CG relative to the ROC frame. Distance between CB and CG need to be at the center of the ROC in order for it to be stable on top of water. The DC motor must be attached with the wheels of the ROC. To runs on the ROC in the underwater, ROC must be stable to submerged or floating. The stability can affect the vertical movement of the ROC. So from coordinate the centre of mass of ROC design is negative buoyancy and it will submerged automatically until it reach in seabed.

Centre of mass:

X: 234

Y: 6.53

Z: -219

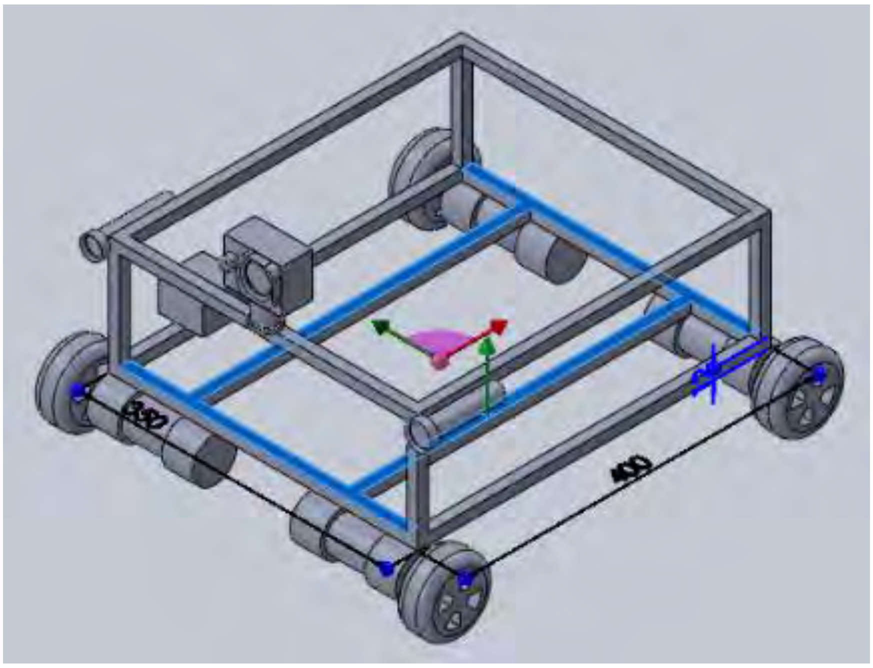


Figure 3.5 : Centre of Gravity

3.4.2 Hardware development of ROC

3.4.2.1 Development of body structure of ROC

To develop the body structure of the ROC, the material that will be used is metal. This is because the metal is heavy in weight and the capability to withstand high pressure at underwater. This is to ease the ROC to be submerged in water. Besides that, Archimedes Principle state that the buoyant force on an object fully submerged in a liquid depends on the objects mass and the mass of the fluid. If the mass of an object is higher than mass of fluid the crawler will be submerge and making direct contact with the seafloor. In order to protect metal from corrosion, the body structure is coated and then spray with the selected color. The weight of body in Figure 3.6 is 0.9kg. In this project, two driven wheels with four tires are being used because of the wide surface of contact area of the tires. Due to its wide surface which is having the diameter of 81mm and width of 35mm, the crawler is able to maintain its stability without flipping over while run on rough surface. According to the pressure formula $P = \frac{F}{A}$, where p is the pressure, F is the force and A is the surface area. This shows that when the surface area of object is high then the pressure will be low. It is prove that the wide of surface area of the tires contribute to the stability of the crawler. Besides that, since the ROC is able to run on lab pool, it also is able to be running on uneven surface. Another performance using wheel is when running on the lab pool the ROC can climb over a bump and can run on uneven surface. The Figure 3.6 shows that the body structure of ROC and the Figure 3.7 shows that the pool in Underwater Laboratory in FKE UTeM for the observation class. The Lab pool have 1.2m depth, 3m long and 1.5 m wide.

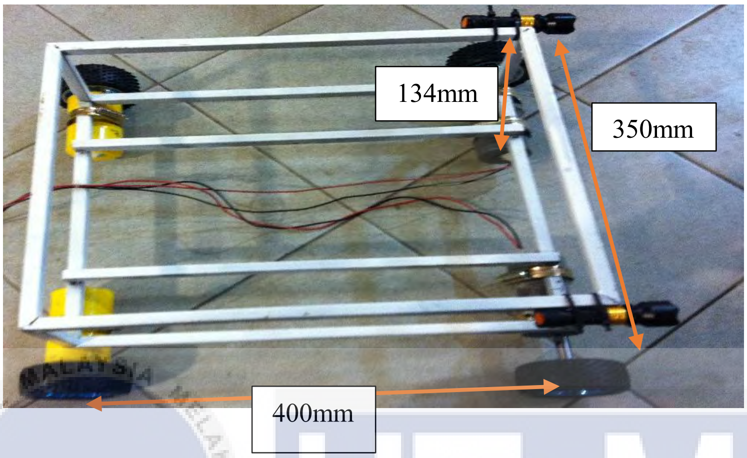


Figure 3.6 : Body structure of ROC

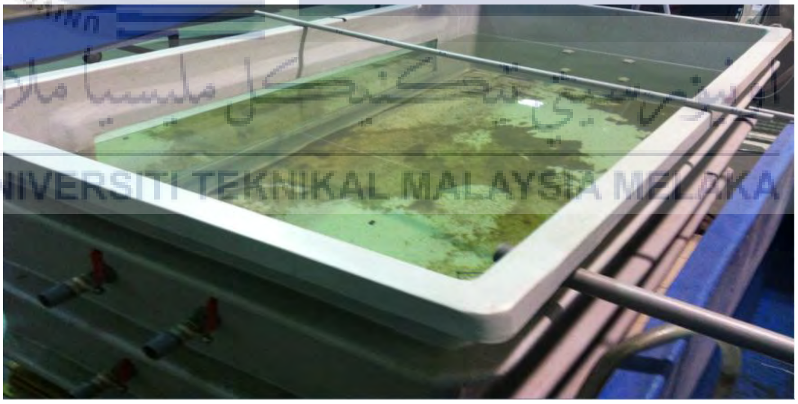


Figure 3.7 : Pool in Laboratory in FKE UTem

3.4.2.2 Waterproof DC geared motor

For designing of ROC the important part is to test each component underwater. Each electronic components is needed to be sealed correctly, such as dc motor to avoid any water from entering it. If the electronic parts can be protected from water then it will certainly last longer and the vehicle can be operated in underwater. Figure 3.8 shows that DC geared motor waterproof by using pipe PVC for cover the DC motor.

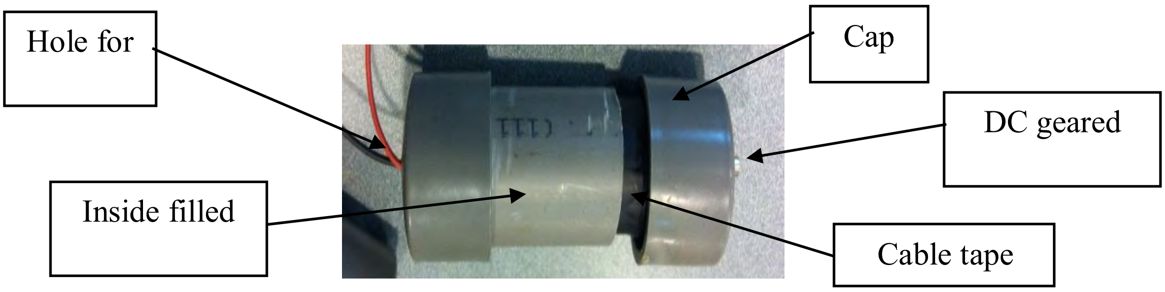


Figure 3.8: Waterproof DC geared motor

The thrusters are the main component in the ROC. It is controls the movement of the ROC and consists of motor and wheel of tire as shown in Figure 3.8. It helps the ROC to move forward, reverse, left and right. Besides that, two motor of DC geared motor are used in this project which have speed 108rpm. The DC geared motor are attached to the right and left of the ROC. This is to ensure that the motor can runs on smoothly and stably at lab pool. These motors is enough to control the movement of ROC and the from the manufacturer specification of the DC geared motor used have specification are:

- DC 12V
- Diameter = 38mm
- Output Power : 3.4 watt
- Rate speed: 108rpm
- Rated Current: 0.9A
- Rated Torque : 1960mNm

From the specification of the motor the torque of this project is by using high torque which is 1960mNm. Due to its torque, the motor can rotate when force acting on it. So the wheels are easily to climb over the bump and run on the uneven surface in underwater.

Figure 3.9: DC geared motor with wheel of tire

Calculation for the torque of motor.

The above equation gives power:

$$P = \tau \times 2\pi \times \omega \tag{3.1}$$

Where

P = Power

τ = torque

ω = angular velocity

If torque is in pounds-force feet and rotational speed in revolutions per minute, the above equation gives power in foot pounds-force per minute. The horsepower form of the equation is then derived by applying the conversion factor 33,000 ft·lbf/min per horsepower:

To convert angular velocity to revolution per minute is:

$$\frac{ft.lbf}{min} \times \frac{horsepower}{33000 \times \frac{ft.lbf}{min}} = \frac{\tau \times rpm}{525.11} \tag{3.2}$$

Where $$\frac{33000}{2\pi} = 525.11$$

The angular velocity to linear velocity is:

$$v = r \times \omega \tag{3.3}$$

Where

$$v = Velocity$$

$$r = radius, in\ meter$$

The RPM to linear velocity is:

$$v = r \times rpm \times \frac{2\pi}{60} \tag{3.4}$$

So to change the speed of DC motor to linear velocity is

$$v = 19 \times 108rpm \times \frac{2\pi}{60}$$

$$= 0.21ms^{-1}$$

3.4.2.4 Controller of ROC

In order to control the DC motor, there is needed control box with electronic circuit that needs to install on the ROC. For this ROC, it will control by PSC28A circuit by Cytron. These circuits already build in and connect with play station two (PS2) controller joystick. It is built in with standard connector socket for PS2 controller [14]. This circuit directly interfaces with input and output. The input will be PS2 controller and the output will be motor and so on. By referring the connection in datasheet, some modification needs to be done. It is needed motor driver circuit to control the motion of motor [14]. The Figure 3.10 shows that the overview of ROC electronic system.

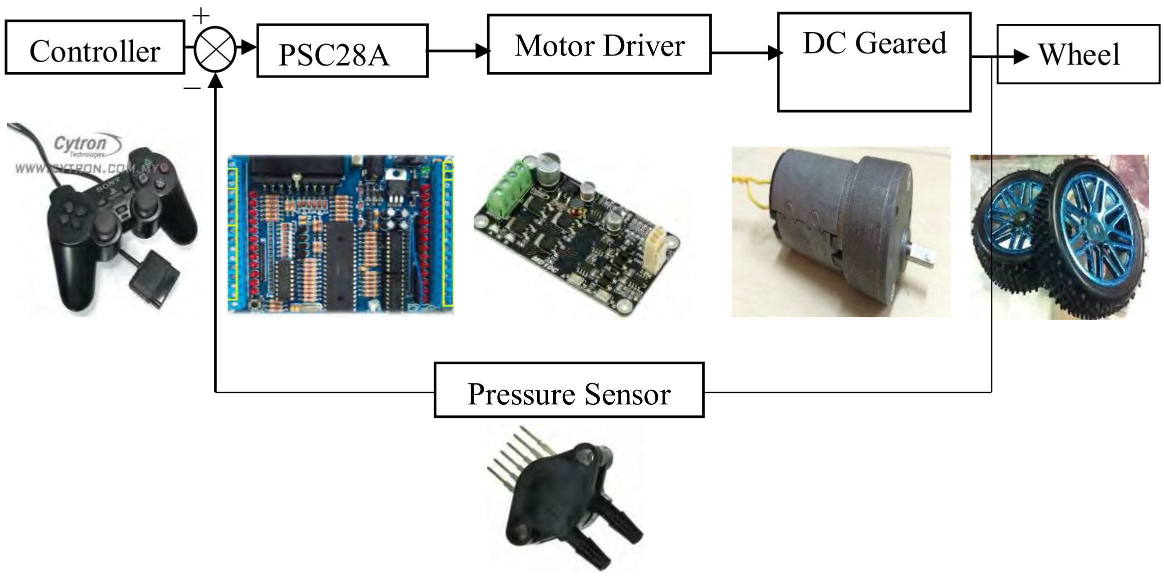


Figure 3.10: ROC electronic system [14]

PSC28A (Controller circuit)

The PSC28A shows in Figure 3.11 is a circuit board play as an interface between PS2 controller and other device that need to control. It is connected through microcontroller or directly I/O device.

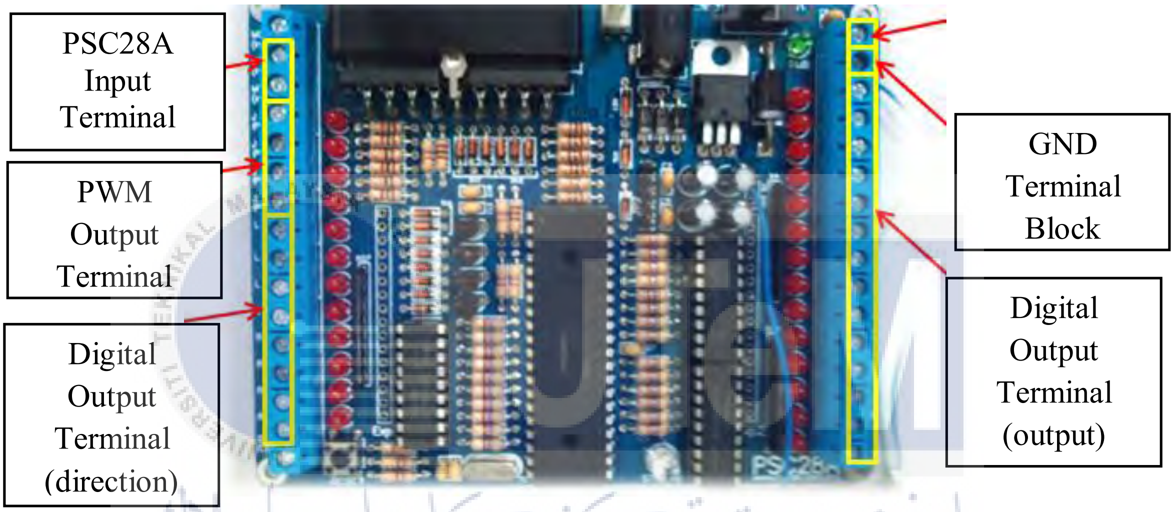


Figure 3.11: PSC28A Circuit

Motor Driver

Enhanced 10Amp DC motor driver is a motor driver which is used to drive DC geared motor to move either in the full speed or slower speed by Pulse Width Modulation (PWM) and in a clockwise or anti-clockwise direction. By using the PSC28A as shown in Figure 3.12 there are 2 input terminals, 4 PWM output terminals, 8 digitals output terminal (direction), 1 power out terminal that provide 12V to another peripheral such as motor driver. Other than that, this motor driver is to control DC geared motor by MD10 with PSC28A. MD10 is designed to drive high current DC geared motor up to 10A continuously. This project of ROC using two of motor driver to drive both DC geared motor as shown in Figure 3.12.

Figure 3.12 : MD10 Motor Driver

Electronic wiring

Based on the Figure 3.13 and Figure 3.14 are the part of electronic circuit and connection diagram that needs to install to the ROC. For this ROC, it will control by PSC28A circuit connect with PS2 controller joystick and two motor driver circuit to control the motion of motor. According to the datasheet PSC28A with standard connector socket for PS2 controller, this circuit directly interface with input and output. The input will be PS2 controller and the output will be the DC motor.

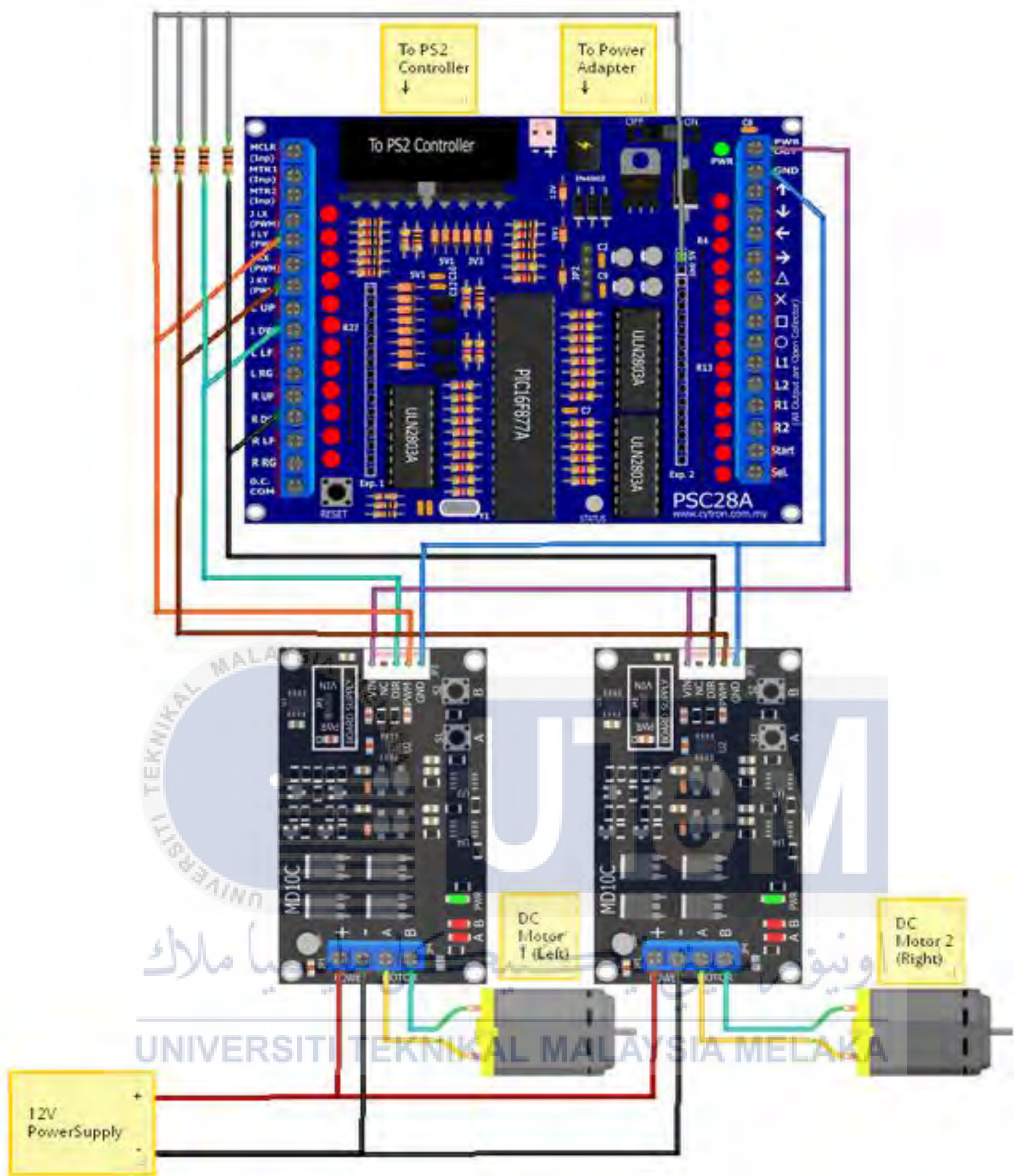


Figure 3.13: Connection diagram between PSC28A and two motor driver with DC motors

3.4.2.5 Ballast Tank System

In the development of ballast tank mechanism for floating of the ROC, ballast tank

MD10 of

Motor Driver

water vehicles which help controlling it buoyancy. The type of material

lyethene and polyvinyl which is the child buoys. The material must have

s as a balloon which can shrink during no air filled and expand when air is

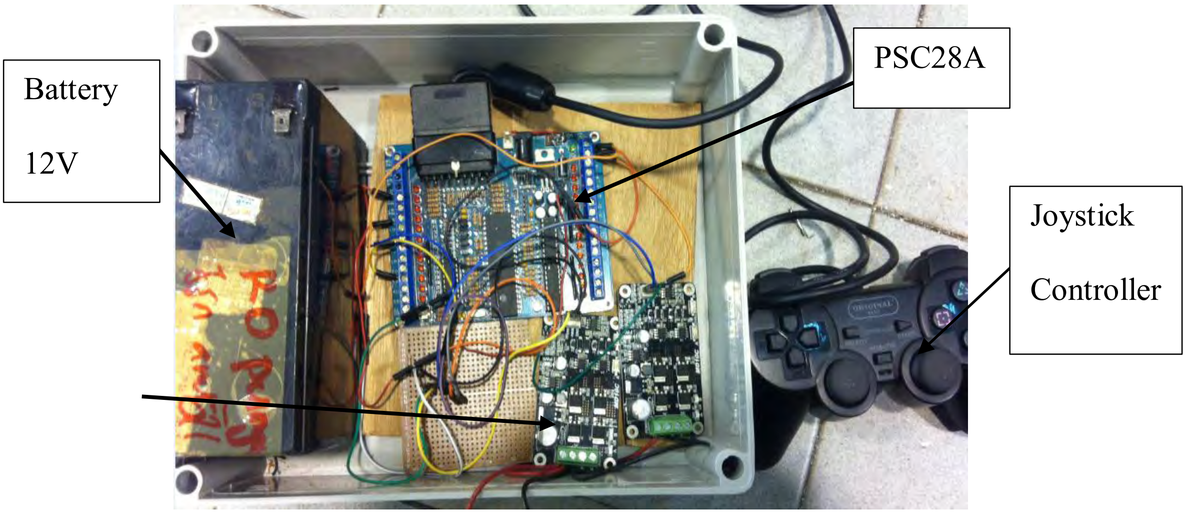


Figure 3.14 : Electronic assembly

filled by use the compressor. The ballast tank in Figure 3.15 has a simple system construction in ROC which only use compressor to fill the air into the ballast tank to expand the ballast tank for floating of the ROC.

Figure 3.15 : Ballast tank for floating the ROC

As the ROC go deeper, the pressure contact with the ballast tank will increase based on the principle of pressure where, pressure is the ratio of force to the area over which force is distributed as shown in Figure 3.16 where arrow represented the depth pressure.

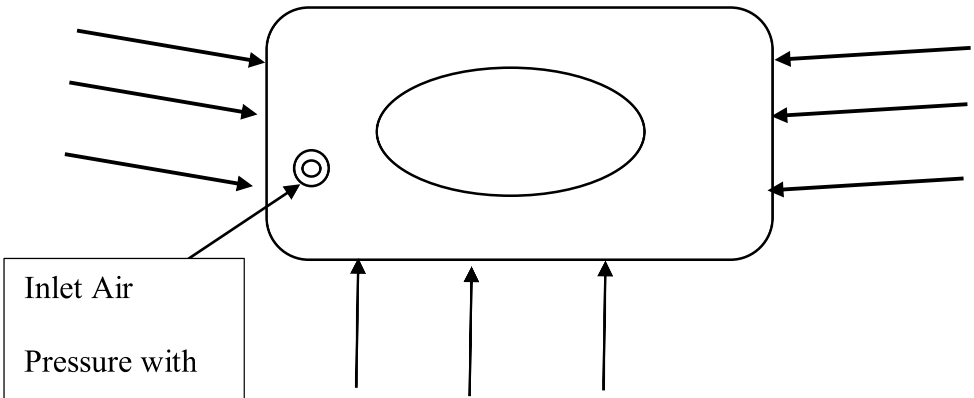


Figure 3.16: Concept of Pressure toward surface contact

Figure 3.17: The body structure with ballast tank

3.5 Experiment Implementation

There are several experiments that are carried out to measure the performance of the project.

3.5.1 Experiment 1: Waterproof Testing

Objective

1. To determine the sealing condition of the DC geared motor.

Procedure

1. The DC motors are wrapped by using cable tape and covered with high performance sealant.
2. The DC motors are inserted into a PVC pipe and sealed with caps.
3. The DC motors are submerged into water for 1 hours.
4. The DC motors is connected power supply with 12V.
5. The condition of DC motors are observed.
6. The data of the DC motors are recorded.

Figure 3.18: DC motor submerged in water

3.5.2 Experiment 2: Buoyancy of ROC

Objective

1. To determine the condition of ROC buoyancy

Procedure

1. Measured the weight for ROC without any iron columns was attached for weighed.

2. Put the ROC into the lab pool for 5 minutes and observe the position of ROC.
3. Increased the weight of ROC using iron columns (1.1kg) when the ROC is not submerge in underwater and observed the ROC position.
4. The ROC will submerged at the bottom surface of the pool. By observation check the buoyancy types either negatively buoyant, neutral buoyant or positively buoyant.
5. Observed and recorded the data.
6. The ballast tank is then tested by attaching with the air compressor that filled with air of the pressure of 2 bar for floating the ROC.
7. The condition for floating is observed.

Figure 3.19 : Buoyancy of ROC

3.5.3 Operation test of underwater crawler

There are several experiments to be carry out to measure the performance of the ROC. The testing is to check the ROC maneuver ability underwater.

3.5.3.1 Experiment 3: Forward and backward movement

Objective

1. To determine the speed of ROC in forward and reverse movement

Procedure

1. The ROC is place into the lab pool with the depth of 1.5 meters.
2. The ROC is checked for buoyancy.
3. The main switch of the ROC is turned on with the supply of 12V and the controller is checked to make sure whether the ROC functioning.
4. Control the ROC by using PS2 joystick controller to make a movement.
5. The ROC horizontal wheels are controlled to move in every 5 seconds for 20 seconds.
6. The distance in every 5 seconds are recorded.
7. The step 4 is repeated for reverse movement.
8. Observed and record the data

Figure 3.20 : Forward and Reverse movement

3.5.3.2 Experiment 4: Left and right turn

Objective

1. To determine the speed of ROC during left and right turn

Procedure

1. The ROC is place into the lab pool with the depth of 1.5 meters.
2. The ROC is checked for buoyancy.
3. The main switch of the ROC is turned on with the supply of 12V and the controller is checked to make sure whether the ROC functioning.

4. The time taken for the ROC to turn left in 2 meters is recorded.
5. The ROC is controlled by using PS2 joystick controller to make a movement.
6. The data is recorded for left and right turning condition until 45˚.
7. The step 4 is repeated for the right movement.
8. Observed and record the data.

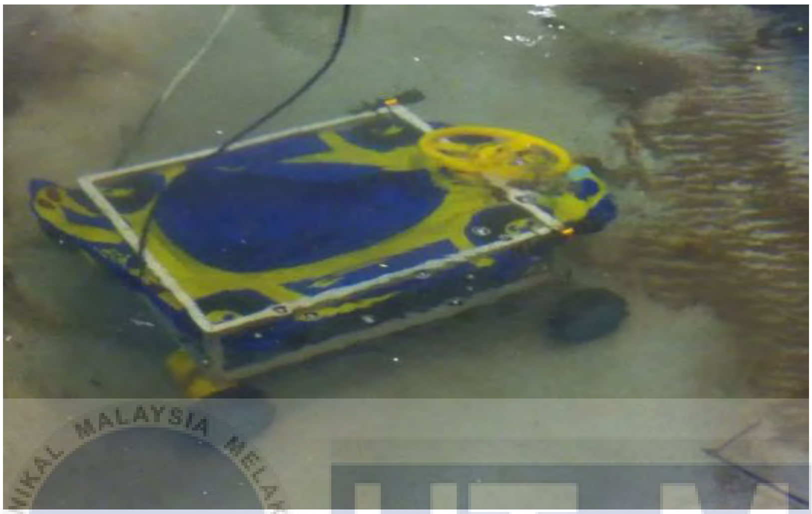


Figure 3.21 : Left and Right turn of the ROC

3.5.3.3 Experiment 5: Obstacle testing

Objective

1. To determine the ability of the ROC to run on obstacles

Procedure

1. The ROC is place into the lab pool with the depth of 1.5 meters.
2. A piece of plate metal with the thickness of 5mm is placed on the lab pool floor with the distance of 0.3 meters.

3. The main switch of the ROC is turned on with the supply of 12V and the controller is checked to make sure whether the ROC functioning.
4. Control the ROC by using PS2 joystick controller to make a movement.
5. The time taken of the ROC to move passed the obstacle is recorded.
6. The step 2 until 5 is repeated by adding the piece of plate metal.
7. Observed and record the data.

Figure 3.22: Obstacle testing

3.5.3.4 Experiment 6: Uneven Surface

Objective

1. To determine the ability of the ROC to run on uneven surface.

Procedure

1. The ROC is place into the lab pool with the depth of 1.5 meters.
2. To test the ROC on sand floor in underwater.

3. The main switch of the ROC is turned on with the supply of 12V and the controller is checked to make sure whether the ROC functioning.
4. The ROC is tested for the movement within 2 meters.
5. The ROC is observed and time taken is recorded.
6. Steps 2 to 5 is repeated for stone floor.

CHAPTER 4

RESULT AND ANALYSIS

4.1 Introduction

This chapter discusses on the result and the problem within in development process. After development of ROC complete, the ROC have to runs on underwater to ensure the ROC can moving perfectly.

4.2 Mechanical Construction Design

Mechanical part is one of the important part need to be consider during develop the ROC. To build the ROC which is there have several elements that need to be considered such as size, material that used stability, buoyancy and its ability to withstand underwater condition as long as possible.

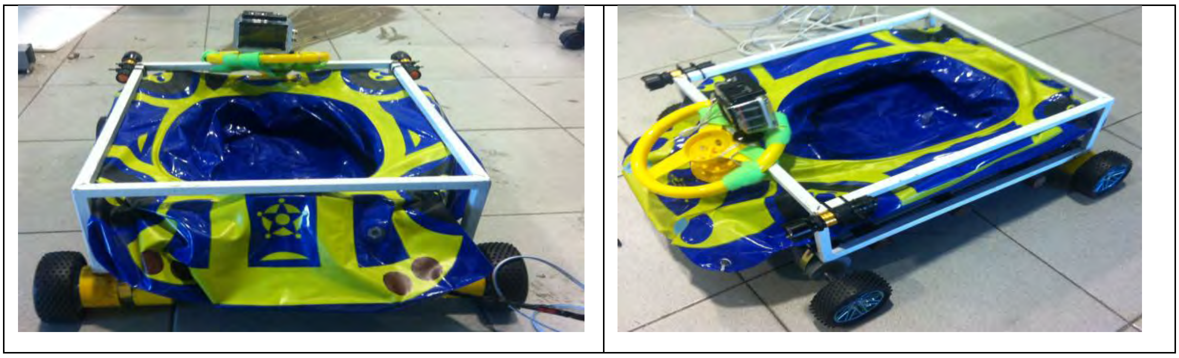


Figure 4.1: Mechanical construction of the ROC from side, top, back and full view

4.3 Experiment Results

4.3.1 Experiment 1: Waterproof test of DC Motor

The DC motor is an important part that need to be waterproofed. The Table 4.1 shows the testing result.

Table 4.1: Waterproof test

Time (min)	Condition		
	Test1	Test 2	Test 3
10	Bad	Good	Good
20	-	Good	Good
30	-	Good	Good
40	-	Bad	Good
50	-	-	Good
60	-	-	Good

From the Table 4.1, for the test 1 shows that at time 10 minutes is tested the condition to be bad because there was a leak at the PVC pipe sealing. To make sure the motor is sealed properly more high performance sealant is coated inside PVC pipe before the next testing. The next testing, it shows that the motor can only operate up to 40 minutes. This might be due to some leakage through the little gap around the cable. Due to this more protection needed to seal the DC motor. Therefore the high performance sealant is coated around the cable to cover the gap. For the last test it shows that the DC motor does not have any leakage and is working properly. As a conclusion, the objective of this experiment is achieved which is to determine the sealing condition of the DC motors.

4.3.2 Experiment 2: Buoyancy of ROC

4.3.2.1 Submerged test

The weight and the buoyancy of the ROC plays an important role for submerged in underwater. Besides that, the weight of the ROC before adding pieces of iron column is 2.88 kg. 1 pieces of iron column is 1.1kg. Other than that, the weight and the buoyancy of the ROC plays an important role for submerged in underwater. The condition of the submerged ROC is recorded in the Table 4.2.

Table 4.2: Submerged test of the ROC

Iron Column (pieces)	condition
0	Positive buoyancy
1	Positive buoyancy
2	Neutral buoyancy
3	Negative buoyancy

From this experiment, one piece of iron column is attached to the crawler one by one until it achieved a negative buoyancy. The Table 4.2 shows that one iron column is not enough to submerge the ROC. After putting two pieces of iron column the ROC started too submerged in the water but not directly contact with the lab pool floor. Lastly the ROC need three pieces of iron column to make it submerged and contact with the pool floor. So it’s proved that from Archimedes Principle that the weight of the ROC is greater than weight of water displaces. So the ROC has a negative buoyancy to immerse in the underwater. In addition, after adding the three of pieces iron column the total weight of ROC becomes 6.18kg. Figure 4.2 shows that the crawler with iron column. In conclusion, we can see that the design of ROC achieves the capability and stability to submerge of the ROC.

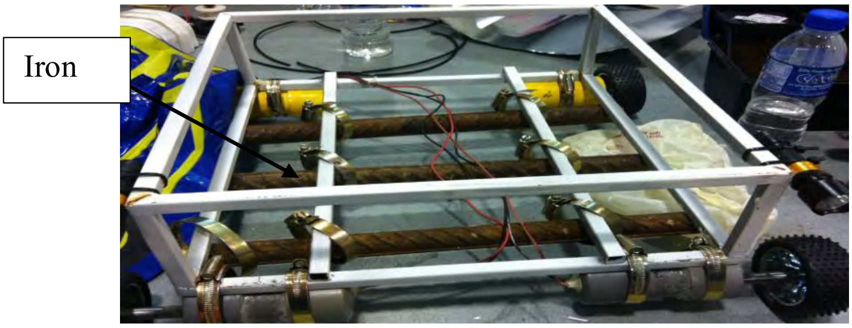


Figure 4.2 : The ROC with iron column

4.3.2.2 Floating test

After testing for underwater at the negative buoyancy, then to make it back positive buoyancy for the ROC to float the ballast tank is filled with 2 bar pressure of air. Other than that, the air pressure and the buoyancy of the ROC plays an important role for floating in underwater. The condition of the floatation ballast tank is recorded in the Table 4.3.

Table 4.3: Floating test of the ROC

Test 1	Time (s)	Condition
1	26	Positive buoyancy
2	26.4	Positive buoyancy
3	27	Positive buoyancy

According to the Table 4.3 shows that the test 1 to test 3 the ballast tank is successfully filled with air and make the ROC to be having positive buoyancy, therefore the floating application of the ROC is working. From the test 1 the time taken of 26 seconds, whereas test 2 having the time taken of 26.4 seconds and lastly test 3 having the time taken of 27 seconds to fully expand. The air from the ballast tank can make the ROC with a load of 61.8 Newton float to the surface of the water. Therefore, the design of ROC achieves the capability and stability to floating of the ROC.

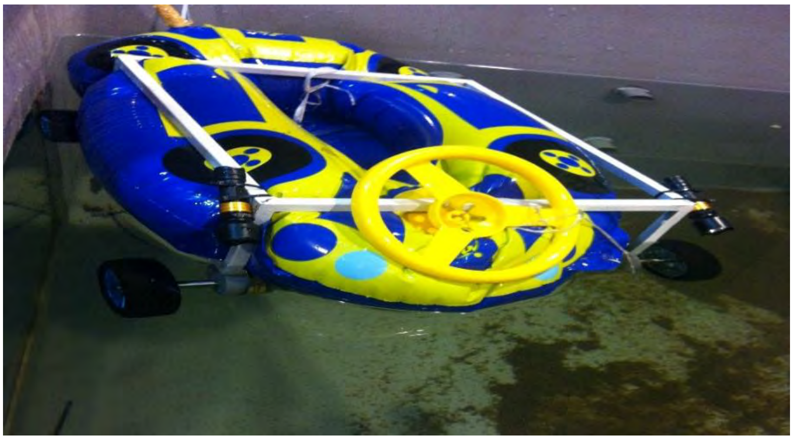


Figure 4.3 : The testing of ROC floatation

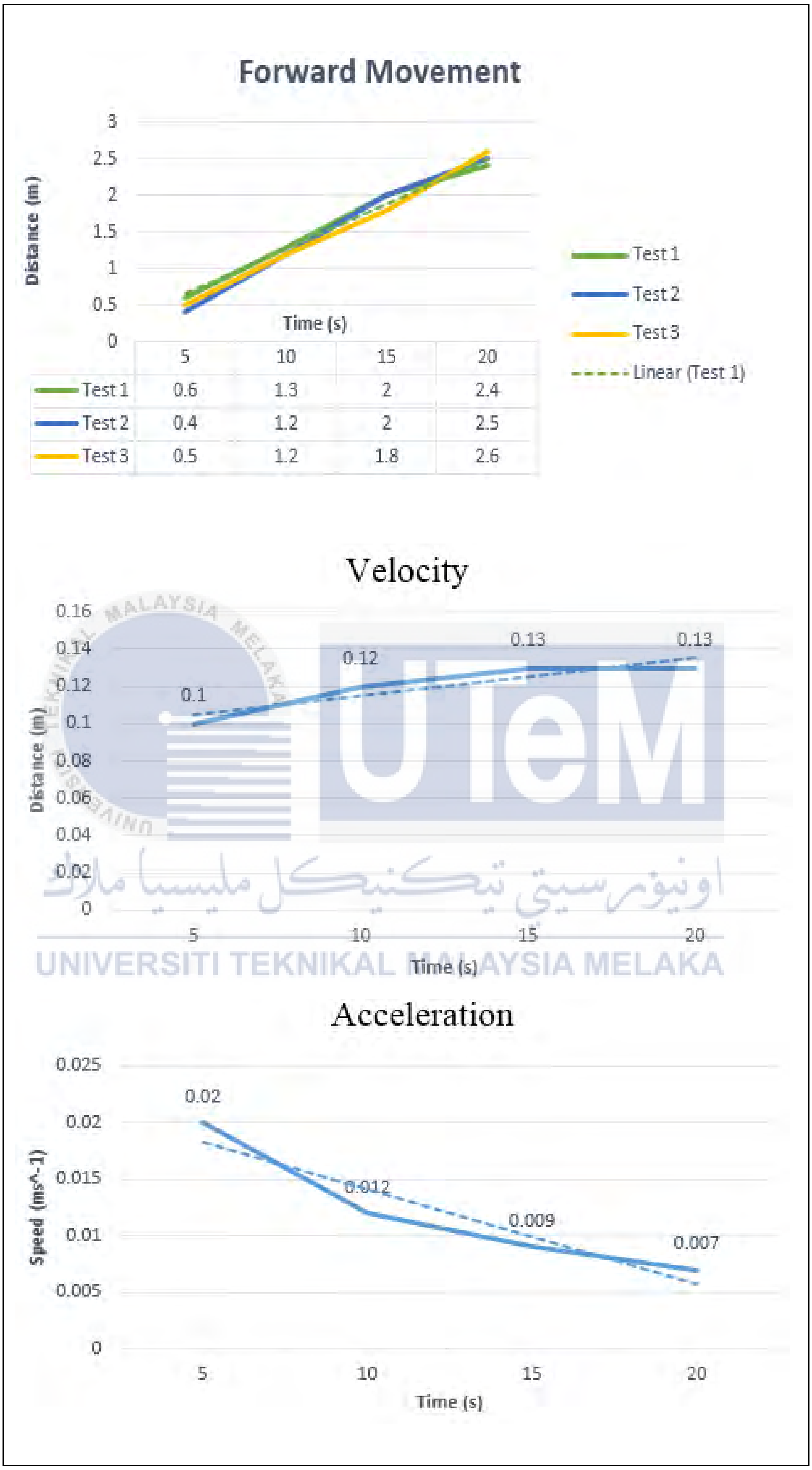
4.3.3 Operation test of underwater crawler

4.3.3.1 Experiment 3: Forward and Reverse Movement

For this experiment, the ROC was tested its capability to move forward and reverse in the lab pool condition and to measure the speed of ROC for both movement. To move forward the both DC motor must turn clockwise, while for the reverse movement the motor rotate anti clockwise. This was simply done by using PS2 joystick controller.

Table 4.4: Forward Movement

Test	Time (s)			
	Distance (m)			
	5s	10 s	15 s	20 s
1	0.60 m	1.30 m	2.00 m	2.40 m
2	0.40 m	1.20 m	2.00 m	2.50 m
3	0.50 m	1.20 m	1.80 m	2.60 m
Average	0.50 m	1.20 m	1.90 m	2.50 m



	5	10	15	20
Test 1	0.6	1.3	2	2.4
Test 2	0.4	1.2	2	2.5
Test 3	0.5	1.2	1.8	2.6

Figure 4.4: Graph of the velocity and acceleration for the forward movement

From the graph in Figure 4.2 shows that the average test in the first 5 seconds the ROC move up to 0.3 meters and then in 10 seconds it move up to 1.2 meters. After that, for the next 15 seconds it move 1.9 meters. At the end, its move up to 2.5 meters which take overall of 20 seconds of times taken. As we can see from the data the first 5 seconds there was a total of 0.7 meters. The next 5 seconds there was total of 0.7 meters. The last 5 seconds there was a total of 0.6 meters. From this it shows that the ROC slows down in the period of time. So the more test that were carried out the speed of ROC become slower. It is because the power supply of the ROC is having a voltage drop due to over use. In addition the condition of the velocity and acceleration of the ROC is also plotted on the Figure 4.4. Besides that, based on Figure 4.4 we can plotted linear line from the tests such as in equation 4.1.

$$y = mx + c \tag{4.1}$$

Gradient for test 1 ; $m_1 = \dfrac{2.4 - 0.6}{20 - 5} = 0.12ms^{-1}$

Gradient for test 2; $m_2 = \dfrac{2.5 - 0.4}{20 - 5} = 0.14ms^{-1}$

Gradient for test 3; $m_3 = \dfrac{2.6 - 0.5}{20 - 5} = 0.14ms^{-1}$

Average of the velocity; $m_{ave} = \dfrac{0.12 + 0.15 + 0.14}{3} = 0.14ms^{-1}$

By comparing the theoretical calculation and real value from experiment, the average value of the experiment is less than the theoretical experiment. The theoretical value of average speed of the DC motor is $0.21ms^{-1}$ and the real value from experiment is $0.14ms^{-1}$. So the different value of speed of ROC in forward movement is $0.07ms^{-1}$. This is because the real value of the average velocity from the experiment reduces compared to actual velocity because of the load of crawler.

Table 4.5: Reverse movement

Test	Time

	Distance			
	5 (s)	10 (s)	15 (s)	20 (s)
1	0.55 m	1.10 m	1.90 m	2.4 m
2	0.40 m	1.10 m	1.80 m	2.45 m
3	0.40 m	1.00 m	1.90 m	2.50 m
Average	0.45 m	1.07 m	1.86 m	2.45 m

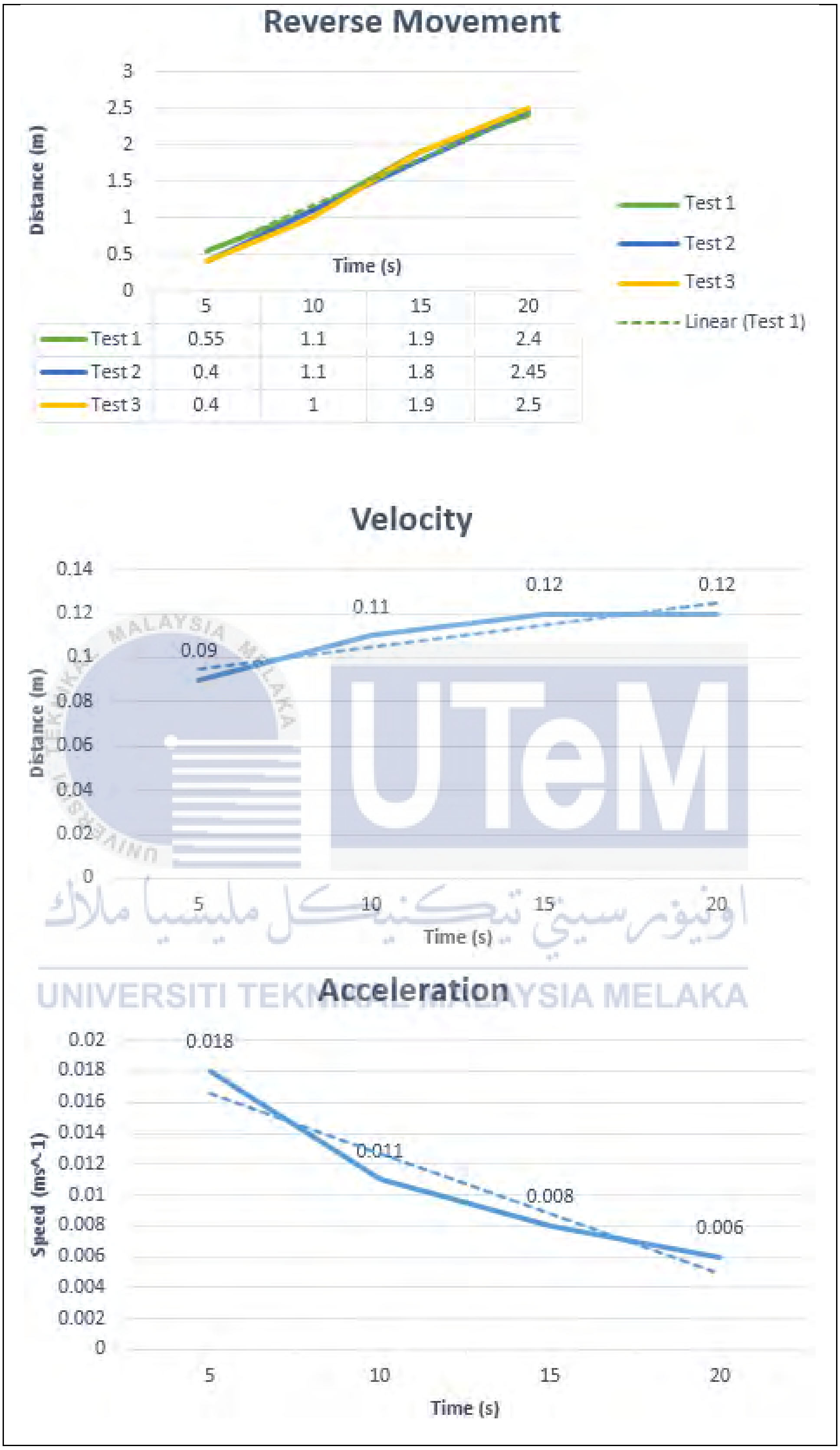


Figure 4.5: Graph of the velocity and acceleration for the reverse movement

From the reverse movement graph in Figure 4.5 shows that for the average test in the first 5 seconds the ROC move up to 0.45 meters and then in 10 seconds it move up to 1.07 meters. After that, for the next 15 seconds it move 1.86 meters. At the end its move up to 2.45 meters in which overall of 20 seconds. As we can see from the data the first 5 seconds there was a total of 0.62 meters. The next 5 seconds there was total of 0.79 meters. The last 5 seconds there was a total of 0.59 meters. From this it shows that the ROC is become slows down in the period of time. Thus, the more tests that are carried out the speed of ROC become slower. It is because the power supply of the ROC is having a voltage drop due to over use and may some constraint disturbance in the Lab pool while the condition of water was waving. In addition the condition of the velocity and acceleration of the ROC is also plotted on the Figure 4.5.

Gradient for test 1 ; $$m_1 = \frac{2.4 - 0.55}{20 - 5} = 0.12ms^{-1}$$

Gradient for test 2; $$m_2 = \frac{2.45 - 0.4}{20 - 5} = 0.14ms^{-1}$$

Gradient for test 3; $$m_3 = \frac{2.5 - 0.4}{20 - 5} = 0.14ms^{-1}$$

Average of the speed; $$m_{ave} = \frac{0.12 + 0.14 + 0.14}{3} = 0.13ms^{-1}$$

For the reverse movement, the theoretical calculation and real value from experiment the average of the experiment is less than the theoretical experiment. The theoretical value of average speed of the DC motor is $0.21ms^{-1}$ and the real value from experiment is $0.13ms^{-1}$. So the different value of speed of ROC in reverse movement is $0.08ms^{-1}$. This is because the real value of the average velocity from the experiment reduces compared to actual velocity because of the load crawler. Besides that, by comparing the forward and reverse movement, we can see that the speed of forward is better than reverse. It is because the two DC motor is only attached to the front wheels that also carries the back wheels. Other than that, water resistance may contribute for the motor to be slowed down. So from this experiment we can conclude that the objective to study the performance of ROC in terms of moving forward and reverse is achieved.

4.3.3.2 Experiment 4: Left and right turn

For this experiment, the ROC is tested its capability to move left and right in the Lab pool and to measure the speed of ROC for both movement. For right movement the left DC motor is turned off whereas for the left movement the right DC motor is turn off. This is simply done by using PS2 joystick controller.

Table 4.6: turn left test

Test	Time (s)	Velocity (m/s)	Angular velocity (rad/sec)
1	13.20	0.15	0.06
2	12.00	0.17	0.06
3	11.51	0.17	0.07
Average	12.24	0.16	0.06

Table 4.7: turn right test

Test 1	Time (s)	Velocity (m/s)	Angular velocity (rad/sec)
1	13.43	0.15	0.06
2	12.40	0.16	0.06
3	12.00	0.17	0.07
Average	12.61	0.16	0.06

From the Table 4.6 and Table 4.7 it shows that the ROC is tested for moving left and right with the wheels positioned at 45 degree. The velocity and angular of the crawler for both turning left and right is the same but the time taken of turning left and right have a difference 0.37 seconds. This is because to the voltage drop at the right DC motor on the ROC. This is happened because the power supply that supplied for both DC motor comes from the same source which is 12V battery. By comparing the value of this experiment, we can conclude that the ROC has achieved the objective to determine the speed of ROC during left and right turn.

4.3.3.3 Experiment 5: Obstacle testing

For this experiment, the ROC is tested its ability to move on obstacle by using metal plate. This experiment starts with the plate thickness of 5mm. The plate is added gradually and the time taken for the ROC to move over the obstacle is recorded.

Table 4.8: Obstacle Testing

Thickness (mm)	Pass / Not pass	Time (s)		
		Test 1	Test 2	Test 3
5	✓	1.19	1.63	1.26
10	✓	1.35	1.28	1.28
15	✓	1.29	1.69	1.41
20	✓	1.38	1.42	1.40
25	✓	1.66	1.99	1.47
30	✓	1.59	1.61	1.74
35	✓	1.8	1.90	1.88
40	×	×	×	×

From the Table 4.8 it shows that overall the test 1 has the lowest time need to overcome the obstacle from 5mm to 35mm. From the data taken from test 1 to test 3 it shows that there was increment of the time taken. This may due to the reduced power of the battery after using it for taking the test 3 times. The longest time taken to pass the obstacle is test 3 when to bypass the thickness of 35 mm at 1.90 seconds while the fastest time taken to pass the obstacle is at test 1 when to bypass the thickness of 5mm at 1.19 seconds. This may due that increasing the obstacle will increase the force needed to pass the obstacle. Therefore, we can conclude that ROC has the ability to run over up to 35mm thickness of obstacles.

4.3.3.4 Experiment 6: Uneven Surface

For this experiment, the ROC is tested its ability to move on uneven surface with two different environment which are at stone and sand.

Table 4.9: Uneven surface of the sand

Test	Time (s)					
	Distance (m)					
	5s	10 s	15 s	20 s	25 s	30 s
1	0.40 m	0.90 m	1.20 m	1.70 m	2.10 m	2.17 m
2	0.50 m	0.90 m	1.40 m	1.70 m	1.90 m	2.15 m
3	0.50 m	0.90 m	1.20 m	1.60 m	1.80 m	2.13 m
Average	0.47 m	0.90 m	1.27 m	1.67 m	1.93 m	2.15 m

Table 4.10: Uneven surface of the stone

Test	Time (s)					
	Distance (m)					
	5s	10 s	15 s	20 s	25 s	30 s
1	0.20 m	0.60 m	0.70 m	0.80 m	0.90 m	1.10 m
2	0.30 m	0.40 m	0.70 m	0.90 m	1.00 m	1.05 m
3	0.35 m	0.50 m	0.70 m	0.70 m	0.90 m	1.03 m
Average	0.28 m	0.50 m	0.70 m	0.80 m	0.93 m	1.06 m

From the Table 4.9 and Table 4.10 it shows that the ROC is tested for two different environment of uneven surface which on sand and stone floor. The average test in the first 5 seconds on sand the ROC move up 0.47 meters and then in 10 seconds it move up to 0.90 meters. After that, for next 15 seconds it move 1.27 meters and the next 20 seconds it move 1.67 meters. Besides that, for the 25 seconds it move 1.93 meters and at the end its move up to 2.15 meters in overall of 30 seconds. While for the stone floor, the average test in the first 5 seconds the ROC move up 0.28 meters and then in 10 seconds it move up to 0.50 meters. After that, for next 15 seconds it move 0.70 meters and the next 20 seconds it move 0.80 meters. Besides that, for the 25 seconds it move 0.93 meters and at the end its move up to

1.06 meters in overall of 30 seconds. As we can see from the data, the different distance between sand and stone floor is at the first 5 seconds was 0.19 meters differences. The next 10 seconds, there was total of 0.4 meters of difference distance. Then at 15 seconds, the different was 0.57 meters, 20 seconds was different 0.87 meters, 25 second was 1 meters and at the end for 30 seconds the differences distance was 1.09 meters. From these result, it shows that the performance of ROC on stone floor has lower period of time than sand floor. It is because the power supply of the ROC having a voltage drop due to over use and may some constraint disturbance in the Lab pool while the condition of water was waving.

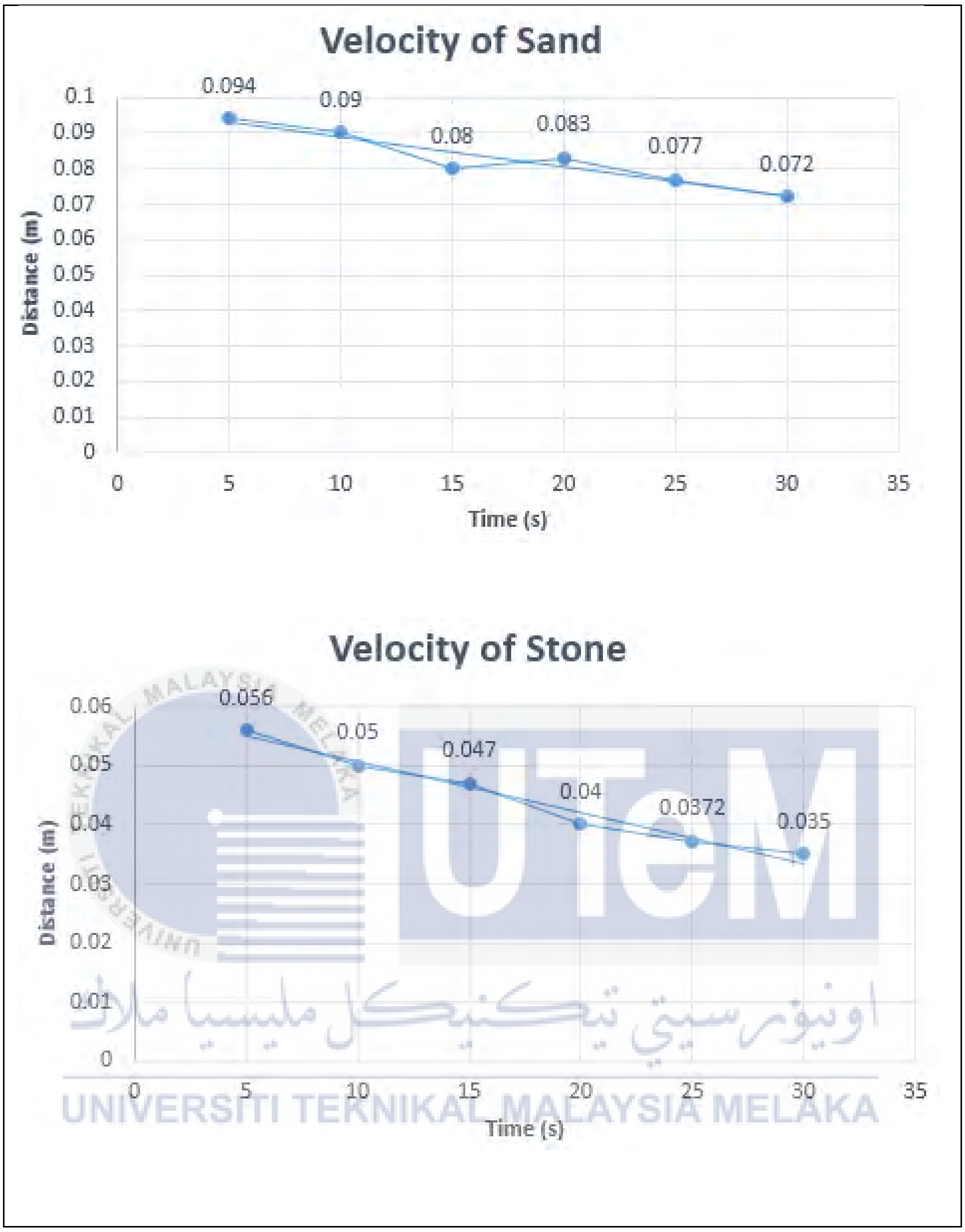


Figure 4.6: The graph velocity on the sand and stone floor

The calculation of the speed on sand:

Gradient for sand ; $$m_{sand} = \frac{2.15 - 0.47}{30 - 5} = 0.07ms^{-1}$$

Gradient for stone ; $$m_{stone} = \frac{1.06 - 0.28}{30 - 5} = 0.03ms^{-1}$$

By comparing the floor of sand and stone, we can see that the speed of ROC move slower on stone compared to the sand. It is because the ROC exerted more friction force on the tires while move on the rough surface. When ROC moves on sand floor, it shows less of friction force. So the value of speed move on sand floor is 0.07 meter per seconds while the speed move on stone floor is 0.03 meter per second. Other than that, water resistance may contribute for the tires to runs on the sand and stone floor. Therefore, from this experiment we can conclude that the objective to study the ability of ROC to run on uneven surface is achieved.

Based on equation of constant coefficient in rolling resistance which is

$$F = N\mu \tag{4.2}$$

Where

F = Friction resistance force

N = Normal force

μ = Rolling resistance coefficient

Resistance of coefficient have a constant value is 0.01

$$F = m \times a \times \mu \tag{4.3}$$

Acceleration of sand;

$$a_{sand} = \frac{0.0024 - 0.0188}{30 - 5} = 6.56 \times 10^{-4} ms^{-2}$$

Acceleration of stone;

$$a_{stone} = \frac{0.0024 - 0.0112}{30 - 5} = 3.52 \times 10^{-4} ms^{-2}$$

Friction resistance force on the sand.

$$F_{sand} = 6.18 \times 6.56 \times 10^{-4} \times 0.01$$
$$= 4.054 \times 10^{-5}\ N$$

Friction resistance force on the stone.

$$F_{stone} = 6.18 \times 3.52 \times 10^{-4} \times 0.01$$
$$= 2.18 \times 10^{-5}\ N$$

By using Equation 4.2 we can see that the force on sand is 4.054×10^{-5} Newton while on stone is 2.18×10^{-5} Newton. So the friction resistance force moving on stone is lower than moving on sand. It is because the stone have the rough surface compared to the sand. In addition due to water resistance it will also increase the pressure on the tires which will produce less torque that it should be release.

CHAPTER 5

CONCLUSION

5.1 Introduction

This chapter discuss about the conclusion of the project, which is the whole project that have be done after all design and development of the mechanical and the electrical part as well as the controller from the beginning with the literature study until the result and analysis is implemented of the project. Other than that, this chapter also states the recommendation for the future development and more efficiently rather than previous system.

5.2 Conclusion

At the end of this project it can be conclude that the first objective of this project is achieved. The first objective in this project is to design and development of unmanned underwater Remotely Operated Crawler (ROC) for monitoring system. It started by designing the body structure of the ROC by using SolidWork software. After that, for the development of the ROC, the material selection was important for body structure in order to get low cost material that can withstand the underwater pressure and anti-corrosion. In addition, this project also waterproof DC geared motor by using PVC pipe and can undergo 2m depth for controls the movement of the ROC with wheel of tires. This project is successfully moved in four degree of freedom controlled by PS2 joystick by using the PSC28A controller.

In this project, the second objective of it about the analysis the performances in terms of stability, maneuverability and velocity is achieved. The ROC design is perfectly stable while the ROC totally submerged by adding three iron column to submerged in the water and direct contact with the pool floor. Besides that, the stability to floating the ROC also working by using the ballast tank to float to the surface of the water. To float the ROC, the ballast tank was filled with 2 bar of pressure air in order to fully expand the ballast tank. Other than that, the controller that been attach to the electronic circuit capable to send command either forward, reverse, left or right. It can be conclude that, the maneuverability of the ROC is fulfilled requirement for monitoring application. In addition, the ROC is successfully for moving the crawler turn left and right with the wheels positioned at 45 degree. Furthermore, the effectiveness of the maneuverability of the ROC was proven by the tests were completed by the ROC to overcome the several height of obstacle and also can be operated at several condition of surface without having a problem.

Hence, after completing this project, all the objectives were successfully been fulfilled in order to design and develop the unmanned underwater ROC for monitoring application.

5.3 Recommendation

In order to improve this project, there are several recommendations that have been identified throughout the project. Firstly, to improve the body structure of the ROC by using a close-solid frame and proper design that can withstand high pressure underwater and waterproof. Instead of using hollow metal, it is much more suitable and proper to fabricate compact steel as the body of the ROC. Besides that, the material usage for this project also can be improve by using better material in terms of weight so it can be easier to float or submerged. The other recommendation for this project is the system needs a switch that operates such transmitter and receiver by using underwater acoustic signal communication due to the strong signal attenuation when dealing with underwater which to control the ballast tank system to make the ROC floating after inspection finish.

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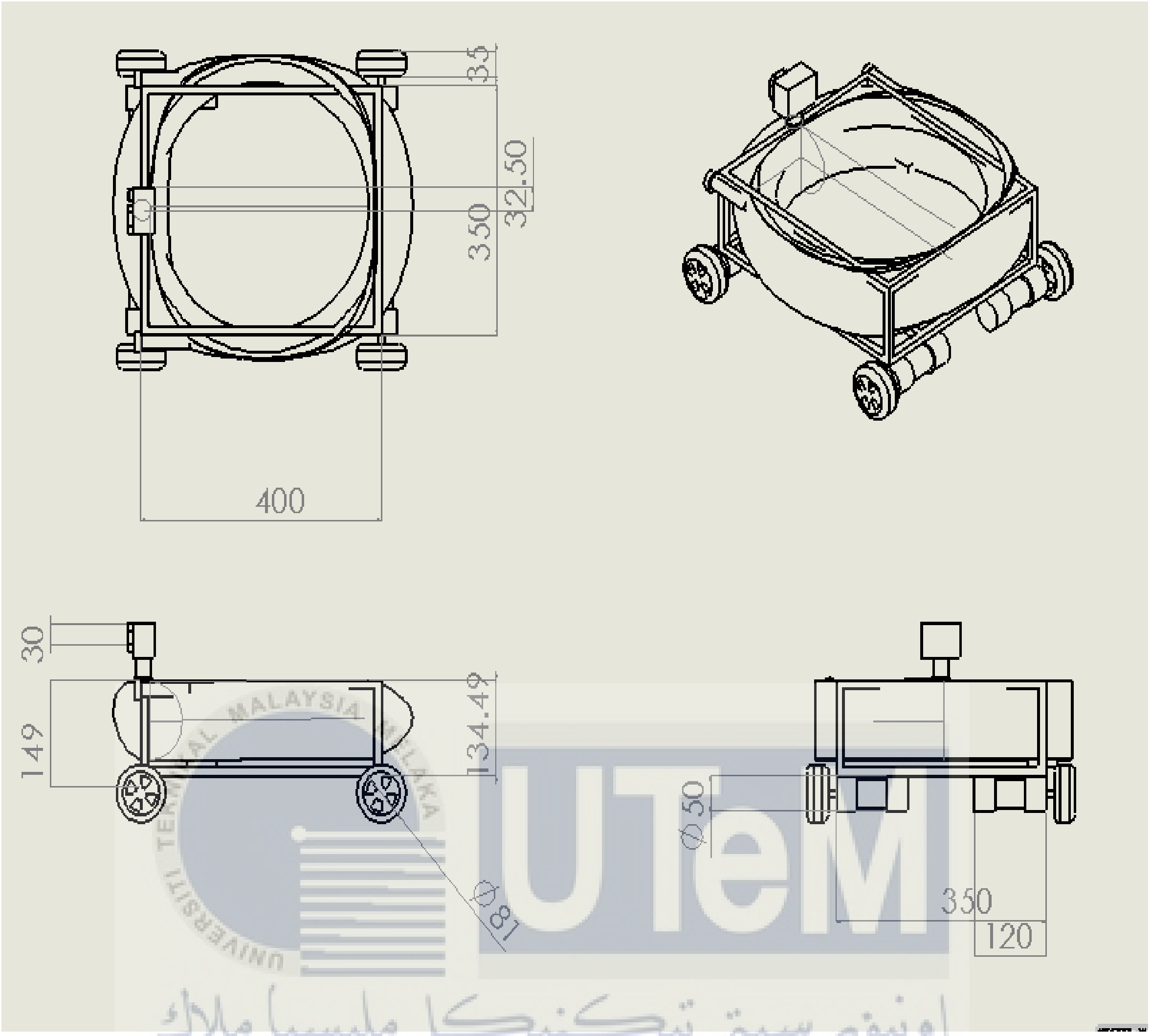
APPENDIX A

ROC view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134.49
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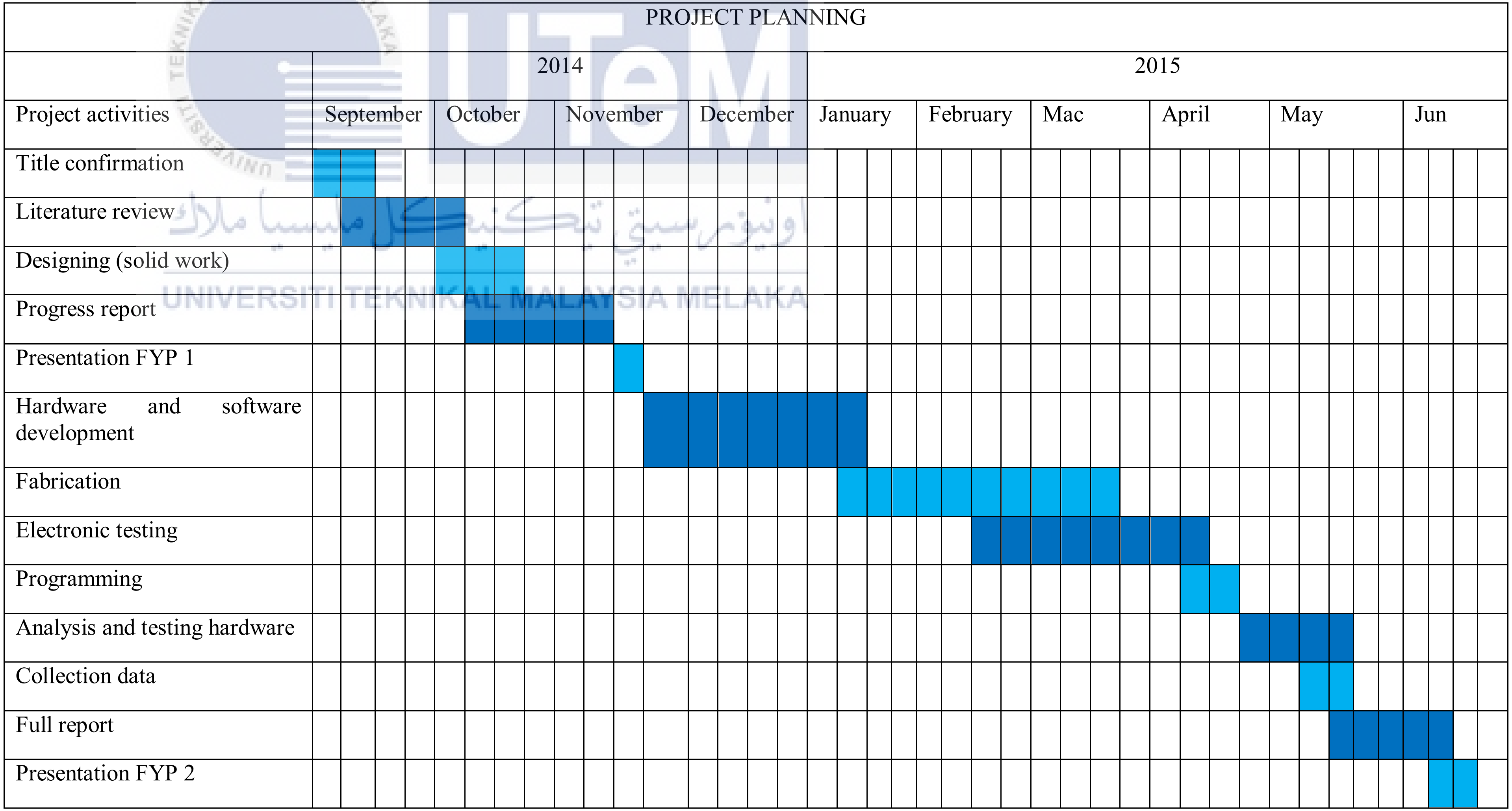
350
120

APPENDIX B

Gantt chart



APPENDIX C

Mechanical Design