UNDERWATER REMOTELY OPERAATED CRAWLER (ROC) LEG-LIKE WHEEL DESIGN

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A report submitted in partial fulfilment of the requirements for the degree of Bachelor of Mechatronics Engineering

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2017/2018

"I hereby declare that I have read through this report entitle "Underwater Remotely Operated Crawler (ROC) Leg-Like Wheel Design" and found that it has comply the partial fulfilment for awarding the degree of Bachelor of Mechatronics Engineering.

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Date : ....

To my beloved mother and father

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ABSTRACT

Remotely Operated Crawler (ROC) is an underwater vehicle that used to explore the deep sea underwater field which categorized under Unmanned Underwater Vehicle (UUV). The aim of this study was to investigate the performance of the ROC on an uneven surface of seabed with the ability to operate in various condition of underwater environment, in particular focus on the designing of wheel mechanism to overcome any obstacle. SolidWorks software was used as a platform in designing the overview idea of the ROC with leg-like type wheel and the simulation test was done by using the application available in the software which is the SimulationXpress. The simulated wheel mechanism and other part of the ROC were able to withstand the pressure of the water within 3 meters of depth without any obvious deformation that able affect the performance of the ROC. This shows that the ROC with leg-like type wheel mechanism able to overcome obstacle without having to change the wheel frequently. The performance of the ROC then further investigate in term of velocity, overcoming obstacle, and maneuverability. The velocity of ROC were investigate with type of surface and type of medium. Then, the maximum height that ROC able to crawl over is 4cm. Lastly, the accuracy of changing direction without using sensor is 10%.

ABSTRAK

Crawler yang dikendalikan dari jauh (ROC) adalah kenderaan bawah laut yang digunakan untuk menerokai lapangan bawah laut yang dikategorikan di dalam Kenderaan Air Tanpa Manusia Air (UUV). Tujuan kajian ini adalah untuk mengkaji prestasi ROC di atas permukaan dasar laut yang tidak rata dengan keupayaan untuk beroperasi dalam pelbagai keadaan persekitaran bawah air, terutamanya fokus pada merancang mekanisme roda untuk mengatasi sebarang halangan. Perisian SolidWorks digunakan sebagai platform dalam merancang gambaran keseluruhan ROC dengan roda jenis seperti kaki dan ujian simulasi dilakukan dengan menggunakan aplikasi yang terdapat dalam perisian yang merupakan SimulationXpress. Mekanisme roda simulasi dan bahagian lain ROC mampu menahan tekanan air dengan kedalaman 3 meter tanpa sebarang perubahan bentuk yang jelas yang dapat mempengaruhi prestasi ROC. Ini menunjukkan bahawa ROC dengan mekanikal roda jenis seperti kaki boleh mengatasi halangan tanpa perlu menukar roda dengan kerap. Prestasi ROC kemudiannya menyiasat lebih lanjut dalam hal halaju, mengatasi halangan, dan kebolehlaksanaan. Halaju ROC telah disiasat dengan jenis permukaan dan jenis medium. Kemudian, ketinggian maksimum yang dapat dirangkul oleh ROC ialah 4cm. Terakhir, ketepatan perubahan arah tanpa menggunakan sensor adalah 10%.

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LIST OF ABBREVIATION

UTeM	-	University Teknikal Malaysia Melaka
UAV	-	Unmanned Aerial Vehicle
USV	-	Unmanned Surface Vehicle
UGV	-	Unmanned Ground Vehicle
UUV	-	Unmanned Underwater Vehicle
AUV	-	Autonomous Underwater Vehicle
ROV	-	Remotely Operated Vehicle
ROC	-	Remotely Operated Crawler

CHAPTER 1

INTRODUCTION

1.1 Introduction

An unmanned system is a machine or device that has been used by human since the last 10 years and more. This system is equipped with data processing units, sensors, automatic control, and communications systems. Unmanned Systems include Unmanned Aerial Vehicle(UAV) which operate in the air, Unmanned Ground Vehicle(UGV) which operate on land, Unmanned Surface Vehicle(USV) which operate on the surface of the sea, and Unmanned Underwater Vehicle(UUV) which operate below the surface of the sea. These system has the capability to operate in the field without having human maneuver it inside. It is also widely used by military, marine, air-force and other field which have the risk of taking human life[1].

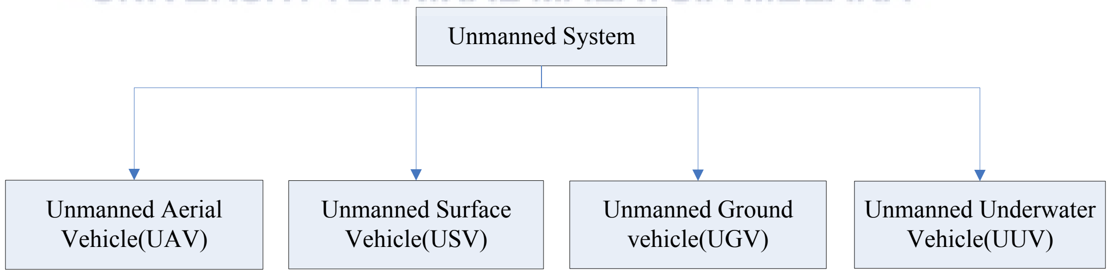


Figure 1.1: Classification of Unmanned System

The Earth's surface is covered by land and water. In fact, 71% of the Earth's surface is covered with water. There are infinite area that still yet to uncovered. The whole underwater terrain of the sea are still unknown especially deep sea terrain and until today it is still not completely mapped. Most of the deep sea creatures also yet to discovered by human. Thus, various underwater technology were developed as a tool to help human to uncover it and work to observe and inspect the deep sea such as Autonomous Underwater Vehicle (AUV), Underwater Remotely Operated Vehicle (ROV), Underwater Remotely Operated Crawler(ROC), sonar and submarine [2].

Nowadays, Autonomous Underwater Vehicle(AUV) and Underwater Remotely Operated Vehicle(ROV) are tremendously been used to observe and inspect the deep sea. These underwater technology are widely used in the underwater industry as it can maneuver to it desire place yet it cannot inspect the seafloor. Underwater Remotely Crawler(ROC) may help to inspect the seafloor since this system stay on the ground of the sea at all time. Thus, this research is focused on the development of designing and constructing a Underwater Remotely Operated Crawler(ROC).

Underwater Remotely Operated Crawler(ROC) is one of the unmanned system that operate manually underwater by wired remote control or wireless remote control that controlled by human which located above the sea surface. By understanding the name given to this system which is ROC shows that this system only operates on the seafloor. Thus, this system needed to stay on the ground of the sea at all time by overcoming the buoyancy force acted on it. The design should also preventing it from wheelie by having an equilibrium center of gravity. There are various type of wheel crawler that can be consider for having it as a design for the ROC movement. These wheel crawler has its own advantages and disadvantages.

Type of wheel crawler	Advantages	Disadvantages
Tire 	1. Have more efficiency in speed performances 2. Have less friction force on surface 3. Have more power and speed to maneuver	Have poor ability in turning in left and right at tight place
Belt 	1. Have an excellent climbing ability 2. Have good ability in turning at tight place	1. Complicated system 2. Very slow in turning
Omni-wheel 	Have the best ability in turning in all direction	1. High coat implementation 2. Less power and speed to maneuver

Figure 1.2: Advantages and Disadvantages of wheel mechanism[1]

For a ROC to overcome the terrain of seabed it should have all the listed out advantages based on the Figure 1.2. Thus, this research aim is to used a suitable design of wheel crawler by having more efficiency in speed performances, an excellent climbing ability and ability in turning in all direction at a tight space.

1.2 Motivation

Figure 1.3: Graph of E&A spend with exploration share of upstream capax by years[3]

By referring the graph on Figure 1.3 show that profit of oil and gas exploration on year 2015 reduce until year 2016. This show that many people especially investor will not wanting to involve themself on oil and gas exploration. Then on year 2017, it is expected that the profit of oil and gas exploration will increase by years. Wood Mackenzie's analysis of the 2017 global exploration outlook shows that exploration in 2017 will continue its transformation to a smaller and more efficient industry[3]. As big exploration used up to much cost like drilling. A smaller exploration would needed smaller technology thus using less cost. This show that smaller UUV to reduce the cost of exploration. Drilling at random place to find oil and gas would increase the cost of exploration. Instead use an underwater vehicle like ROC would help to observe the area before drill. ROC also can help to inspect the terrain and mapped out the surface to avoid damaging the drill bit. This technology maneuver will be handle by people on the surface of the sea, it show that this operation would not risk diver lives as the temperature of the water at deep sea is low. Thus, this kind of incident can save many explorer lives which motivates people to study and do research on ROC.

1.3 Problem Statement

ROV has been widely used in underwater industry for deep sea exploration. Evan so, how well a system or technology function would still have few limitation same goes to ROV. The main limitation of ROV is the usage on the seafloor. ROV also has certain depth that is limit which would not allow it to direct contact with the seafloor. The disorder of the seafloor makes ROV even harder to maneuver around and the thruster on ROV would blow the sand or mud which reduce visualization on surrounding. Stability of ROV also one of the limitation due to environment disturbance such as sea waves and unexpected underwater current condition. Thus, ROC is the most suitable to operate on the seafloor.

Table 1.1: Comparison between ROV and ROC[1]

ROV	ROC
Only be operated in underwater	Can be operated at the seafloor of underwater
Actuated and maneuver by using propeller	Maneuver by using wheel application
Faster capability to travel through water	Better capability to perform at the seafloor

The main concern on operating the ROC is the wheel mechanism. The wheel is the main part which allow the ROC to function properly. Some wheel mechanism makes the ROC unable to climb over the obstacle while some wheel mechanism stop functioning due the pebbles in environment. The ROC with a crawler system tends to wheelie more in water medium than on land[2]. As ROC start to crawl over an obstacle with high speed, it will experience unstable as the front wheel start to crawl over the obstacle. This shows that the wheel position plays an important role as it will affect the center of gravity of the ROC. The maximum height that ROC able to crawl over an obstacle depends on the wheel structure. Without knowing the maximum height that the ROC can crawl over would damage its component either electronic or mechanical parts. The pressure acted on the wheel would decrease the speed of ROC. This would increases the time of ROC in operating on the seafloor and wasted the battery usage. Lastly the accuracy of changing in direction to avoid any unwanted collision that would damage the ROC.

1.4 Objective

The purposes of developing an underwater Remotely Operated Crawler (ROC) during this FYP are as follows:

1. To design and develop wheel mechanism of Remotely Operated Crawler (ROC) that suitable in any underwater terrain.
2. To investigate the performances of Remotely Operated Crawler (ROC) in terms of speed, overcoming obstacle and maneuverability.

1.5 Scope

The scope of this project are limited into a few aspects. First of all, the crawler would have only two degree of freedom(DOF) for maneuver. The motion would consist of forward-reverse and left-right and also it can turn. This project is focusing on the wheel mechanism of ROC that able to crawl on 3 main surface which is smooth surface, rough surface and uneven surface. Then, the motion of crawling over an obstacle is tested on land which to investigate the performance of ROC in term of overcoming obstacle. The maximum height of the obstacle for the ROC to test on would be 10cm only as the size of prototype ROC should be small. The controller would be using wire as wireless controller need to provide suitable frequency for the receiver to receive signal form transmitter underwater. The cable from controller to ROC would be about 4 meter long as the water depth is 2 meter high. For underwater test, the speed and overcoming obstacle performance of the ROC result is use to compare with the result on land. This is to understand the different medium that acted on the ROC with its wheel performance. The wheel of the ROC will be high durability and shock resistance. This is because of the experiment on the field either on land or underwater is extreme that could cause unwanted collision. The cable will be waterproof high durability as it may snap when the ROC is maneuver on land and underwater.

1.6 Organisation of Report

The whole chapter 2 is about literature review that described the background theory and comparison design of this project. The background theory consist of factors that affect the ROC while the comparison design consist of discussion on different type of mechanical design based on publish paper. Then, chapter 3 is about methodology of this project that shows how ROC would be design based on the literature review on comparison design. Next, chapter 4 is about the result and discussion based on the analysis of this project. Finally, on chapter 5 is about conclusion of this whole project based on result and discussion. There are also some recommendation for future study of this project.

1.7 Summary

This chapter show the important of a ROC in underwater industry which help human to avoid risking their life. Still the use of ROC in underwater industry is limited because of the specification of designing of ROC required component which is very crucial such as imbalance movement of ROC and waterproof matter. For this technology to fully embrace by underwater industry, the ROC should be design with low cost, high performance in long term and environment friendly.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter discussed about literature review. It consists of theory and principle apply on ROC, mechanical design by comparing each ROC design from publish paper, and comparing power supply and software being used. The information is been taken by books and publish paper that related to ROC. Then, the comparison is being discuss to choose the best method to archive the objective of this project.

2.2 Theory and Principle

Before designing the ROC, must first understand the theory and principle which required. The theory and principle of designing ROC consist of density, buoyancy, hydrostatic pressure, environment forces, and hydrodynamic.

2.2.1 Density

Density of substance or material is define as mass over volume. Mass is the measurement of matter in an object whereas the SI unit is kg. Volume is the amount of space occupied by substance in an object whereas the SI unit is m^3. Thus, the SI unit of density is kg/m^3.

Table 2.1: Densities of some common substances[4]

Substance	Density g/cm³	Density kg/m³
platinum	21	21×10^3
gold	19	19×10^3
mercury	14	14×10^3
lead	11	11×10^3
steel	7.9	7.9×10^3
average density of the earth	5.5	5.5×10^3
glass, brick, stone and concrete	approx. 2.6	2.6×10^3
water	1.0	1.0×10^3
ice	0.92	920
alcohol, petrol and paraffin oil	approx. 0.8	800
oak wood	0.65	650
cork	0.24	240
expanded polystyrene	approx. 16×10^{-3}	16
air (at sea level)	1.3×10^{-3}	1.3

The density of a ROC should be higher than density of water to ensure the ROC stay sinking at all time.

2.2.2 Hydrostatic Pressure

Hydrostatic pressure is a type of pressure that exerted by a equilibrium point surrounding the fluid due to gravity forces. As depth that measured from the surface of the fluid is increases, the weight of fluid exerting on it with downward force will also increases same as the pressure on it. The reason pressure will increases due to increases of force is Pascal's Law stated that:

$$P = \frac{F}{A} \quad (1) \qquad (2.1)$$

$F =$ Force acting on the object

$P =$ Pressure acting on the object

$A =$ Surface area of the object

By using definition of force:

$$F = mg \quad (2) \qquad (2.2)$$

$F =$ Force given to object

$m =$ Mass of fluid

$g =$ Gravitational acceleration of fluid

And definition of density:

$$\rho = \frac{m}{V} \tag{2.3}$$

$$m = \rho V$$

$\rho =$ Density of fluid

$m =$ Mass of fluid

$V =$ Volume of fluid

Substitute (3) into (2):

$$F = \rho V g \, (4)$$

Then, substituting (4) into (1) to get:

$$P = \frac{\rho V g}{A}$$

Since $V = Ah$, A can be cancel out to get:

$$P_{gauge} = \rho g h \tag{2.4}$$

$P =$ Pressure on the submerged object in a fluid

$\rho =$ Density of the fluid

$g =$ Gravitational acceleration of fluid

$h =$ Height of the fluid above the object

The pressure given above is the gauge pressure. The pressure must add with atmospheric pressure to know the actual pressure that acted on the object as shown below:

$$P_{Actual} = P_{atm} + P_{gauge}$$

$P_{Actual} =$ Actual pressure

$P_{atm} =$ Atmospheric pressure

$P_{gauge} =$ Gauge pressure

Figure 2.1: Fluid in different geometry of container[5]

The fluid pressure only depends on depth, it does not depend on mass, surface area or the geometry shape of the container.

2.2.3 Buoyancy Force (Archimedes Principle)

Buoyancy forces is a type of force that exerted on objects which prevent it from submerged in a fluids. The reason that this force exist in a fluid is the differences in pressure between the bottom and top of the submerged object. As the object submerged depth increases, the force from pressure exerted downward on the top of the object is less then the force from pressure upward on the bottom of the object.

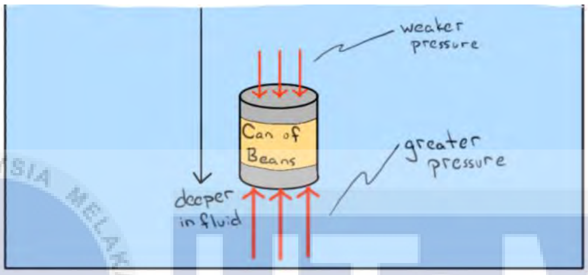


Figure 2.2:Difference pressure acting on the object[6]

$$P_{gauge} = \rho g h \,(1) \qquad (2.5)$$

$\rho =$ density of fluid

$g =$ gravitational acceleration

$h =$ the height of the depth that object submerged

The downward force acting on the object is cause by gravitational acceleration while the upward force acting on the object is cause by fluid which on their density. The difference magnitudes between upward force and downward force is buoyancy force

$$F_{buoyant} = F_{up} - F_{down} \,(2) \qquad (2.6)$$

The above equation can further expand by using definition of pressure:

$$P = \frac{F}{A} \qquad (2.7)$$

$$F = PA \,(3)$$

$F =$ Force acting on the object

$P =$ Pressure acting on the object

$A =$ Surface area of the object

By substituting (3) into (2):

$$F_{buoyant} = (PA)_{bottom} - (PA)_{top} \ (4)$$

Then, by substituting (1) into (4):

$$F_{buoyant} = (\rho ghA)_{bottom} - (pghA)_{top}$$

Since $\rho gA_{bottom} = \rho gA_{top}$, it can be simplifying into:

$$F_{buoyant} = \rho gA(h_{bottom} - h_{top})$$

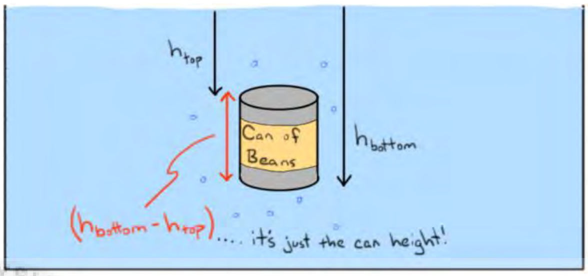


Figure 2.3: Difference height comparison[6]

Then, $h_{object} = h_{bottom} - h_{top}$, it can be replace in it:

$$F_{buoyant} = \rho gAh_{object}$$

Since $V_f = A \times h$, the final equation:

$$F_{buoyant} = \rho gV_f \ (5) \qquad (2.8)$$

$F_{buoyant} =$ Buoyancy force acting on the object

$\rho =$ Density of fluid

$g =$ Gravitational acceleration

$V_f =$ Volume of fluid displaced by the object

The volume of the object is equal to volume of displaced fluid by the object if the object is fully submerge into the fluid. When the object is partially submerged, volume of displaced fluid by the object is use to find its buoyancy force at this state. Archimedes principle state that the buoyant force on an object is equal to the weight of the fluid displaced by the object.

So by substitute density formula, $\rho = \frac{m}{V}$, it show that:

$$F_{buoyant} = m_f g$$

Which it also can be expressed by:

$$F_{buoyant} = W_f$$

$$W_f = \text{Weight of fluid displaced by the object}$$

This proven that Archimedes principle is true and the equation can be use. Thus, every object is buoyed upwards by a force equal to the weight of the fluid that object displaced. The weight of ROC must higher than weight of water displaced by ROC to overcome the buoyancy force acting on ROC to ensure it remain sinking underwater.

2.2.4 Environment Forces

The mechanism of belting wheel is affected by external force which are gravity and normal component of reaction[1]. The wheel will also affected by sea current and wave which will influence the velocity and acceleration of ROC which would needed more power to overcome these forces.

2.3 Mechanical Design

The two main part of mechanical design in ROC are the chassis and the wheel mechanism. As wheel mechanism is to overcome the seafloor terrain while the chassis is to maintain the stability while maneuver.

2.3.1 Comparison of ROC on chassis structure

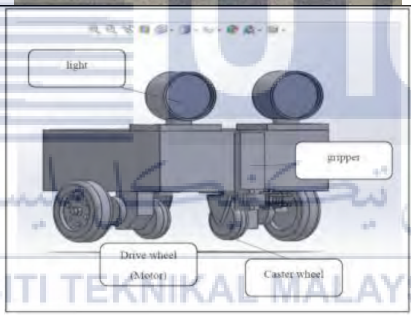
There are benefits and limitation of choosing the proper design chassis structure for a ROC. The design depends on the purpose of crawler since the Table 2.2 shown are not all underwater crawler. Chassis of ROC act like a human backbone. The durability of ROC depends on the design of chassis structure. It is also important that the material for ROC chassis has high durability to withstand pressure and uneven surface of terrain. The lower the resistance, the higher speed generated [7].

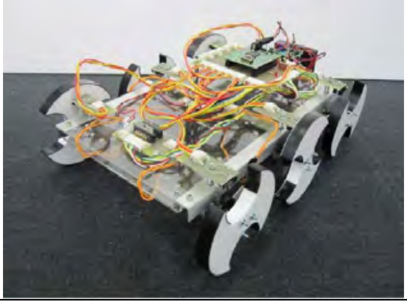
Adding a skirt or vertical tail could reduce the turbulence and drag of the rear part[2]. A cylindrical shape or a ball type is most suitable for the shape of the pressure vessel. It is not good with an aspect of energy efficiency for a deep and long cruising range underwater vehicle so that the pressure vessels hold a big part of the weight of the body. Therefore light and strong structure material for pressure vessel is important [8].

Based on the Table 2.2, the 2nd design name ROC prototype, they used stainless steel as their material for chassis structure. The shape of chassis is trapezium shape. The reason for having trapezium shape is that it can go up a higher terrain. It also to reduce drag by having an hydrodynamic body which reduce using more power to maneuver. By using stainless steel it also can avoid it from corrosion.

Table 2.2: Comparison of ROC based on chassis structure

Name	Design	Description
KEIOS-III [9]		➢ 120mm(L) with crawler section 115mm(L)[10] ➢ Blade=15(L)x10(W)mm ➢ 11 blades attached at 25mm intervals[10] ➢ Blades made of rubber plates with 1mm thickness ➢ Gyro precession stabilizer installed at the lowest possible position[9]
ROC Prototype [11]		➢ 450(L)x297.6(W)x100(H)mm ➢ Height of Chassis to ground=±30 mm ➢ Gear Ratio 1:1 ➢ DC geared motor ➢ Stainless Steel ➢ 9.8kg + 7kg weighter

Omni-Crawler [12]		➢ 420(L)x314(W)x190(H)mm ➢ Distance between 2 crawler=210mm ➢ Motor for sideling motion=Faulhaber 26W ➢ Material of lug surface=Nitrile Rubber ➢ Material of lug supporter=SUS304
ROV with Crawler [13]		➢ 652(L)x764(W)x530(H)mm ➢ Motor 4x150W ➢ 59.2kg in air
ROC [1]		➢ 395(L)x395(W)x150(H)mm ➢ 9.2kg ➢ Power window motor ➢ Hard tire and round wheels ➢ Acrylic material for body cover ➢ Steel material for frame
Seabed Tracked ROV [14]		➢ 2.3(L)x1.6(W)x1.2(H)m ➢ Track contact length 1.6m ➢ Track width 0.36m ➢ Weight 2.35tons ➢ Distance between centre lines of tracks 1.2m ➢ Hydraulic control system

Mobile Robot [15]		➢ No information

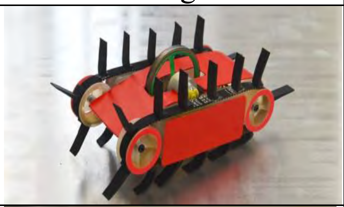
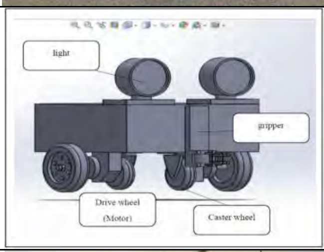
2.3.2 Comparison based on ROC wheel mechanism

For a crawler which has wheel mechanism that cannot even move forward or backward is not a crawler at all. Thus, it is also important for a ROC to have a proper wheel mechanism which not just for motion, also for moving on an uneven terrain.

Based on Table 2.3, the 3rd design name Omni-Crawler, they used Omnidirectional crawlers for their wheel mechanism. A spherical mechanism such as the spherical wheel can be used to achieve omni-directional motion[12]. Change of direction is easy when using omnidirectional crawlers which not needed much space to do so. The mechanism was inspired by the Omni-Ball that has a circular cross-section ans can realize sideling motion[12]. In addition, to allow it to follow the shape of the running surface, a mechanism for driving the end axis of the belt is suitable, as this allows deflection[16]. The problem faced is the maximum step which the mobile robots can overcome is significantly small relative to the size of the whole wheel because of the small diameter of the passive wheels[12].

The crawler wheel mechanism also important to choose the suitable material. The crawler wheels and the tension wheels are made by rubber polymer materials with high abrasion resistance and anti-impact capability, and the link rods of the swing arms employ aluminum alloy materials, while for the main parts bearing stress, such as the transmission shafts and the hollow shafts sleeve, employ alloy steel in order to meet the requirement for stiffness[17]. Chin Type, tracked type and flipper type wheel mechanism has obstacle capability to overcome the sloping and uneven ground[18]. The problem face are hollow body which unable to sink, unbalance weight when crawl over obstacle, and wheel slip occur when climbing.

Table 2.3: Comparison of ROC based on wheel mechanism

Name	Design	Type of Motion	Problem Faced
KEIOS-III [9]		Blade-Type Crawlers with Gyro Wheel	The weight configuration disturb the climbing motion
ROC Prototype [11]		Chain-Type Crawlers	Hollow Body makes it unable to sink
Omni-Crawler [12]		Omnidirectional Crawlers	Maximum height of obstacle can overcome is relatively small
ROV with Crawler [13]		Flipper-Type Crawler	The external force acting on the wheel make it difficult to maintain it velocity
ROC [1]		Tire-Type Crawler	Not stated
Seabed Tracked ROV [14]		Tracked-Type Crawler	Slip phenomenon occurs for locomotion on the seabed

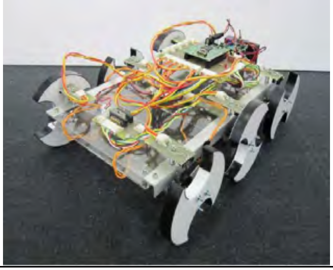
Mobile Robot [15]		Leg-Like-Type Crawler	Not stated

Table 2.4: Status of practical use of mobile robots with different locomotion[19]

Type	Situation
Leg type	It has not been put to practical use yet.
Wheel type	There are some practical uses (for instance, cleaning robots).
Crawler type	There are a few practical uses (for instance, in the leisure and construction fields).
Composite mechanism type	It has not been put to practical use yet.

Based on the above Table 2.4, shown the summarize of wheel mechanism used by people in the present of time. The crawler type normally used for heavy duty while the wheel used for light duty in their own field.

2.4 Power Supply

Any remote vehicle needed power supply for movement which instructed by controller in the form of signal control by people. The power supply could be at the remote controller or in the crawler. As power supply in crawler, the wiring used less and short since the only one long wiring needed yet waterproofing all the electrical components needs detailing seal it. Vice versa when power supply in remote controller.

Based on 1st design, name as KEIOS-III, 7.4V x 300mAh lithium polymer battery as power supply which is mounted on the bottom of the vehicle body. The max output of the vehicle is 64W[9]. The small weight of the vehicle helps it to reach maximum speed which is 2.1meter per second.

For Omni-Crawler[12] is used 14V power supply of battery while ROC[1] used 12V power supply of battery. The power supply depends on the type of motor used in crawler. For 14V battery it used Faulhaber 26W for sideling motion and 90W (NIPPO MM-26E) for forward and backward motion. On 12V battery it uses power window motor. This show that how high voltage of battery required to supply depends on how many motor uses.

2.6 Summary

This Chapter introduces the whole mechanical design part of other paper. It also discussed some experience of ROC hardware in term of mechanical system of ROC. The basic idea to develop and modelling of ROC optimized after doing research on previous subtopics. Previous ROC design and development are useful for further research in underwater field.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter discusses the flow of this project. Basically, it will describe about the procedure or technique to achieve the research goals of the project. It gives the general idea to the reader of this project from the initial stage to the final stage. From an introduction and background of the project until the project design, this chapter will provide step by step guide to the reader so that they can understand the project well.

Firstly, overall project research flowchart is included in this chapter as shown in Figure 3.1. It explained briefly how the project starts until the end. After that, a more specific flow chart regarding the methodology project flow of this chapter is provided as shown in Figure 3.2. This flowchart gave an overall view about what is going to be discussed in this chapter.

Next, some of the project hardware design being drawn and provided with a diagram. Moreover, the type and method of analysis done in SolidWorks software is discussed. Lastly, the experiment implementation procedure of the project is listed out with step by step with pictures of the experiment setup.

3.2 Project Research Flow Chart

Every project should have a project research flowchart. The reason for having a project research flowchart is to show the overall process that has been taken to complete the project. Figure 3.1 shows an idea of the above surface of project which consists of project planning, gathering information for design fabrication and experimental test.

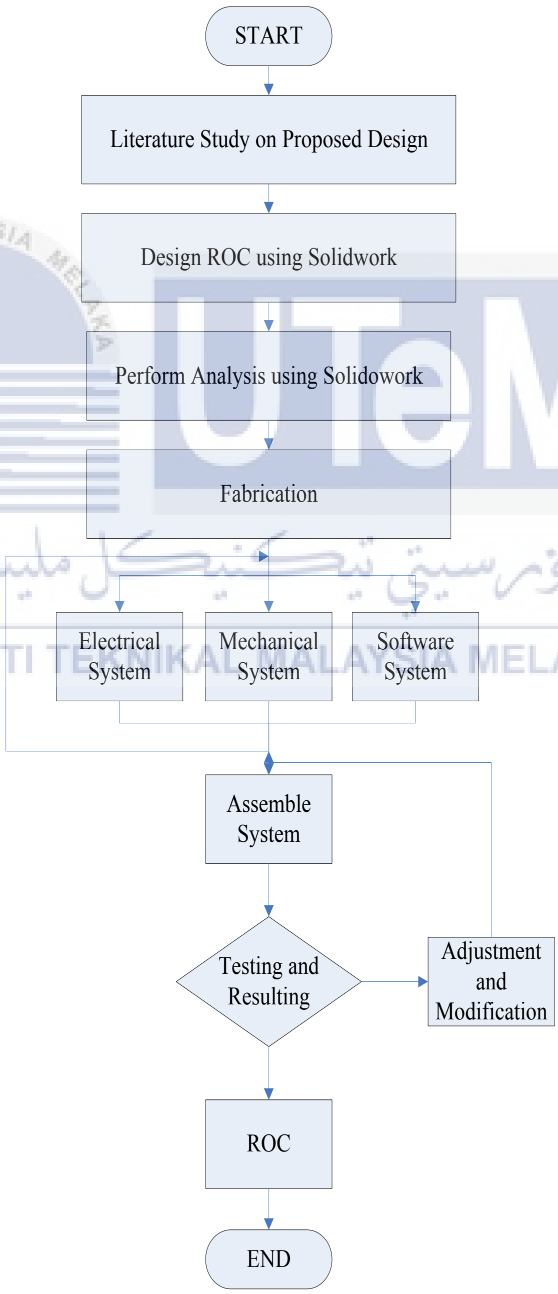


Figure 3.1: Project research flow chart of ROC

3.3 Research Methodology Flow Chart

Project methodology flow chart shows the overview of this chapter which the method to conduct the whole project after obtaining required design from chapter 2. Figure 3.2 shows the methodology of designing a ROC of this project.

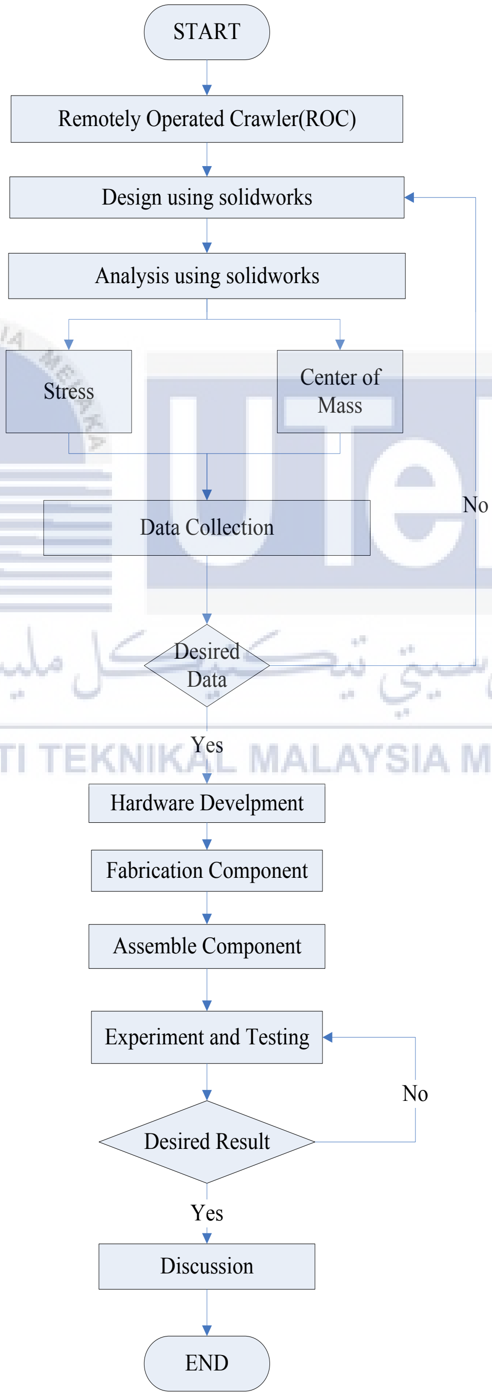


Figure 3.2: Project methodology flow chart of ROC

3.4 Project K-Chart

K-Chart of a project act as a tool for the purpose of planning and monitoring. Figure 3.3 shows K-Chart of this project.

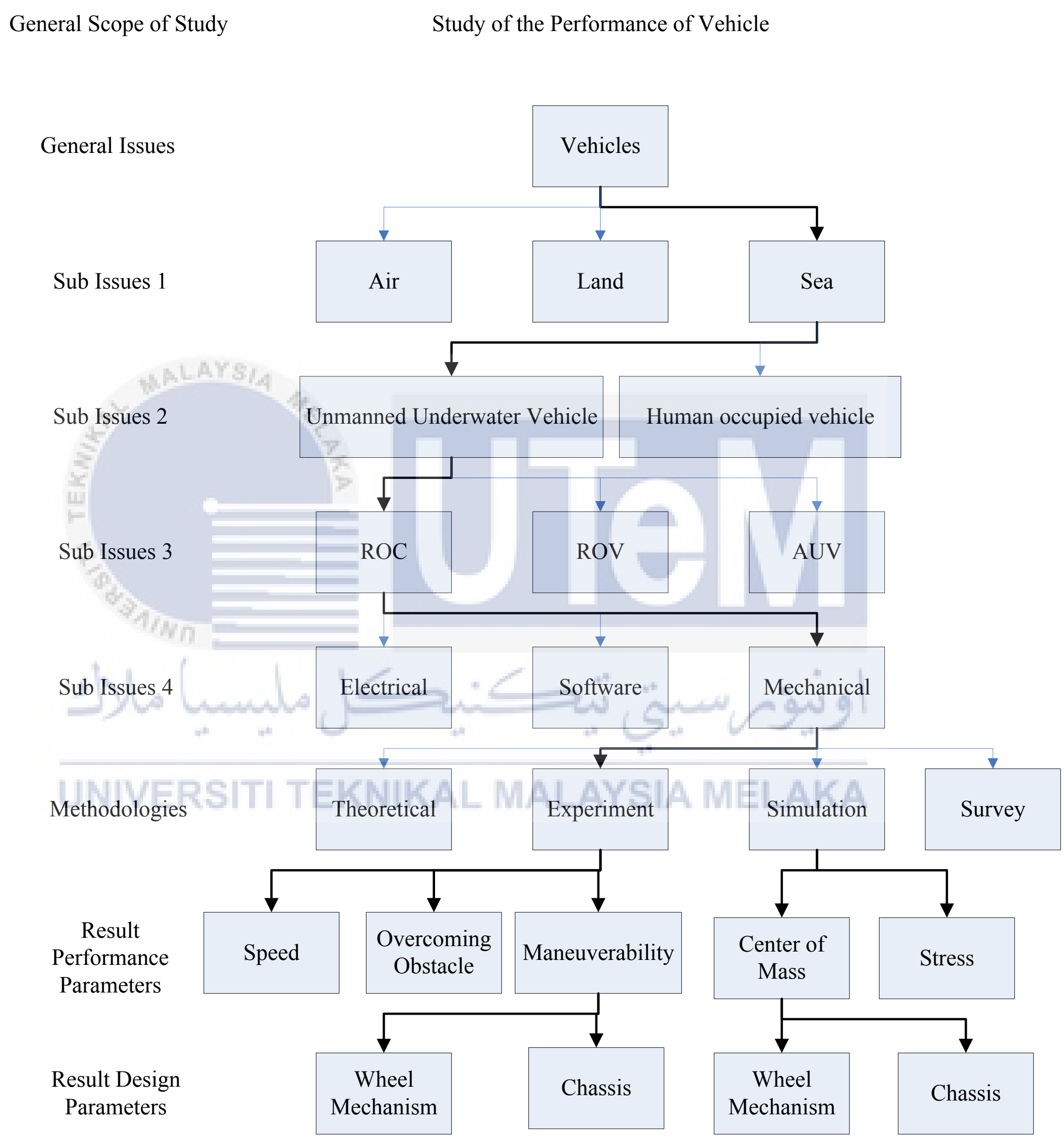


Figure 3.3: K-Chart of ROC

3.5 Gantt Chart

Activities	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14
Define Project Problem														
Research on ROC design														
Literature review														
Proposed design														
Perform analysis simulation in SolidWorks														
Design the experiment procedures														
Data collection and analysis														
Presentation														
Report writing														

3.6 SolidWorks

The designs of ROC were first sketched based on literature study on Chapter 2 and drew it in SolidWorks software based on scope requirement. SolidWorks software can be drew it in 3-dimentional drawing which easy to interpret the idea of designing. The main function of using SolidWorks to draw a design is that it has simulation application to simulate the design. From the assembly design, SimulationXpress will convert the solid body to a mesh body drawing and analysed the drawing. The simulation will evaluate the capability of the ROC design when forces and pressure is applied. The forces and pressure is applied on surfaces of the ROC design. The fixed geometry of the forces and pressure is depend on the condition of the ROC. The result simulations on the ROC design is discuss in Chapter 4.

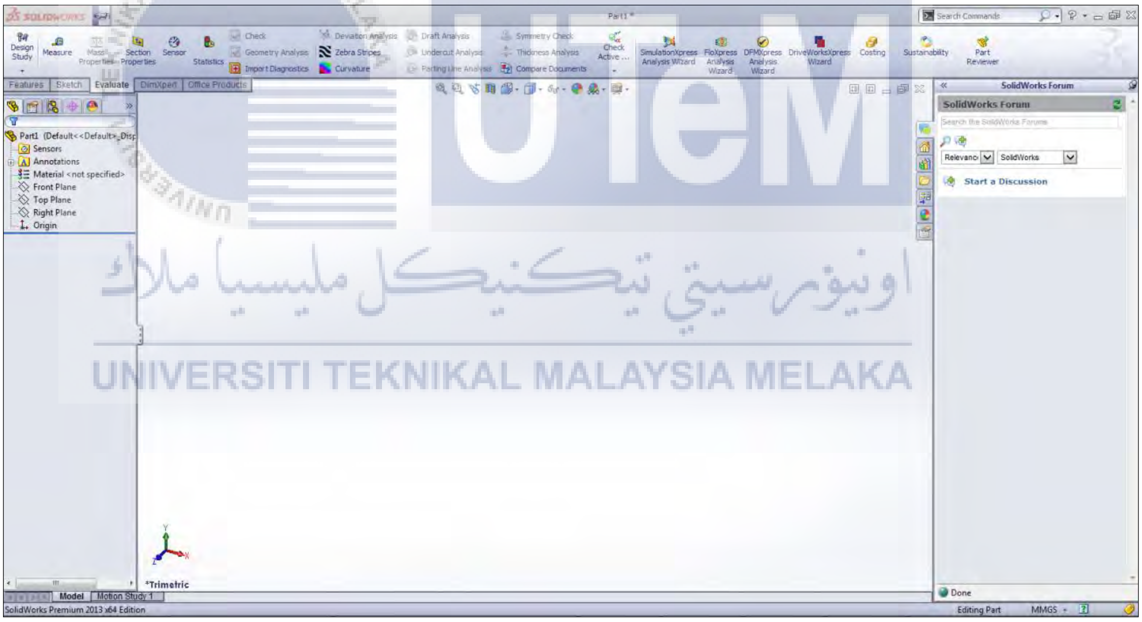


Figure 3.4: SolidWork Drawing Interface

3.7 Electronic Construction

Remotely Operated Crawler, the remotely operated meaning there is a need for a controller to control the crawler. For this project, the controller that used is arduino UNO as shown in Figure 3.5. The motor that uses for this project is XYD-6D-350 model of electric motor as shown in Figure 3.8. The motor driver that compatible for the motor is MDS40A motor driver for each motor uses as shown in Figure 3.7 and the keypad arduino 4x4 act as controller for this project as shown in Figure 3.6. The circuit for this electronic construction were connected based on the programming that been program in the ardiuno UNO. Two 12V lead acid battery connected in series is used to power up the motor by connected to motor driver and 5V output from the motor driver is connected to arduino UNO. The motor driver DIP switch are in PWM mode. The motor driver configuration can be refer to Cytron Technologies user manual[21]. The coding that been upload into the ardiuno UNO can be find in the appendix after Chapter 5 conclusion.

Figure 3.5: Arduino UNO

Figure 3.6: Keypad Arduino 4x4

Figure 3.7: MDS40A motor driver

Figure 3.8: XYD-6D-350 Electric Motor

3.8 Project Experiment

The purpose of conducting the experimental test is to achieve the objective mentioned of this project. There are few experiment test to be conducted including simulation test and field test.

3.8.1 Experiment 1: Center of mass simulations on ROC

Objectives:

To determine the center of mass of ROC to prevent wheelie when maneuver

Equipment and Apparatus:

1. Computer
2. SolidWork software

Procedure:

1. The assemble part is opened in SolidWorks.
2. In the drawing, click ‘Insert > Model Items Property Manager’.
3. Under Reference Geometry, click ‘Center of Mass’.
4. The position of the center of mass appears in the drawing.
5. The image of the center of mass is captured.
6. Click the mass properties tab and change the units to any suitable units.
7. The center of mass refers to 3 axes is recorded in the table.

3.8.2 Experiment 2: Stress simulation on ROC

Objectives:

To determine the maximum stress can withstand by ROC

Equipment and Apparatus:

1. Computer
2. SolidWork software

Procedure:

1. The assemble part is opened in SolidWorks followed by Simulation Xpress.
2. Add a fixture by selecting the face model (show green arrows).
3. Add load by applying a force or pressure to the particular area on the model (show red arrows).
4. Calculate the stress and displacement by selecting a material to the part/body.
5. The mesh setting can be changed between coarse and fine and run the simulation.
6. Next, either to 'continue' or 'go back' to edit the study parameters
7. Click 'continue', the 'stress, displacement and factor of safety' will show out
8. Finally, the report can be generated in either Microsoft Word or eDrawings format.

3.8.3 Experiment 3: Speed Test on Different Surface

Objectives:

1. To observe the movement of ROC on different surface and maximum speed it can achieve
2. To ensure ROC can adapt to move on any surface.

Equipment and Apparatus:

1. ROC hardware
2. Stopwatch
3. Floor tile surface
4. Grass surface
5. Road surface
6. Measuring Tape

Type of Variable:

Manipulated Variable : Type of surface
Responding Variable : Time taken for ROC to reach 10 meter distance
Constant Variable : The steepness of the surface

Procedure:

1. The ROC is set to crawl floor tile surface.
2. The distance of 10 meter distance is measure using measuring tape and the end position is mark. To ensure the crawling distance is 10 meter.
3. The crawler will moves on the surface from the starting position until end position.
4. The time for ROC to crawl until 10 meter distance will be taken using stopwatch.
5. The movement of crawler in this experiment is observed
6. The result is recorded in a table.
7. The experiment is repeated with road surface and grass surface.

3.8.4 Experiment 4: Crawl Over Obstacle Test

Objectives:

1. To observe the crawling ability of ROC on wooden plank.
2. To identify the maximum height the ROC can climb.

Equipment and Apparatus:

1. ROC hardware
2. A floor tile surface with no obstacles
3. 10 pieces of wooden plank with 0.5cm thick
4. Stopwatch
5. Measuring Tape

Type of Variable:

Manipulated Variable : Height of Wooden plank
Responding Variable : Time taken for ROC to crawl over the wooden plank
Constant Variable : Type of surface, Crawling distance of ROC

Procedure:

1. The ROC is set to crawl a wooden plank with 0.5cm thick.
2. The distance of starting position to end position is measure using measuring tape for data in result in next chapter.
3. The time for the ROC to crawl over the wooden plank is taken using stopwatch.
4. The crawler is observed in this experiment of crawl over the wooden plank.
5. The result is recorded in a table.
6. The experiment is repeated with additional of another wooden plank with 0.5cm thick until the crawler unable to climb over to set it as maximum height of the crawling ability of the ROC.

3.8.5 Experiment 5: Underwater Speed Test

Objectives:

1. To observe the movement of ROC in water tank and maximum speed it can achieve
2. To compare the speed of ROC in water medium and in air medium

Equipment and Apparatus:

1. ROC hardware
2. Stopwatch
3. A tank full of water
4. Measuring tape

Type of Variable:

Manipulated Variable : Type of medium

Responding Variable : Time taken for ROC to reach 2 meter distance

Constant Variable : Depth of water, Type of surface

Procedure:

1. The tank is filled with water until 2meter height.
2. The ROC is placed in the tank full of water.
3. The ROC is set to crawl until 2 meter distance.
4. The distance of starting position to end position is measure using measuring tape and mark it for easy to conduct the experiment.
5. The time for the ROC to crawl until 2 meter distance will be taken using stopwatch
6. The ROC movement in the water is observed.
7. The result is recorded in a table.
8. The experiment is repeated for getting average crawling time of the ROC.
9. The result is compared with experiment 3 on floor tile surface.

3.8.6 Experiment 6: Underwater Crawl Over Obstacle Test

Objectives:

1. To observe the crawling ability of ROC underwater.
2. To ensure ROC can adapt to crawl over an obstacle underwater.

Equipment and Apparatus:

1. ROC hardware
2. Stopwatch
3. A tank full of water
4. A 4cm think block of cement
5. Measuring Tape

Type of Variable:

Manipulated Variable : Type of medium
Responding Variable : Time taken for ROC to crawl over the cement
Constant Variable : Cement thickness, Type of surface, Depth of water

Procedure:

1. The ROC is placed in the tank full of water.
2. The distance of starting position to end position is measure using measuring tape and mark it for easy to conduct the experiment.
3. The ROC is set to crawl over a 4cm thick block of cement underwater.
4. The time for the ROC to crawl over the brick is taken using stopwatch.
5. The ROC crawling motion is observed.
6. The result is recorded in a table.
7. The experiment is repeated for getting average crawling time of ROC.
8. The result is compared with experiment 4 on maximum height that ROC can crawl.

3.8.7 Experiment 7: Underwater maneuverability direction changing

Objectives:

1. To observe the accuracy of ROC changing direction underwater.

Equipment and Apparatus:

1. ROC hardware
2. Stopwatch
3. A tank full of water
4. Protector
5. Measuring Tape

Procedure:

1. The ROC is placed in the tank full of water.
2. The angle of 90 degree is mark at the side of the tank using protector.
3. The ROC is set to change direction for 90 degree.
4. The time for the ROC to change direction is taken using stopwatch.
5. The angle is measure using a measuring tape to mark it on side of the tank.
6. The ROC direction changing motion is observed.
7. The result is recorded in a table.
8. The experiment is repeated for getting an average direction changing time of ROC.

3.9 Summary

As a summary, this chapter described the mechanical systems of the ROC that was designed and will be developed. The flow of the ROC projects from the starting to the ending is included and illustrated in different flowcharts. Besides, the procedure on the drawing and design was discussed in SolidWorks. Finally, the guideline on how to carry out different analysis in SolidWorks simulation and experiments were listed in last subtopic of Chapter 3.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter shows all the simulations and results of this project. The simulation result consists of stress test and center of mass of the ROC design. The results are recorded in a table and the graph is draw based on the table to provide a better view and understanding which make it easier for analyse. The simulation result include 2 different part of design and assemble part of design.

4.2 SolidWorks Simulation Result

4.2.1 Result of experiment 1: Center of Mass of ROC

The purpose of this analysis is to find the center of gravity of the ROC which in SoildWorks know as center of mass of the ROC. The main purpose to find the center of mass of ROC is that to prevent ROC wheelie while maneuver. This application helps to calculates the design properties which are mass, density and volume of the constructed model based on material part by part. The process for determining the center of gravity without the help of SolidWorks is hard due to uneven mass of the design. Figure 4.1 show the center of mass of ROC plane while Figure 4.2 show the indicator of simulation in SolidWorks.

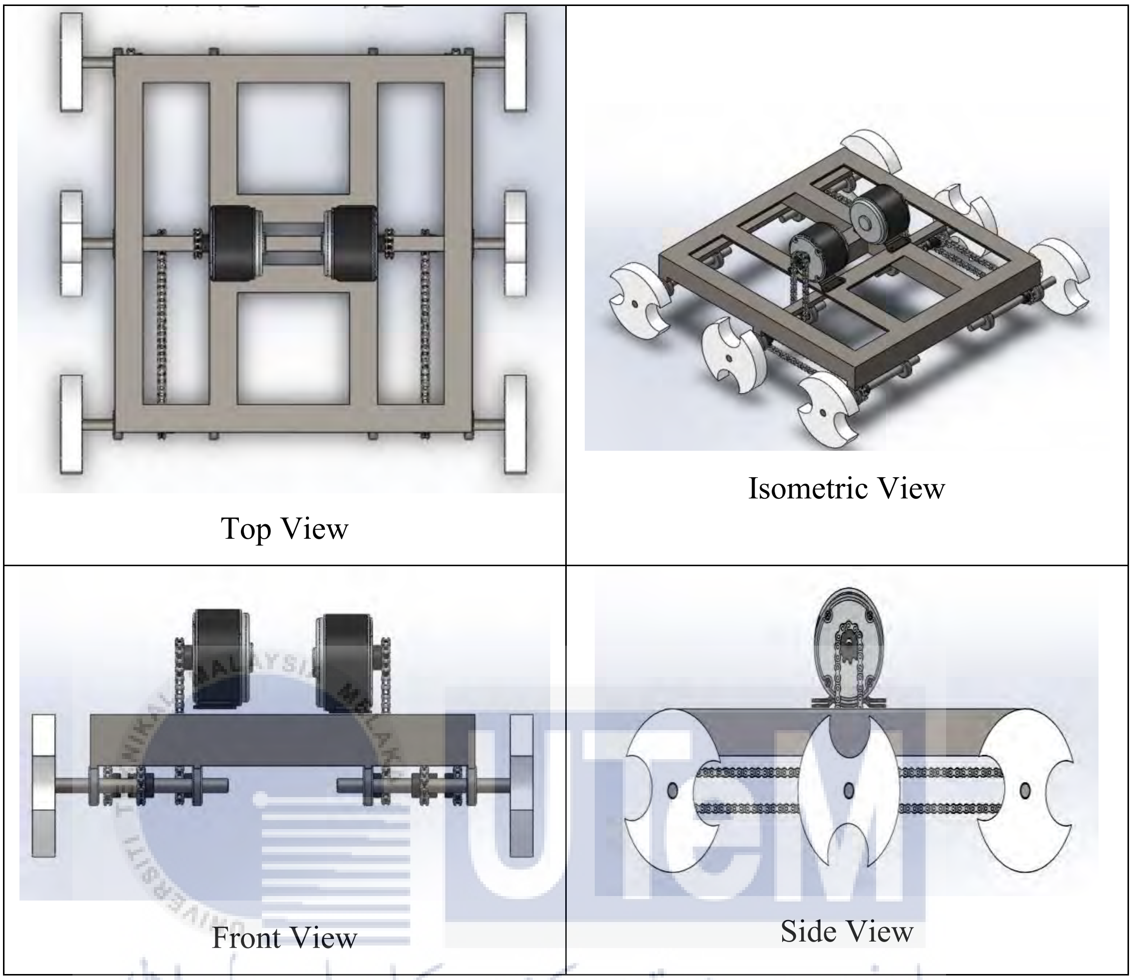


Figure 4.1: Overview of ROC center of mass simulation

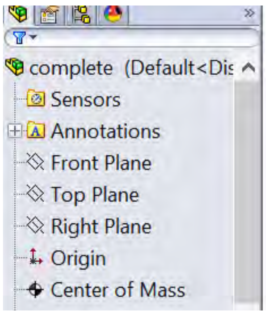


Figure 4.2: Center of mass indicator in SolidWorks

Mass properties of ROC

Mass = 22408.92 grams

Volume = 5440.26 cubic centimeters

Surface area = 15128.04 square centimeters

Center of mass: (centimeters)

X = 24.65

Y = 26.97

Z = 40.38

Principal axes of inertia and principal moments of inertia: (grams * square centimeters)

Taken at the center of mass.

Ix = (1.00, 0.00, 0.00) Px = 7101581.70

Iy = (0.00, 0.00, -1.00) Py = 7865591.09

Iz = (0.00, 1.00, 0.00) Pz = 13619673.72

Moments of inertia: (grams * square centimeters)

Taken at the center of mass and aligned with the output coordinate system.

Lxx = 7101603.06	Lxy = 11797.07	Lxz = 23.00
Lyx = 11797.07	Lyy = 13619652.28	Lyz = 725.53
Lzx = 23.00	Lzy = 725.53	Lzz = 7865591.18

Moments of inertia: (grams * square centimeters)

Taken at the output coordinate system

Ixx = 59936350.05	Ixy = 14912061.30	Ixz = 22305413.53
Iyx = 14912061.30	Iyy = 63770993.77	Iyz = 24404863.38
Izx = 22305413.53	Izy = 24404863.38	Izz = 37786690.12

Based on the mass properties of ROC that generated by SolidWorks simulation show that the center of mass of ROC is coordinated at 24.65 of X-axis, 26.97 of Y-axis, and 40.38 of Z-axis. The center of mass simulation include all the mechanical part of ROC design.

Table 4.1 Center of mass of ROC in SolidWorks

Axis	Coordinates (cm)
X	24.65
Y	26.97
Z	40.38

The coordinates point axis of X, Y, and Z shows that the stability of the ROC in the SolidWorks indicate that the ROC not easily to flip over in any direction when it is maneuver. It is important that the ROC would not flip over especially when ROC crawl over a obstacle to avoid wheelie as it may damage the motor with crashing on to the terrain.

4.2.2 Result of experiment 2: Stress Test on ROC

The stress test of ROC are simulated for the structural analysis in SolidWorks by the Finite Element Analysis (FEA) simulation Xpress. For this project, ROC used Nylon 101 for the wheel part, chrome stainless steel for radial ball bearing and shaft, and steel for the body and the chain. This software used to analyse the property of stress. The purpose of the analysis is to predict the overall performance of the ROC mechanical construction under the water pressure when operating in depth environment. The pressure acting on the submerged part depends on the depth.

By using this FEA simulation Xpress, the deformation and stress distribution on each layer of materials can be analyse. The procedure of this analysis is described in the previous chapter. The geometry of the body base is determined as shown in the following Table 4.2 to Table 4.10.

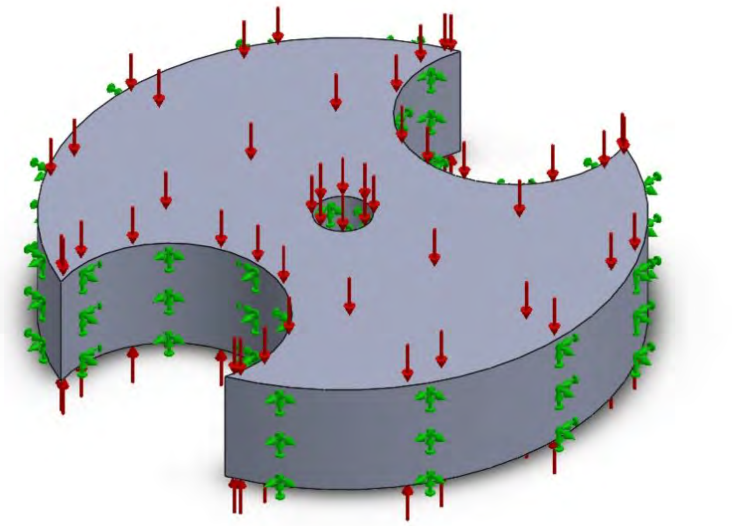


Figure 4.3: Fixed geometry and Pressure applied on ROC Leg like Wheel

Table 4.2: Model Information

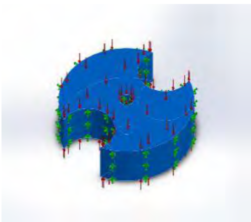
Solid Bodies			
Document Name and Reference	**Treated As**	**Volumetric Properties**	**Document Path/Date Modified**
Cut-Extrude3 	Solid Body	**Mass:0.452989 kg** **Volume:0.000393904 m^3** **Density:1150 kg/m^3** **Weight:4.43929 N**	**E:\Leg like wheel.SLDPRT** May 7 18:17:06 2018

Table 4.3: Material Properties

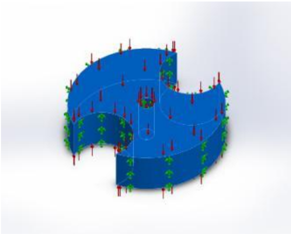
Model Reference	Properties	Components
	**Name:** Nylon 101 **Model type:** Linear Elastic Isotropic **Default failure criterion:** Unknown **Yield strength:** 6e+07 N/m^2 **Tensile strength:** 7.92897e+07 N/m^2	SolidBody 1(Cut-Extrude3)(Leg like wheel)

Table 4.4: Loads and Fixture

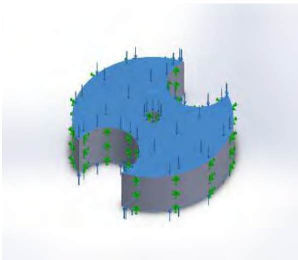
Fixture name	Fixture Image	Fixture Details
Fixed-1		**Entities:** 5 face(s) **Type:** Fixed Geometry
Load name	**Load Image**	**Load Details**
Pressure-1		**Entities:** 2 face(s) **Type:** Normal to selected face **Value:** 101325 **Units:** N/m^2

Table 4.5: Mesh Information

Mesh type	Solid Mesh
Mesher Used:	Standard mesh
Automatic Transition:	Off
Include Mesh Auto Loops:	Off
Jacobian points	4 Points
Element Size	0.733236 cm
Tolerance	0.0366618 cm
Mesh Quality Plot	High

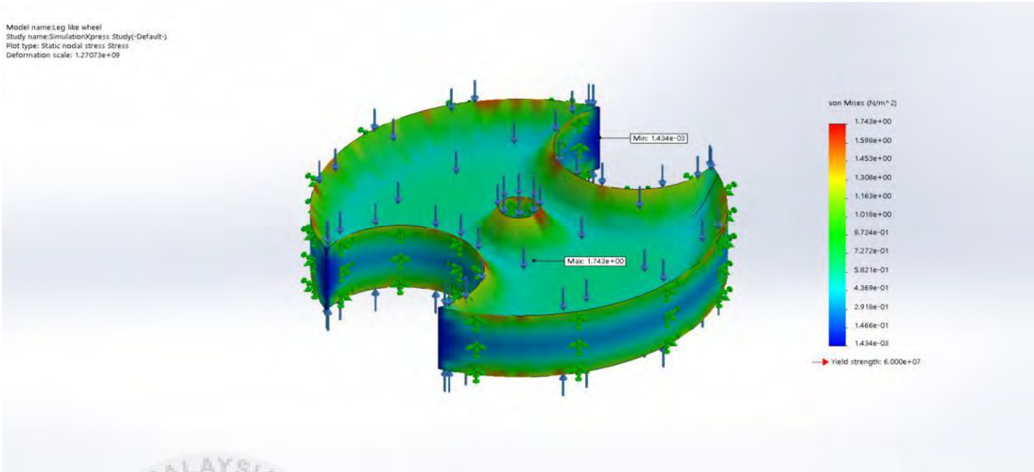
Table 4.6: Mesh Information Detail

Total Nodes	11772
Total Elements	7464
Maximum Aspect Ratio	3.7818
% of elements with Aspect Ratio < 3	99.9
% of elements with Aspect Ratio > 10	0
% of distorted elements(Jacobian)	0
Time to complete mesh(hh;mm;ss):	00:00:02

Figure 4.4: Mesh Result

Table 4.7: Stress Study Result

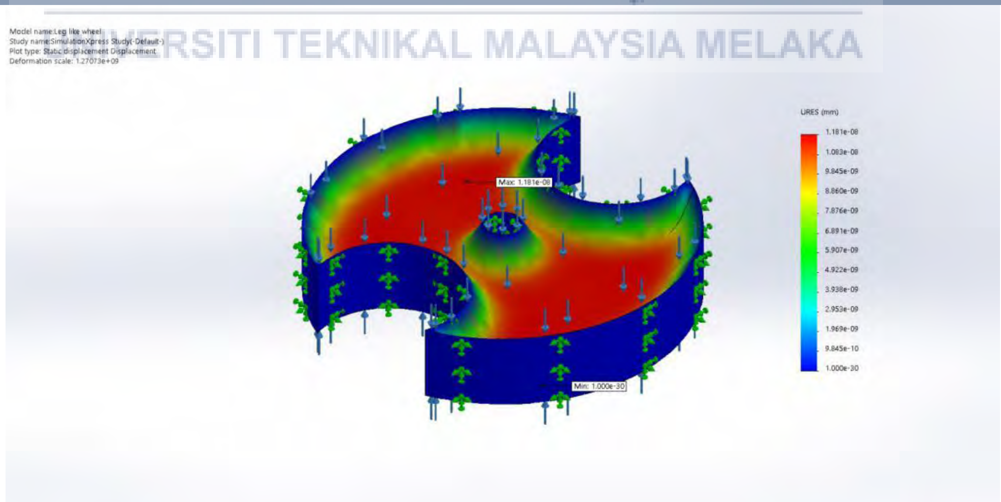
Name	Type	Min	Max
Stress	VON: von Mises Stress	1.434e-03 N/m^2 Node: 10629	1.743e+00 N/m^2 Node: 11600



Leg like wheel-SimulationXpress Study-Stress-Stress

Table 4.8: Displacement Study Result

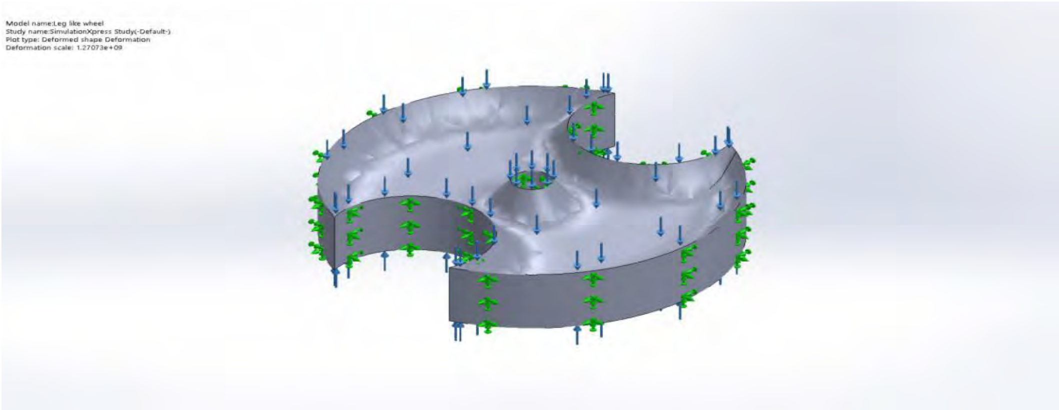
Name	Type	Min	Max
Displacement	URES: Resultant Displacement	0.000e+00 mm Node: 1	1.181e-08 mm Node: 826



Leg like wheel-SimulationXpress Study-Displacement-Displacement

Table 4.9: Deformation Study Result

Name	**Type**
Deformation	Deformed shape



Leg like wheel-SimulationXpress Study-Displacement-Deformation

The Table 4.2 and 4.3 show the wheel of ROC has a 1150 kg/m^3 in density (0.452989 kg, 0.000393904 m^3) with 7.92897e+07 N/m^2 in tensile strength and 6e+07 N/m^2 in yield strength. The fixture and load with 101.325 kN/m^2 pressure exerted in the fixture of the finite element analysis is shown in Table 4.4. The mesh property is shown in Table 4.5 and 4.6 and the meshing visualization displayed in Figure 4.2. Some of the study tests is simulated include the stress simulation shown in Table 4.7, displacement simulation shown in Table 4.8, and deformation simulation shown in Table 4.9.

194.1943 N/m^2 is the maximum stress since only 101.325N/m2 is applied. By referring to the safety factor the material is fully safe since in blue colour since it has a 1150kg/m^3 density, 7.92897e+07 N/m^2 tensile strength and 6e+07 N/m^2 yield strength

0 meter depth (surface) =1atm =14.7 psi = 101.325kPa = 101.325kN/m2

10 meter depth =2atm =29.4 psi = 202.650kPa = 202.650kN/m2

$$\frac{x}{10} = \frac{34436.9545}{202.6500}$$

x = 1699.33 meter sea depth

Table 4.10: Relationship between water depth and maximum stress of wheel

Depth(m)	Pressure(kPa)	Maximum Stress(kPa)
0	101.3250	176.5403
1	111.4575	194.1943
2	121.5900	211.8483
3	131.7225	229.5024
4	141.8550	247.1564
5	151.9875	264.8104
6	162.1200	282.4644
7	172.2525	300.1184
8	182.3850	317.7725
9	192.5175	335.4265
10	202.6500	353.0805
1699.33 (Break)	34436.9545	60000

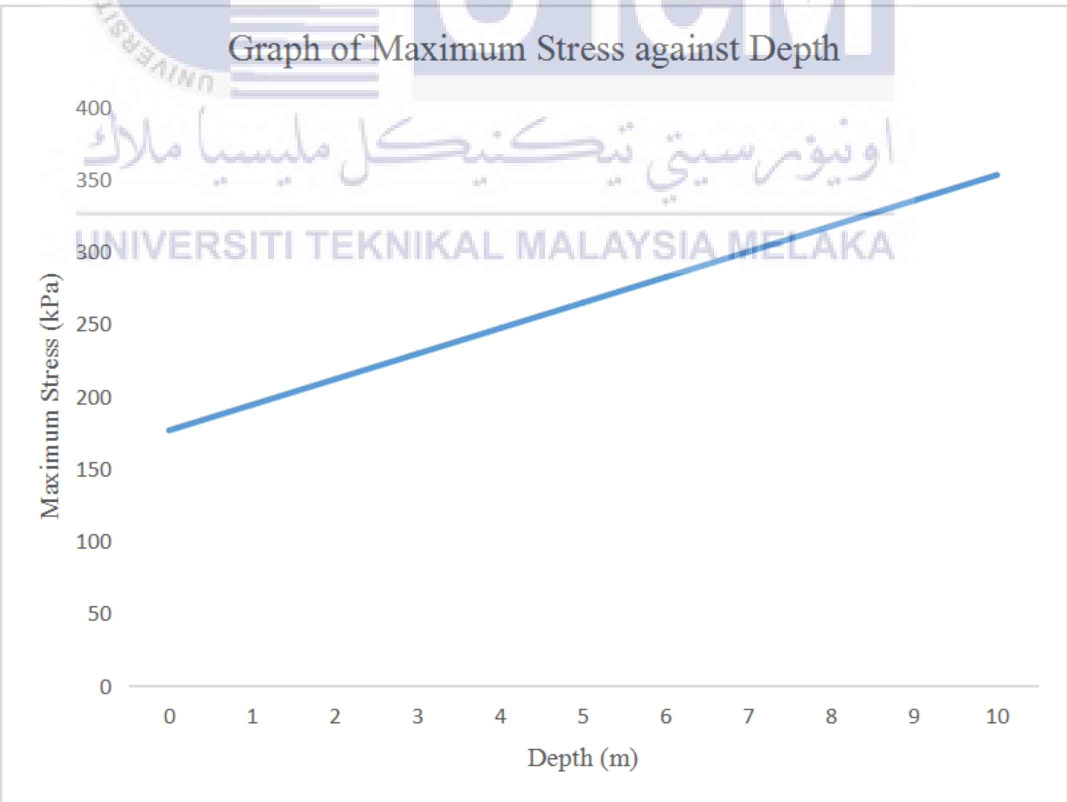


Figure 4.5: Graph of Maximum Stress against Depth

The following stress test are simulated for the structural analysis of its assembly structure in SolidWorks by the Static simulation. In this simulation, the material used are ASTM A36 for the base body, Nylon 101 for the leg like wheel and chrome stainless steel for the radial ball bearing. The geometry of the assembly is determined as shown in the following Table 4.11 to Table 4.17.

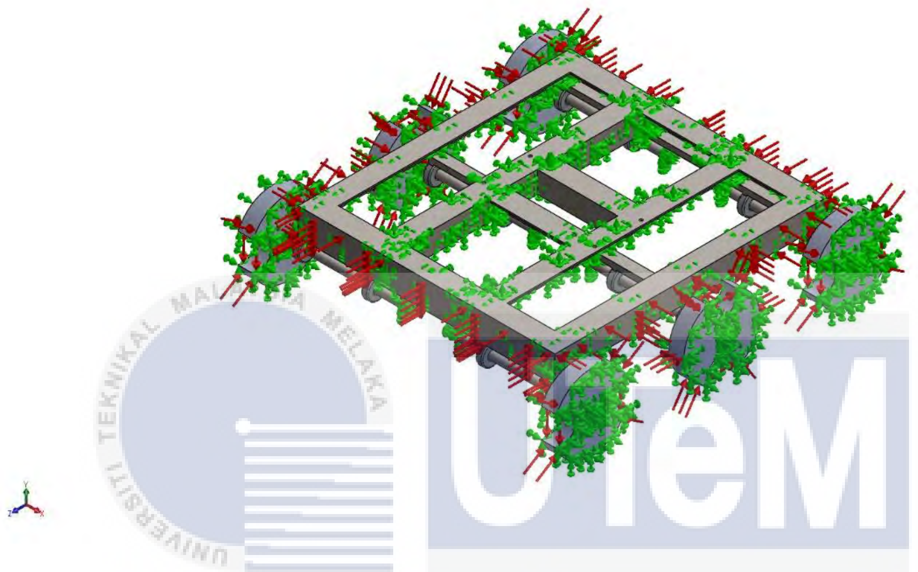


Figure 4.6: Fixed geometry and Pressure applied on ROC

Table 4.11: Model Information

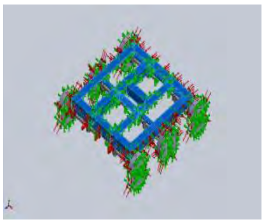
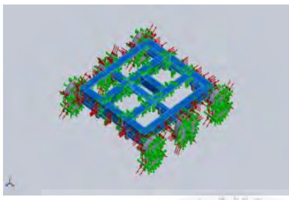
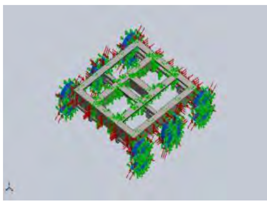
Solid Bodies			
Document Name and Reference	**Treated As**	**Volumetric Properties**	**Document Path/Date Modified**
Cut-Extrude3 	Solid Body	**Mass:9.1899 kg** **Volume:0.00117069 m^3** **Density:7850 kg/m^3** **Weight:90.061 N**	**F:\Drawing\Body. SLDPRT** May 05 00:15:26 2018

Table 4.12: Material Properties

Model Reference	Properties	Components
	**Name:** ASTM A36 Steel **Model type:** Linear Elastic Isotropic **Default failure criterion:** Unknown **Yield strength:** 2.5e+008 N/m^2 **Tensile strength:** 4e+008 N/m^2 **Elastic modulus:** 2e+011 N/m^2 **Poisson's ratio:** 0.26 **Mass density:** 7850 kg/m^3 **Shear modulus:** 7.93e+010 N/m^2	SolidBody 1(Cut-Extrude3)(Body-1), SolidBody 1(Chamfer1)(Shaft-1), SolidBody 1(Chamfer1)(Shaft-2), SolidBody 1(Chamfer1)(Shaft-3), SolidBody 1(Chamfer1)(Shaft-4), SolidBody 1(Chamfer1)(Shaft-5), SolidBody 1(Chamfer1)(Shaft-6)
	**Name:** Nylon 101 **Model type:** Linear Elastic Isotropic **Default failure criterion:** Unknown **Yield strength:** 6e+007 N/m^2 **Tensile strength:** 7.92897e+007 N/m^2 **Elastic modulus:** 1e+009 N/m^2 **Poisson's ratio:** 0.3 **Mass density:** 1150 kg/m^3 **Thermal expansion coefficient:** 1e-006 /Kelvin	SolidBody 1(Cut-Extrude3)(Leg like wheel-1), SolidBody 1(Cut-Extrude3)(Leg like wheel-2), SolidBody 1(Cut-Extrude3)(Leg like wheel-3), SolidBody 1(Cut-Extrude3)(Leg like wheel-4), SolidBody 1(Cut-Extrude3)(Leg like wheel-5), SolidBody 1(Cut-Extrude3)(Leg like wheel-6)

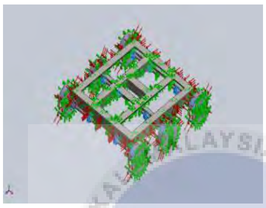
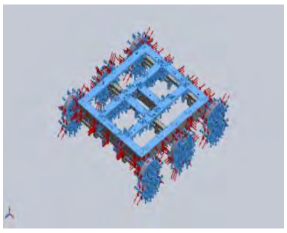
	**Name:** Chrome Stainless Steel **Model type:** Linear Elastic Isotropic **Default failure criterion:** Unknown **Yield strength:** 1.72339e+008 N/m^2 **Tensile strength:** 4.13613e+008 N/m^2 **Elastic modulus:** 2e+011 N/m^2 **Poisson's ratio:** 0.28 **Mass density:** 7800 kg/m^3 **Shear modulus:** 7.7e+010 N/m^2 **Thermal expansion coefficient:** 1.1e-005 /Kelvin	SolidBody 1(Bearing)(Radial Ball Bearing-1), SolidBody 1(Bearing)(Radial Ball Bearing-10), SolidBody 1(Bearing)(Radial Ball Bearing-11), SolidBody 1(Bearing)(Radial Ball Bearing-12), SolidBody 1(Bearing)(Radial Ball Bearing-2), SolidBody 1(Bearing)(Radial Ball Bearing-3), SolidBody 1(Bearing)(Radial Ball Bearing-4), SolidBody 1(Bearing)(Radial Ball Bearing-5), SolidBody 1(Bearing)(Radial Ball Bearing-6), SolidBody 1(Bearing)(Radial Ball Bearing-7), SolidBody 1(Bearing)(Radial Ball Bearing-8), SolidBody 1(Bearing)(Radial Ball Bearing-9)

Table 4.13: Loads and Fixture

Fixture name	Fixture Image	Fixture Details
Fixed-2		**Entities:** 45 face(s) **Type:** Fixed Geometry

Resultant Forces

Components	X	Y	Z	Resultant
Reaction force(N)	-2.73759e-006	-2.39286e-005	-1.36531e-005	2.76853e-005
Reaction Moment(N.m)	0	0	0	0

Load name	Load Image	Load Details
Pressure-2		**Entities:** 28 face(s) **Type:** Normal to selected face **Value:** 101325 **Units:** N/m^2 **Phase Angle:** 0 **Units:** deg

Table 4.14: Mesh Information

Mesh type	Solid Mesh
Mesher Used:	Standard mesh
Automatic Transition:	Off
Include Mesh Auto Loops:	Off
Jacobian points	4 Points
Element Size	21.3831 mm
Tolerance	1.06916 mm
Mesh Quality Plot	High
Remesh failed parts with incompatible mesh	Off

Table 4.15: Mesh Information Details

Total Nodes	33571
Total Elements	17316
Maximum Aspect Ratio	88.415
% of elements with Aspect Ratio < 3	53.6
% of elements with Aspect Ratio > 10	1.18
% of distorted elements(Jacobian)	0
Time to complete mesh(hh;mm;ss):	00:00:12

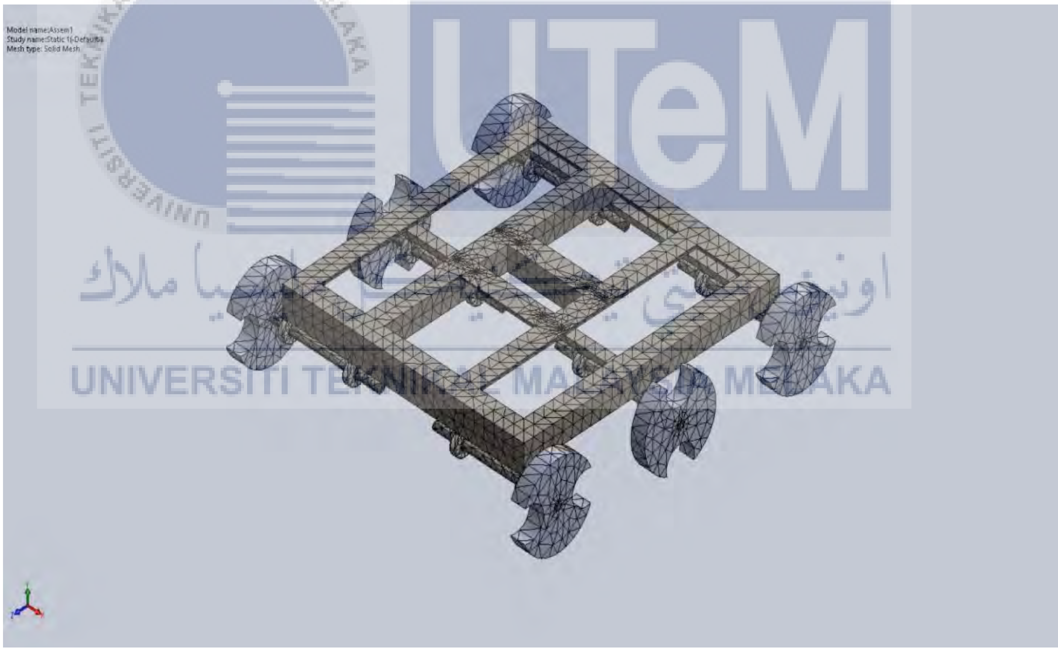


Figure 4.7: Mesh Result

Table 4.16: Stress Study Result

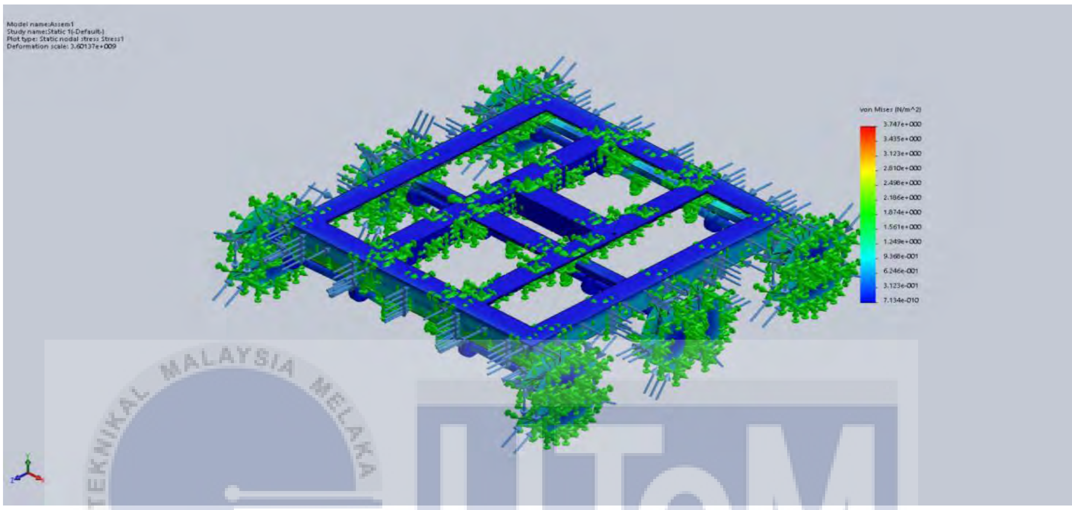
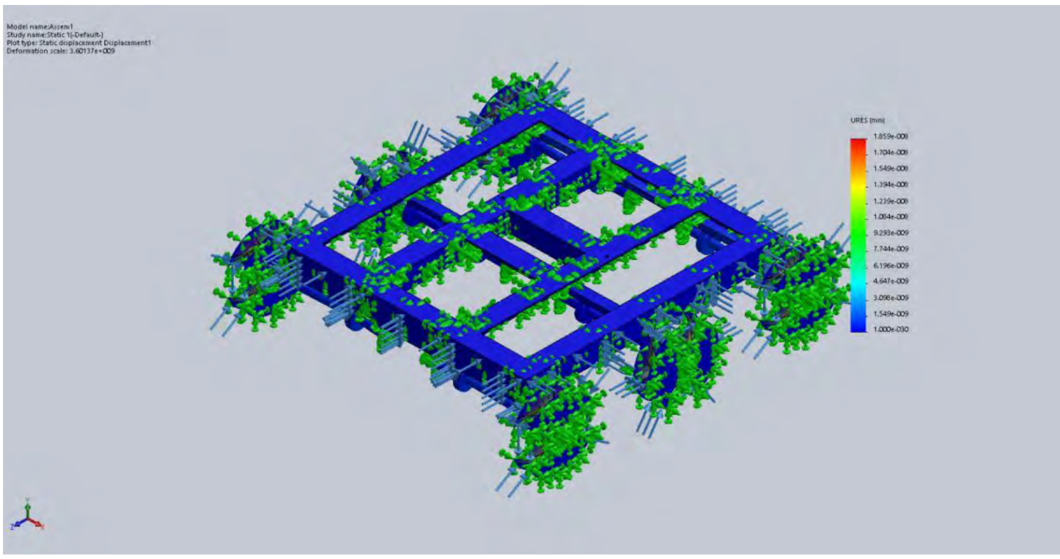
Name	**Type**	**Min**	**Max**
Stress1	VON: von Mises Stress	7.134e-010N/m^2 Node: 6129	3.747e+000N/m^2 Node: 10673
 Assem1-Static 1-Stress-Stress1			

Table 4.17: Displacement Study Result

Name	**Type**	**Min**	**Max**
Displacement1	URES: Resultant Displacement	0.000e+000mm Node: 64	1.859e-008mm Node: 17869
 Assem1-Static 1-Displacement-Displacement1			

The Table 4.11 and 4.12 show the assembly of ROC has a 7850 kg/m^3 in density (9.1899 kg, 0.00117069 m^3) with 90.061 N in weight. The fixture and load with 101.325kN/m2 pressure exerted in the fixture of the finite element analysis is shown in Table 4.13. The mesh property is shown in Table 4.14 and 4.15 and the meshing visualization displayed in Figure 4.6. Some of the study tests is simulated include the stress simulation shown in Table 4.16, displacement simulation shown in Table 4.17.

417.6657 N/m2 is the maximum stress since only 101.325 N/m2 is applied. By referring to the safety factor the material is fully safe since in blue colour. Since stainless steel has a 7850kg/m^3 density with resultant displacement shown with almost none which can be assume zero displacement occur.

0 meter depth (surface) =1atm =14.7 psi = 101.325kPa = 101.325kN/m2

10 meter depth =2atm =29.4 psi = 202.650kPa = 202.650kN/m2

$$\frac{x}{10} = \frac{34436.9545}{202.6500}$$

x = 1699.33 meter sea depth

Table 4.18: Relationship between water depth and maximum stress of ROC

Depth(m)	Pressure(kPa)	Maximum Stress(kPa)
0	101.3250	379.6961
1	111.4575	417.6657
2	121.5900	455.6353
3	131.7225	493.6049
4	141.8550	531.5746
5	151.9875	569.5442
6	162.1200	607.5138
7	172.2525	645.4834
8	182.3850	683.4530
9	192.5175	721.4226
10	202.6500	759.3922
1699.33 (Break)	34436.9545	129045.9120

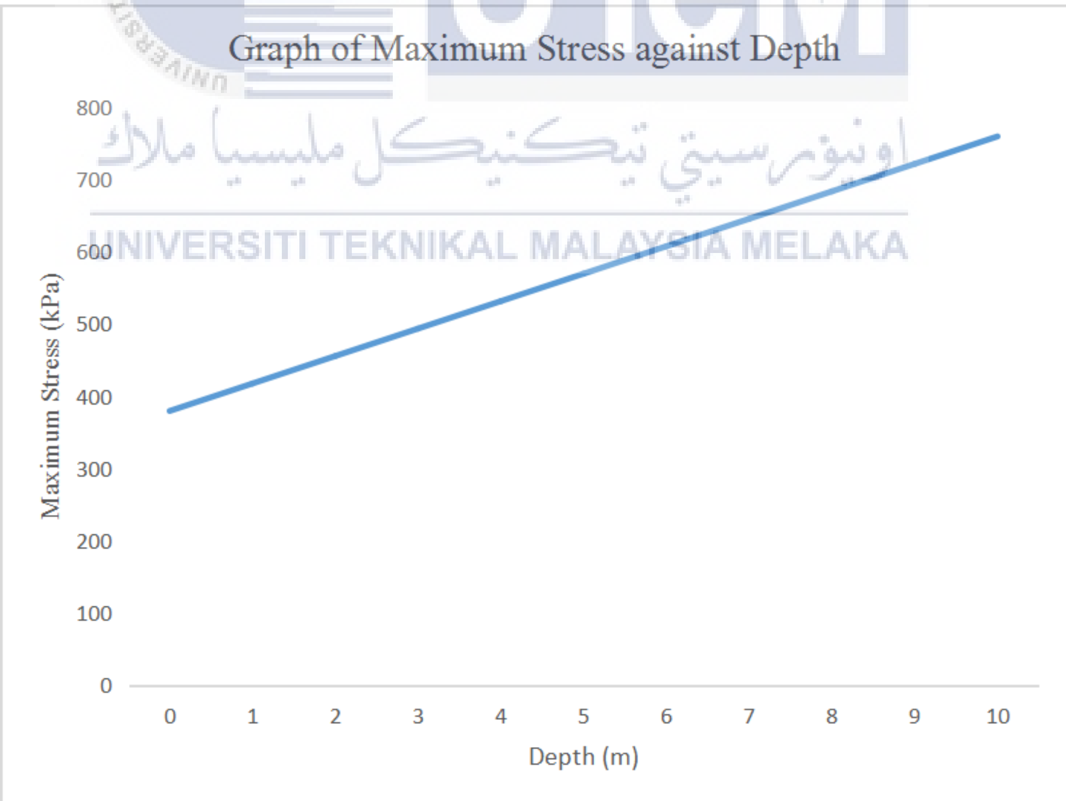


Figure 4.8: Graph of Maximum stress against Depth

The maximum depth of both wheel part and assembly part of ROC are the same. This is because in assembly part of ROC have the wheel part. Thus, the part that will likely to break first is the wheel of the ROC. The stress test on the wheel and the assembly of ROC shows that as the depth increases, the maximum stress increases. At the depth of 1 meter, the atmospheric pressure increases by 10.1325kPa which increases the stress applied to the ROC. As the depth increases to 1699.33 meter, the stress applied also increase and the wheel of ROC will break but other part of ROC still able to withstand the pressure. Since the wheel start to break at the depth of 1699.33 meter, thus the maximum depth of ROC that able to withstand the depth pressure would be 1500 meter.

4.3 Hardware Design Overview of ROC

Figure 4.9: Top View of ROC

Figure 4.10: Isometric View of ROC

Figure 4.11: Control Box External View

Figure 4.12: Control Box Internal View

4.4 Field Test Result

4.4.1 Result of experiment 3: Speed test on different surface

The purpose of this experiment is to investigate the performance of ROC in term of speed on different terrain. By observing the underwater terrain, there are 3 main terrain with different type of surface which are smooth surface, rough surface and uneven surface. Floor tile surface, road surface and grass surface were choose those 3 type of surface. The floor tile surface will represent as smooth surface, the road surface will represent as rough surface and grass surface will represent as uneven surface. The variable for this experiment were stated on previous chapter. The experiment were taken place based on the procedure and the data were tabulated and graph were plotted as follows:

Table 4.19: Time taken for ROC to crawl on different surface until 10 meter distance

Test	Time taken for each surface (s)		
	Floor Tile	Road	Grass
1	15.23	35.50	68.35
2	15.43	35.45	68.40
3	15.56	35.62	68.39
4	15.55	35.47	68.38
5	15.40	35.56	68.29
6	15.31	35.65	68.32
7	15.35	35.68	68.33
8	15.45	35.58	68.42
9	15.36	35.49	68.36
10	15.38	35.63	68.41
Average	15.40	35.56	68.37

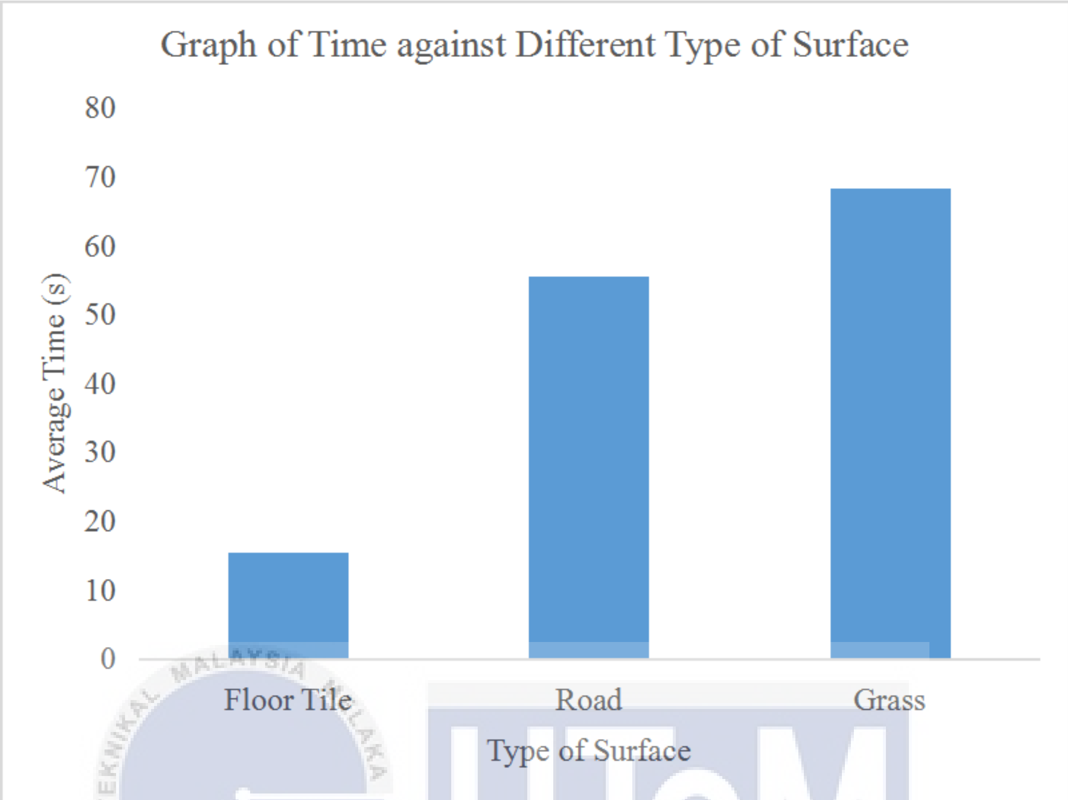


Figure 4.13: Graph of Time against Type of Surface

Figure 4.14: ROC on floor tile

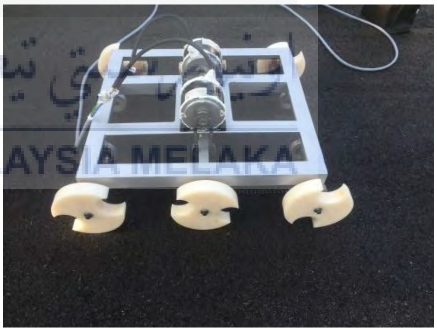


Figure 4.15: ROC on road

Figure 4.16: ROC on grass

The graph shows that the time taken for ROC to reach 10 meter on floor tile increases as on road surface and further increases on grass surface. On the grass surface, the ROC uses the longest time to reach 10 meter. This is because the grass surface is uneven surface which cause higher friction on the wheel of ROC compare to other surfaces. For that reason, the ROC needed more torque to overcome these friction. On the floor tile surface, the ROC uses the shortest time to reach 10 meter. This is because the floor tile cause less friction on the wheel and can be consider as frictionless which is smooth surface. By having the time and the distance of the ROC crawl on different surface, the speed of the ROC on those surface were able to calculate by using the following formula:

$$\text{Speed} = \frac{\text{Distance}}{\text{Time}}$$

Table 4.20: Speed of ROC on different surface

	Floor Tile	Road	Grass
Speed (ms^{-1})	0.6493	0.2812	0.1463

The speed of ROC on floor tile is the highest while on grass is the lowest. This show that the roughness of the surface has high effect on the speed of ROC as high friction acted on it. The experiment were conducted for 10 times for each surface but the time taken were different. There are few factors causing it, which are the power that supply by the battery keep decreasing as it been use up on previous test, the method that the ROC has been controlled and the reaction to stop the stopwatch in time. Assuming that these experiment were take place underwater, the time taken for ROC to crawl on each surface will be longer compare on the ground. The reason is that the underwater environment such as water resistance and wave will make ROC have drag force when crawl underwater.

4.4.2 Result of experiment 4: Crawl Over Obstacle Test

The purpose of this experiment is to investigate the performance of ROC in term of overcoming obstacle with different height. By observing the underwater obstacle, it consist of different height. The wooden plank is use to represent those obstacle. The crawling distance were measure as 2 meter distance on floor tile. The variable for this experiment were stated on previous chapter. The experiment were taken place based on the procedure and the data were tabulated and graph were plotted as follows:

Table 4.21: Time taken for ROC to crawl over wooden plank on floor tile

Wooden plank height (cm)	Time taken (s)	Observation
0.5	2.56	Able crawl over
1.0	2.75	Able crawl over
1.5	2.93	Able crawl over
2.0	3.07	Able crawl over
2.5	3.39	Able crawl over
3.0	3.63	Able crawl over but slightly stuck
3.5	3.87	Able crawl over but slightly stuck
4.0	4.10	Able crawl over but slightly stuck
4.5	4.58	Able to crawl over but low chance
5.0	-	Unable to crawl over

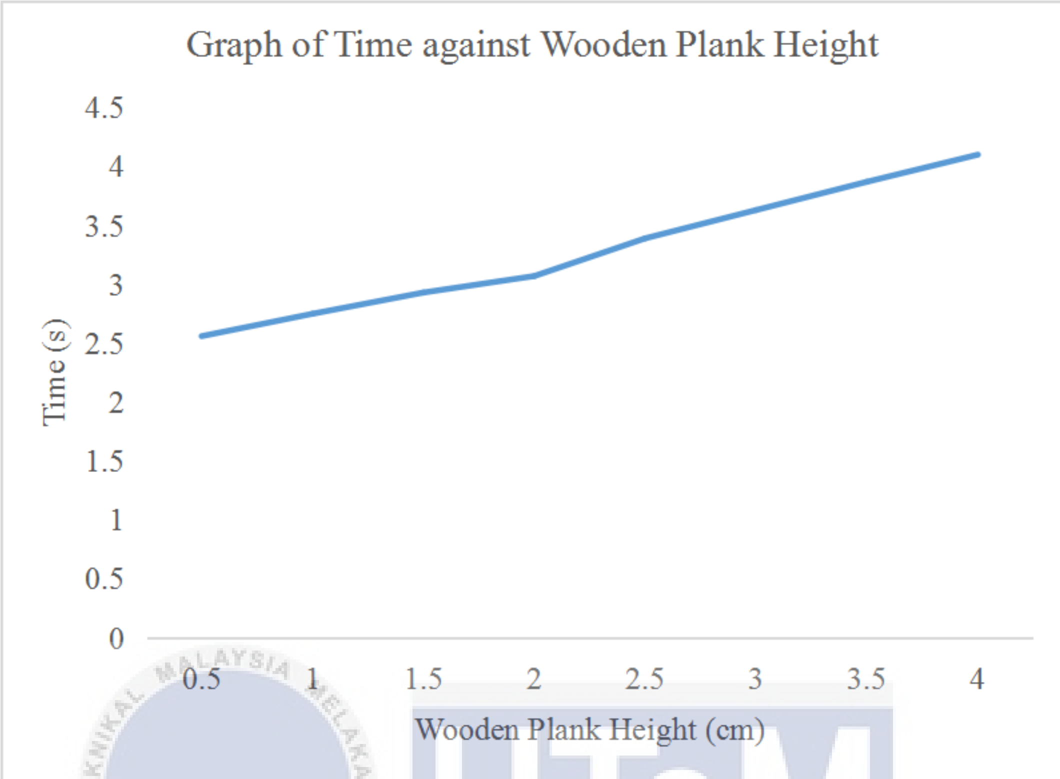


Figure 4.17: Graph of Time against Wooden Plank Height

Figure 4.18: ROC crawling over 4cm height obstacle

As the wooden plank height increases, the time taken for ROC to crawl over it increase. This is because the ROC need time to crawl over higher obstacle. The maximum height that the ROC able to crawl over is 4cm. The data for 4.5cm indicate ROC able to crawl with low chance in hand were not choose as the maximum height. The reason is that the low chance meaning for the ROC to crawl over 4.5cm height obstacle depends on luck which is not consider as a valid data. The experiment were carried out further by fixed the wooden plank height of 4cm to observe the smoothness of ROC when crawl over it. The data were tabulated as follows:

Table 4.22: Time taken for ROC to crawl over 4cm wooden plank on floor tile

Test	Time taken (s)	Observation
1	4.05	Smooth crawl
2	4.19	Slightly stuck
3	4.07	Smooth crawl
4	4.15	Slightly stuck
5	4.13	Slightly stuck
6	4.09	Slightly stuck
7	4.12	Slightly stuck
8	4.10	Smooth crawl
9	4.08	Smooth crawl
10	4.06	Smooth crawl
Average	4.10	-

The ROC crawl over 4cm height wooden plank smoothly with 5 out of 10 trial test while another 5 test were slightly stuck but it able to crawl over. The back wheel of ROC constantly stuck on all 5 test. This is because the weight of ROC has been putting on the middle wheel by having high stability with lower center of mass to avoid being wheelie. This condition can be overcome by having larger size wheel with larger torque output to the wheel with the help of gear ratio on the chain and sprocket. In addition will increases the crawling over obstacle ability of ROC.

4.5 Underwater Field Test Result

4.5.2 Result of experiment 5: Underwater Speed Test

The purpose of this experiment is to investigate the performance of ROC in term of speed in underwater. The bottom of the water tank surface is smooth. Thus, by using the previous result on floor tile surface result as comparison between on ground and underwater. The water depth of the water tank is 2 meter. The variable for this experiment were stated on previous chapter. The experiment were taken place based on the procedure and the data were tabulated and graph were plotted as follows:

Table 4.23: Time taken for ROC to crawl until 2 meter distance in water tank

Test	Time taken (s)
1	6.45
2	6.52
3	6.59
4	6.43
5	6.51
6	6.58
7	6.55
8	6.50
9	6.49
10	6.46
Average	6.51

Table 4.24: Speed of ROC in different medium

Type of Medium	Air	Water
Speed (ms^{-1})	0.6493	0.3072

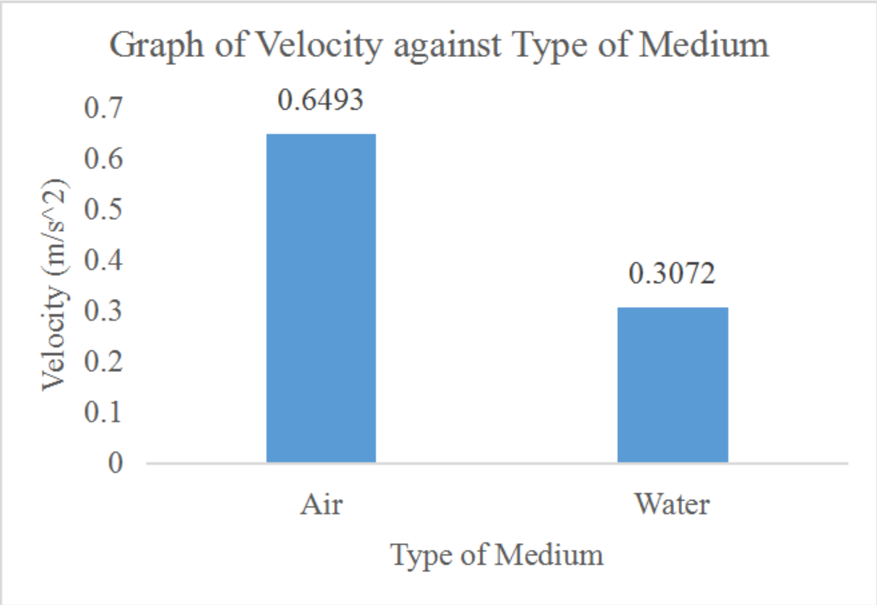


Figure 4.19: Graph of Velocity against Type of Medium without obstacle

Figure 4.20: A tank full of water

Figure 4.21: ROC in a water tank

The velocity decreases as the ROC is operated in the water. This is because the water resistance acted on it is high. The air resistance and water resistance will reduce the speed of the ROC. The reason that the water resistance reduce the speed of the ROC in higher amount is because water is much denser than air. Thus, the drag force acted on ROC is higher in water medium than in air.

$$\frac{0.6493-0.3072}{0.6493}\times 100\% = 52.69\%$$

The calculated value above show that ROC experience 52.69% decreases in velocity when it crawl in a water medium.

4.5.3 Result of experiment 6: Underwater Crawl Over Obstacle Test

The purpose of this experiment is to investigate the performance of ROC in term of overcoming obstacle in a water medium. The height of the obstacle choose as 4cm which is the maximum height of ROC able to crawl over the wooden plank. The reason for changing the obstacle material from wooden plank to cement is because cement much denser compare to wooden plank. Thus, to ensure the obstacle always stay underwater the material chosen should be denser than the water. The crawling distance were measure as 2 meter distance. The variable for this experiment were stated on previous chapter. The experiment were taken place based on the procedure and the data were tabulated and graph were plotted as follows:

Table 4.25: Time taken for ROC to crawl over 4cm block of cement in water tank

Test	Time taken (s)	Observation
1	8.77	Smooth crawl
2	8.75	Smooth crawl
3	8.89	Slightly stuck
4	8.83	Slightly stuck
5	8.85	Slightly stuck
6	8.78	Smooth crawl
7	8.82	Slightly stuck
8	8.80	Smooth crawl
9	8.79	Slightly stuck
10	8.76	Smooth crawl
Average	8.80	-

Table 4.26: Speed of ROC to crawl over obstacle in different medium

Type of Medium	Air	Water
Speed (ms^{-1})	0.4878	0.2273

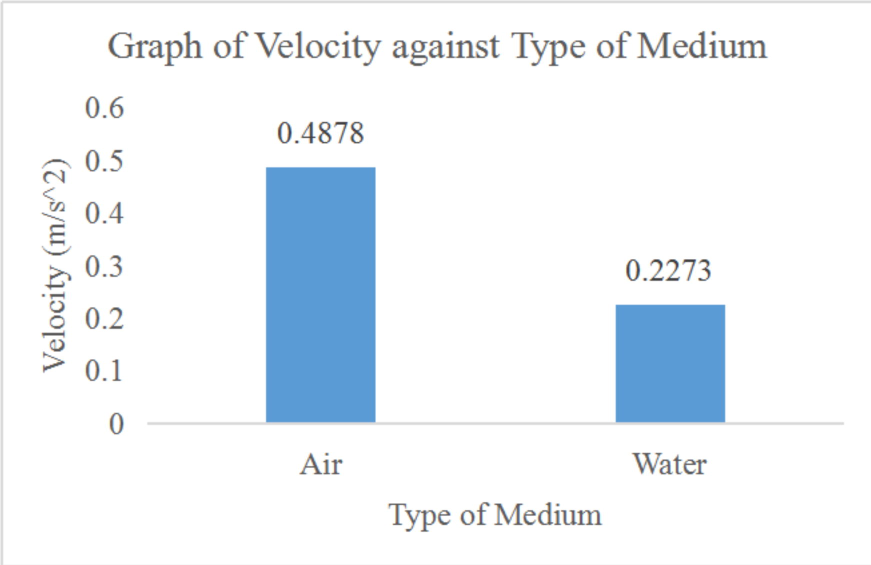


Figure 4.22: Graph of Velocity against Type of Medium with obstacle

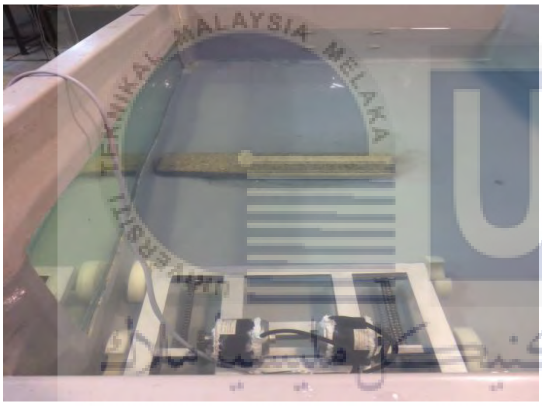


Figure 4.23: Top View of ROC in water tank with obstacle

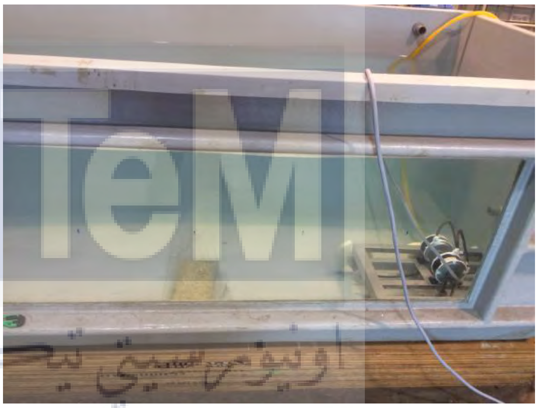


Figure 4.24: Side View of ROC in water tank with obstacle

The velocity decreases as the ROC is operated in the water. Even with the obstacle, the result in operating in the water medium still makes ROC decreases its speed. The drag force acted on the ROC in water medium is larger then in air medium. This has proven in both the bar chart of comparison in water and in air.

$$\frac{0.4878-0.2273}{0.4878}\times 100\% = 53.44\%$$

The calculated value above shows that the ROC experience 53.44% decreases in velocity when it crawl over a obstacle in water medium. In previous experiment, ROC also experience decreases in velocity that is 52.69% which proven that the ROC experience decrease in velocity about 50% when operate in water medium. Thus, the drag force cause by water medium is much larger than air medium.

4.5.4 Result of experiment 7: Underwater maneuverability direction changing

The purpose of this experiment is to investigate the performance of ROC in term of maneuverability of changing direction in a water medium. The experiment take place in a tank full of water on frictionless surface and none obstacle been place. The reason is to observe the accuracy of ROC changing direction without the help of any sensor. The accuracy can be determined by using precision error formula as follows:

$$\%\text{Error} = \frac{MeasuredAngle - DesiredAngle}{DesiredAngle} \times 100$$

%Error < than |3%| = Accurate

%Error > than |3%| = Not Accurate

The experiment were taken place based on the procedure and the data were tabulated as follows:

Table 4.27: Time taken for ROC to change direction about 90 degree

Test	Time taken (s)	Actual Value (°)	Precision Error (%)	Accurate
1	3.89	95	5.56	No
2	3.81	92	2.22	Yes
3	3.78	87	-3.33	No
4	3.85	93	3.33	No
5	3.87	94	4.44	No
6	3.76	85	-5.56	No
7	3.79	89	-1.11	Yes
8	3.80	90	0.00	Yes
9	3.82	91	1.11	Yes
10	3.77	88	-2.22	Yes
Average	3.81	90.4	-	-

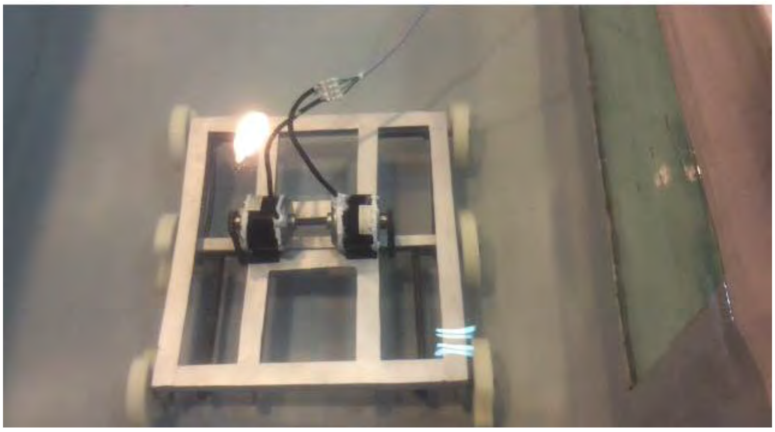


Figure 4.25: ROC in the middle of water tank

The average time taken for ROC to change direction to left/right about 90 degree is 3.81s. 1 out of 10 test the ROC change direction exactly 90 degree while the other 9 test is not accurate. This show that without any sensor, the ROC able to change direction with 50% accuracy in water medium.

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4.6 Summary

The overall chapter 4 discussed about the result obtained from the simulation on SolidWorks and field test experiment. The analysis done in SolidWorks are center of mass and stress test. The field test experiment is done to investigate the speed, crawl over ability and accuracy in changing direction of ROC. The result obtained is tabulated in a table and graph draw for further understanding of the data.

CHAPTER 5

CONCLUSIONS

5.1 Conclusions

As a conclusion, the first objective for this project is to design and develop a suitable wheel mechanism for a ROC. The literature review has been done to understand the problem faced by people who done this research. The method for designing the ROC wheel mechanism by using SolidWorks software with the chosen design based on problem faced in literature review. The SolidWorks software is used to analyse the center of mass and maximum stress of the design by using static simulation. As for the controller parts, an ardiuno UNO with MDS40A motor driver is used to connect with a keypad as controller that act as a control system of the ROC. Further fabrication were done based on the suitable material to use as wheel mechanism. Thus, the first objective has been successfully achieve by developing a suitable wheel mechanism for ROC.

Moreover, the second objective is to investigate the performance of ROC in terms of speed, crawl over obstacle and maneuverability. A few experiments were conducted to achieve this objective. The ROC has the capability to move in four direction which are forward, reverse, left and right. The turning angle of the ROC is depends on the coding that been program into the ardiuno. In the field test, the ROC has been successfully operates on different surface of terrain that been assuming in underwater. The ROC also has successfully overcome the obstacle and the maximum height of the ROC can overcome obstacle has been taken. The data taken has been compare with the air medium and water medium to show the difference in velocity of ROC. Next, the ROC has undergoes accuracy test on changing direction without sensor. The result has been analyse and the discussing has been made. Therefore, the second objective has been successfully achieved.

5.2 Future Work

The project of ROC is an interesting research to do as many challenge can be faced and has been successfully solved. Still there are many challenge waited to be solved and further improvement need to implement in this research such as the maximum height obstacle that can be crawl over by ROC. By increases the size of the wheel, the maximum height to overcome obstacle can be increases. According to this project the gap of the wheel is 6cm, thus the maximum height is 4cm. The other improvement that can look into is the torque input to the wheel. As the weight of the ROC is heavy, it needed high torque to spin the wheel. With sprocket ratio, it can increase the torque given to the motor. Moreover, the additional of various sensor able increase the maneuverability accuracy of ROC.

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APPENDIX

CODING

```
#include <Keypad.h>

const byte ROWS = 4; //four rows
const byte COLS = 4; //three columns
char keys[ROWS][COLS] = {
   {'1','2','3','A'},
   {'4','5','6','B'},
   {'7','8','9','C'},
   {'*','0','#','D'}
};

byte rowPins[ROWS] = {2, 3, 4, 5}; //connect to the row pinouts of the keypad
byte colPins[COLS] = {6,7,8,9}; //connect to the column pinouts of the keypad

Keypad keypad = Keypad( makeKeymap(keys), rowPins, colPins, ROWS, COLS );

//constant variable
const int mtr1_In1 = 10;
const int mtr1_In2 = 12;
const int mtr2_In1 = 11;
const int mtr2_In2 = 13;

void setup(){
   Serial.begin(9600);

//Set the mode for each digital pins whether input or output
   pinMode(mtr1_In1, OUTPUT);
   pinMode(mtr1_In2, OUTPUT);
   pinMode(mtr2_In1, OUTPUT);
   pinMode(mtr2_In2, OUTPUT);
}



void loop(){
   char key = keypad.getKey();
      // just print the pressed key
     if (key){
      Serial.println(key);
   }

   // this checkes if 4 is pressed, then do something. Here    we print the text but you
can control something.
   if (key =='2'){
      Serial.println("Forward");
      delay(200);
      analogWrite(mtr1_In1, 220);
      digitalWrite(mtr1_In2, HIGH);
      analogWrite(mtr2_In1, 220);
```

```
      digitalWrite(mtr2_In2, LOW);
      delay(200);
    }
    if (key =='8'){
      Serial.println("Backward");
      delay(200);
      analogWrite(mtr1_In1, 220);
      digitalWrite(mtr1_In2, LOW);
      analogWrite(mtr2_In1, 220);
      digitalWrite(mtr2_In2, HIGH);
      delay(200);
    }
    if (key =='6'){
      Serial.println("Right");
      delay(200);
      analogWrite(mtr1_In1, 220);
      digitalWrite(mtr1_In2, HIGH);
      analogWrite(mtr2_In1, 150);
      digitalWrite(mtr2_In2, HIGH);
      delay(200);
    }
    if (key =='4'){
      Serial.println("Left");
      delay(200);
      analogWrite(mtr1_In1, 150);
      digitalWrite(mtr1_In2, LOW);
      analogWrite(mtr2_In1, 220);
      digitalWrite(mtr2_In2, LOW);
      delay(200);
    }
    if (key =='5'){
      Serial.println("Stop");
      delay(200);
      analogWrite(mtr1_In1, 0);
      analogWrite(mtr2_In1, 0);
    }
}
```