I hereby declare that I have read through this report entitle “Development Of An Unmanned Underwater Remotely Operated Crawler (Roc) Based On Wheel Mechanism” and found that it has comply the partial fulfillment for Bachelor of Mechatronics Engineering.

Signature : ....

Name : Dr. Mohd Shahrieel Mohd Aras

Date : ....

DEVELOPMENT OF AN UNMANNED UNDERWATER REMOTELY OPERATED CRAWLER (ROC) BASED ON WHEEL MECHANISM.

MUHAMMAD IKTISYAM BIN MOHD ZAINAL

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

Faculty of Electrical Engineering
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

YEAR 2014/2015

I declare this report entitle “Development Of An Unmanned Underwater Remotely Operated Crawler (Roc) Based On Wheel Mechanism” is the result of my own research except as cited in references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ………………………………………………

Name : Muhammad Iktisyam Bin Mohd Zainal

Date : ………………………………………………

ACKNOWLEDGEMENT

Firstly, I would like to thank to Allah s.w.t for giving me an opportunity to finish this research paper. Other than that, a token of appreciation to my supervisors Mdm Fadilah Abdul Azis for my Final Year Project 1 and also Mr. Mohd Shahrieel Mohd Aras for guiding me along the journey to complete this Final Year Project 2. The foremost gratitude to my family that always gives me support to complete this project. In addition, I would like to give my appreciation to my friends that helped me along the way to finish this project.

ABSTRACT

Underwater vehicles are a type of vehicle that a type of vehicles that able to explore the underwater world. Remotely Operated Crawler (ROC) is one of the Unmanned Underwater Vehicle (UUV) that can be categorized in Remotely Operated Vehicle (ROV) class. The specialty of ROC allows for underwater intervention by staying a direct contact with the seabed. The common issues face for the crawlers are the underwater pressure, maneuverability, power and control. Besides that, the surface of the seabed become one of the problems in that restrict on ROC maneuverability. Designing a ROC that can crawl in any surface conditions is one of the issues emerged in this project. This project is about developing such ROC in order to fulfil a specific mission involving certain tasks. ROC lend themselves to long-term work and offer a very stable platform for manipulating objects and taking measurements better than other ROV. SolidWork is used as the software and platform in designing the crawler. Simulation test is done using application available in the software which is the SimulationXpress. Development an ROC based on wheel mechanism that allows the ROC moves with direct contact with the seabed without any glitch and have an ability to operate in any condition of the underwater environment. The wheel mechanism is adapted based on the tanks which is the chain type wheels. The performance of the ROC will be verified based on experiments conducted on the cluttered condition either on the surface or underwater. The ROC is capable to climb an obstacle of the maximum height of 9.5 cm. The operation of ROC can achieve excellent performance with an unexpected level of environmental condition.

ABSTRAK

Kenderaan dalam air merupakan satu kenderaan yang mampu meneroka dunia bawah air. Perangkak Kawalan Jarak Jauh (ROC) merupakan antara satu Kenderaan Tanpa Pemandu (UUV) bawah air. Keistimewaan ROC adalah keupayaannya beroperasi di dasar dengan secara lansung. Isu-isu biasa dihadapi oleh perangkak adalah tekanan bawah air, kebolehan-kendalian, kuasa dan kawalan. Selain itu, permukaan dasar menjadi antara masalah yang membataskan kebolehan-kendalian ROC. Merekabentuk ROC yang boleh merangkak di mana-mana keadaan permukaan adalah satu isu yang muncul dalam projek ini. Projek ini adalah tentang penciptaan ROC yang dapat memenuhi misi yang ditetapkan dalam tugas-tugas tertentu. ROC mampu beroperasi dalam jangka masa panjang dan menawarkan platform yang sangat stabil daripada ROV lain. Perisian SolidWork digunakan dalam proses merekabentuk ROC. Ujian simulasi dibuat menggunakan SimulationXpress. Pembangunan ROC berdasarkan mekanisma roda membolehkan ROC bergerak pada dasar tanpa sebarang masalah dan berupaya untuk beroperasi di bawah air. Mekanisma roda diadaptasikan berdasarkan roda kereta kebal jenis rantai. Prestasi ROC akan dikenalpasti berdasarkan eksperimen yang dijalankan pada keadaan tidak rata sama ada di daratan dan bawah air. ROC mampu mendaki halangan sehingga ketinggian 9.5 cm. Operasi ROC boleh mencapai prestasi cemerlang dengan tahap persekitaran yang tidak dijangka.

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CHAPTER 1

INTRODUCTION

This chapter is introduction of the project that covers briefly about the research background. The motivation and significant of the research is also included in this chapter. By motivation, the problem statement of this project has been concluded. The objectives of the project also explained in detail. In this chapter, the project scopes are determined and lastly, the report outline is executed.

1.1 Introduction

Before the creation of underwater vehicles, people tend to dive into the sea and river. They hunt for food, searching for sea products and even for pleasure. But humans have limits. We cannot dive too deep into the water and dive for a very long time. Most of the Earth's surface is covered by water in the proportion of 71%. This underwater exploration is impossible back then. In 1797, Karl Klingert [1] invents a diving suit that has an airtight metal helmet and a breathing tube as shown in Figure 1.1. Then, in 1934, Charles William Beebe and Ortis Barton made a record-setting descent to 3,028 feet (923m) below the waters of the Bermuda Island in a bathysphere [2]. Figure 1.2 shows a photo of Beebe and Barton with their bathysphere. This is a step in underwater exploration. Then it begins the age of submarines, sea explorations, deep sea dive and later the age of Unmanned Underwater Vehicles (UUV).

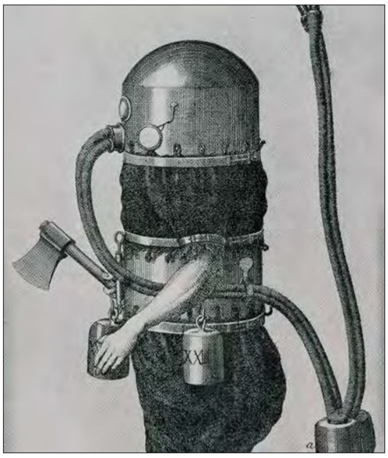


Figure 1.1: Helmet Suit by Karl Klingert [1].

Figure 1.2: Charles William Beebe and Ortis Barton with their bathysphere [1].

The needs of underwater vehicles are getting more important for wildlife research, seabed mapping, weather forecast, offshore and mining industries, archeology and also operation of search and rescue. Types of underwater vehicles are more sophisticated and advance in technologies. The current technologies have removed the need for pilots to control and dive into the deep water and eliminate the risks of man diving. As we know, the UUV remove the need of a man inside the vehicle. This will reduce the risk taken for a pilot to dive deep into the water and giving a chance to travel deeper into the abyss. The design could be smaller and more versatile since there is no needed space for the man inside the vehicle. In this project, the field of research is focusing on the remotely operated vehicle (ROV) which specific discussion on the design and development of a remotely operated underwater crawler. The prototype of the crawler will be tested in the lab and getting the data on depth, pressure, strength and maneuverability of the crawler. Previously, the use of underwater crawler is quite unpopular than the submarine type ROV. So, it is important to design and build a crawler that fits into any field. The significant of this study are targeting more area of usage for the crawler. For example; the crawler can be used in archeology, seabed monitoring for earthquakes, search and rescue, offshore maintenances and even military purposes. The remotely operated crawler (ROC) will be working alongside with the ROV. Both vehicles have their advantages and disadvantages. By working alongside, both vehicles can give more data and sight of a certain situation, for example search and rescue operation.

1.2 Motivation

Oil and gas have become an essential to us. The oil and gas industries give a lot of impact in our civilization. With this type of commodity, many new inventions have been created, changes the landscape of a country, economic growth and more in our life. Most of the time in our daily life related to petroleum base products. As a report by U.S Energy Information Administration (EIA), for the year 2013, United States consumed 6.89 billion barrels of petroleum products at the rates of 18.89 million barrels per day (bbl/d) [3]. In Figure 1.3 shows the world fuel consumption over the year 2009 until 2014 and expected projection in 2015. U.S. Energy Information Administration (EIA) projects world petroleum and other liquids supply to increase by 1.6 million bbl/d in 2014 and by 0.9 million bbl/d in 2015, with most of the growth coming from countries outside of the Organization of the Petroleum Exporting Countries (OPEC). The graph of the world liquid fuels consumption as shown in Figure 1.4. Forecast non-OPEC supply grows by 1.9 million bbl/d in 2014 and 1.2 million bbl/d in 2015. The United States and Canada account for much of this growth. Projected world liquid fuels consumption grows by an annual average of 1.0 million bbl/d in 2014 and 1.2 million bbl/d in 2015 [4].

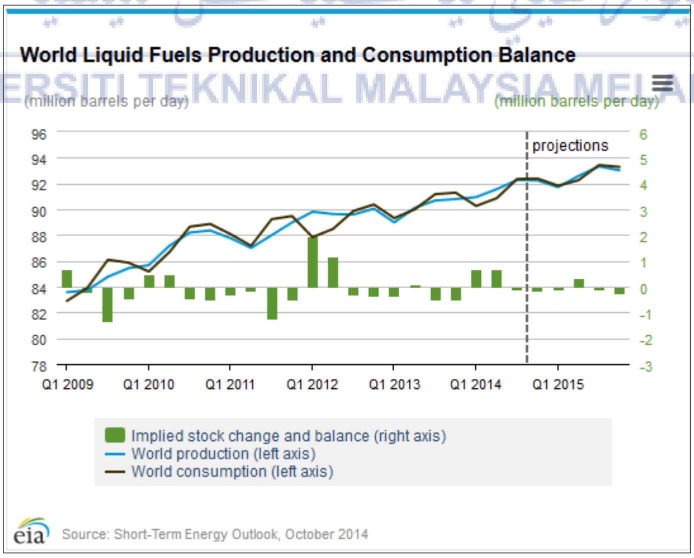


Figure 1.3: Chart of world fuels production and consumption for the year 2009 to 2015 [3].

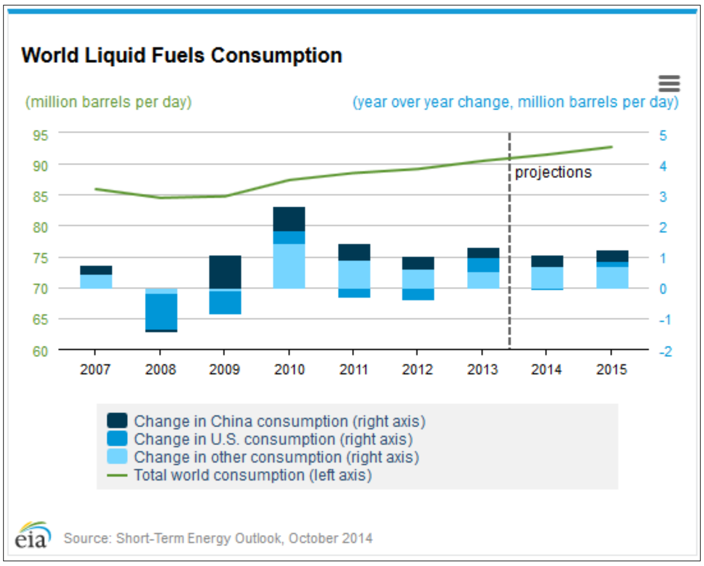


Figure 1.4: The fuel consumption graph for the year 2007 to 2015 [5].

The exploration of the oil and gas industries is not concentrated at on the land, but also in the offshore and deep sea as more oil wells found. Thus, as offshore explorations have increase the risk taken by man and women to drill petroleum. There are many cases regarding on the drilling, pipelines, transportation and storage accidents. Even though there are safety measures performed, yet accident can happen anytime without notice.

Underwater pipelines have a total distance of kilometers. They carry oil, gas, condensate, and their mixtures. Pipelines are among the main factors of environmental risk during offshore oil developments, along with tanker transportation and drilling operation. The causes of pipeline damage can be range from material defects and pipe corrosion to ground erosion, tectonic movements at the bottom of the sea and encountering ship anchors and bottom trawls. Statistical data show that the average probability of accidents occurring on the underwater main pipelines of North America and Western Europe is $9.3x10^{-4}$ and $6.4x10^{-4}$, respectively. The main causes of these accidents are material and welding defects just like what happened in Russia offshore project Sakhalin-1, in the year of 1994 and cause a huge impact to the arctic ecosystems as the pipeline collapse [6].

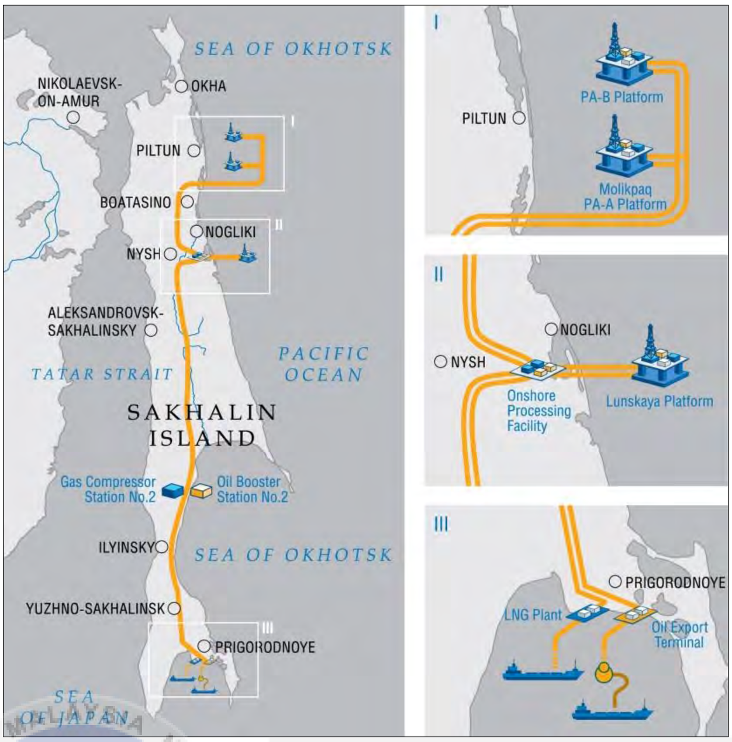


Figure 1.5: Sakhalin Offshore Projects [5].

Modern technology of pipeline construction and exploitation have been introduced. For example the usage of ROV and ROC in construction the underwater pipeline connections. This technology eliminates the risk taken by divers to dive into the deep and cold water condition. The ROC used in pipeline inspections and even constructions on the seabed along with other types of ROV and reduce human intervention doing the welding and inspection process.

Thus, this kind of incident motivates to study on the ROC design requirement to fulfil underwater inspections based on the project's scope and later there will be innovations in the development of ROC that help to build offshore facilities. One of the ROC design for the task of pipeline construction is the subsea crawler as shown in Figure 1.6 owned by IHC Marine and Mineral Projects, South Africa. The crawler is owned by Qinetiq North America as shown in Figure 1.7 which mainly use for Explosive Ordnance Disposal (EOD) Hull inspection.

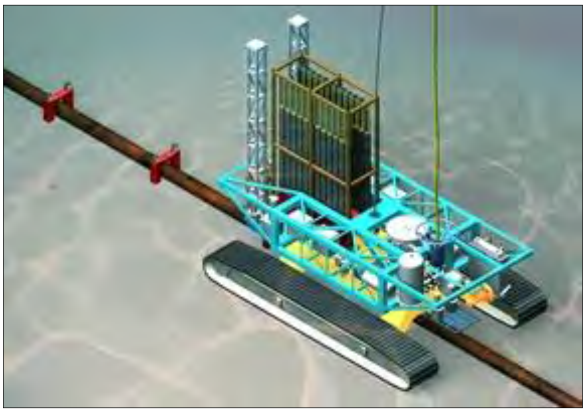


Figure 1.6: Subsea crawler for oil and gas pipeline constructions [14].

Figure 1.7: Hull Crawler by Qinetiq North America [15].

1.3 Problem Statements

The ROV is widely use in sea exploration. Even that so, it has limitations regarding on usage on the seabed. This ROV just at the certain depth and cannot operated in the cluttered environment as expected and direct contact with the seabed. Besides that, the ROV will cause sediment or mud on the seabed to shake and reduce visualization. It is also unstable due to the effect of environmental disturbance such as sea waves, current and unexpected underwater condition.

Investigation have been done in designing an unmanned underwater vehicle (UUV). The most problems are more regarding on the reliability of the UUV to work underwater without any glitch. Tadahiro Hyakudome (2011) from the Japan Agency for Marine-Earth Science and Technology (JAMSTEC) [7], Japan has listed a few problems in designing a UUV such as the seawater and water pressure environment, sinking capability, power unit and controller design. The author also stated that:

> *"When such underwater vehicles are made, it is necessary to consider about the following things such as seawater and water pressure environment, sink, there are no gas or battery charge stations, Global Positioning System (GPS) cannot use and radio waves cannot be used."*

The main concern of the problem is regarding on the underwater pressure environment. The deeper we go, the higher the pressure exerted to the ROC structure. The pressure increase by 10 bars or 1 ATM for every 10 meter dive. The density of the water also influences the pressure exerted. Hence, it is important to determine the pressure exerted so that the structure will not collapse or buckling. Besides that, the underwater environments are unpredictable. Underwater conditions can change anytime. Climate can affect the tides of the shore, waves, temperature and wind. Without proper design and material selections, the structure of the ROC can damage.

Designing a frame and determine the best material could give a headache. From the journal written by researchers in Ocean Engineering at Florida Institute of Technology, USA, they tested every frame's design using many type materials. Modification and strengthening of the frame was necessary after cracks were discovered in several welds of motor support. Adding ribs to the outer frame support between the main frame of the crawler and the motor housing frame made of 1/4" 6061-T6 aluminium solved this issue [8]. The stress on the frame must be considered and choosing the best materials are required. The materials must be lightweight yet strong enough to support the ROC motor and components and withstand the force and pressure. Some materials to be considered in the design are titanium, carbon fibre and aluminium.

Besides that, the design should be hydrodynamic in order to reduce drag and power usage. Based on the conference paper by researchers of Department of Marine Science & Engineering, Malek-Ashtar University of Technology, Iran at International Conference on Underwater Technology (USYS'12), they discussed on the resistance effect on the body of a submarine within different design. They concluded that the lower the resistance, the higher speed generated [9]. The ROC design by another manufacturer is basically using a chain type wheel. This type of wheel increases the tractions and suitable in any condition of sea floor.

Since there is no energy supply beneath the water surface, power source becomes one of the main issues to consider. Designing, development and research of the power source, following things need to be considered:

1. Size and light weight
2. Resist to pressure and water
3. Reliability to supply enough power
4. Maintenance of the power unit (rechargeable or not)
5. Power capacity
6. Low vibration and produce noise

For communication, radio wave is not usable in the sea or underwater. However, it is crucial for ROC or ROV to communicate with the support vessel. The effective method of underwater communication is acoustic telemetry. There are analogue and digital communication for acoustic telemetry [7]. The controller for some ROC design split into two analogue and digital. The analogue use relays while digital uses an Arduino micro-controller. The usage of cables gives less mobility to the ROC since the seabed is not flat and have obstacles.

Basically, from the review of JAMSTEC journal, most power source is the heaviest unit of the vehicle. When the power source becomes big in proportion to scale up of the body, maneuverability and energy efficiency worsen. Low vibration and low noise produce is important so that it will not interfere acoustic equipment and communications devices [7].

1.4 Objectives

The purposes of developing an unmanned underwater Remotely Operated Crawler (ROC) as follows:

1. To design and analysis of unmanned underwater Remotely Operated Crawler (ROC) using CAD software.
2. To develop a Remotely Operated Crawler (ROC) based on the selected design.
3. To analyze the movement and maneuvering of the Remotely Operated Crawler (ROC) underwater and on land.

1.5 Scopes and Limitations

Scopes for this project are limited into few aspects. First, the crawler will have two degrees of freedom (DOF) for the maneuverability. Then, upon completion, the crawler will be tested on the hard surface underwater bed. The motions of the controller will be designed as forward, reverse, left and right movement. The design specifications are based on the scope drafted which are the operation depth is more or less than 5 meters. The control range of the crawler are strictly depends on the length of the connection cord and the pressure to withstand is about more than 0.5 bars. The crawler must be water and shock resistance and durability in term of maneuverability and movement, either on the land or underwater. The flow of the design is shown in the Figure 1.8 which is the K-chart of the flow of the design.

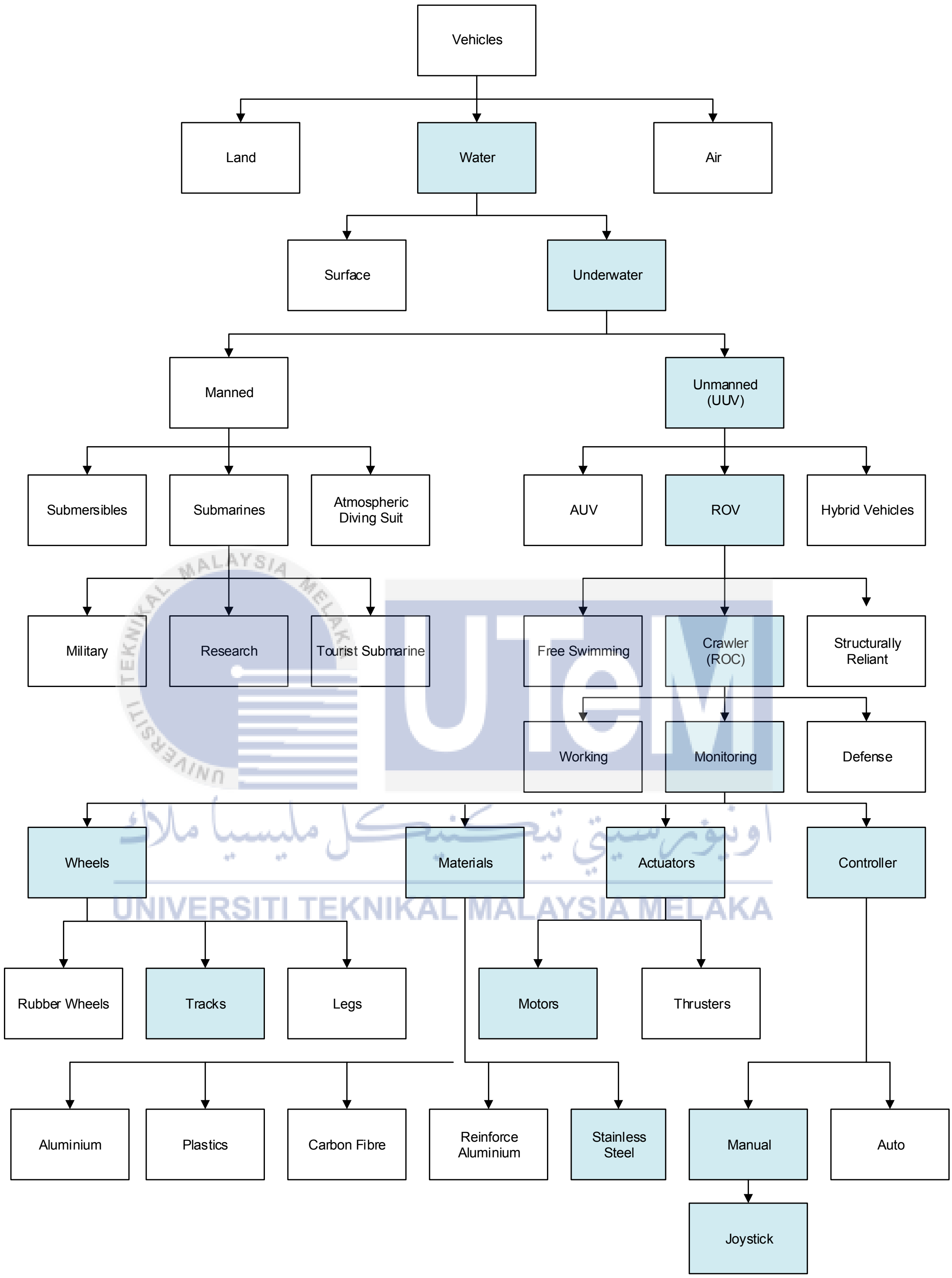


Figure 1.8: The K-Chart of the Project Design.

CHAPTER 2

LITERATURE REVIEW

This chapter covers on the theory and basic principle, review of previous work and the summary and discussion of the review. In the theory and basic principle section, it cover briefly on the theory, problems faced and research in developing an UUV. The comparison between available ROC in the market with this project also been done by reviewing the functions, capability and designs of the ROC.

2.1 Introduction

The Earth's surface consists of approximately 71% of the ocean and still have a lot of unknown parts. Therefore, various studies and development about ocean such as marine environment, submarine earthquake, ocean life, marine resources research and more. The collection of ocean data by survey and observation in the actual sea is indispensable for the studies and the development. The whole deep sea cannot be observed in detail from the surface due to the low transparency while survey and observation with the ship is not enough [7]. This mysterious element has generated and unquenchable curiosity that pushed people like like *Le Prieur*, *Cousteau*, *Piccard*, *Walsh*, and many others, to accomplish what was considered as impossible. All these people show the feasibility of underwater intervention and circumvented the set of technical obstacles of such missions. Designing a system guaranteeing the preservation of the operator's health was their first objective. Removing humans from the immerged system reduces the critical constraints, but poses the problem of the guaranteeing the autonomy of the vehicle, and its effective capabilities [2].

2.2 Problems Face in Designing an Unmanned Underwater Vehicle

Ocean environment filled with sea water. Since the viscosity of sea water is high, it is hard to move in the ocean compared to the atmosphere. The characteristic of the ocean is the environment where; 1 atmospheric pressure increases by every 10 meter diving. As we go deeper, the sea will increase the pressure. The water pressure increases, according to depth, and so the hull of pressure vessel needs to increase the thickness to add to strength depending on depth. However the strong pressure vessels become very heavy weight [7].

A smart control system needs for autonomous underwater vehicles to cruise in safely and precisely for a long time. The system needs to control about the devices such as thruster, INS, rearranging of the information on the vehicle, and motion of the body. The computer of the vehicle needs to make the information processing of a lot of devices. A distributed processing system is necessary, so that processing does not concentrate on one CPU [7]. Researches have been developed for designing controller for the underwater vehicles, including the remotely operated crawler. Based on the paper written by Douglas M Welling and Dean B Edwards with the title of Multiple Autonomous Underwater Crawler Control for Mine Reacquisition, they focus on control for autonomous crawler could be advanced for remotely operated crawler. The important thing is the reliability of the controller. This paper's primary scope is the strategies for crawlers for motion control and mine acquisition. Two acquisitions, scheduling systems were compared, one using a closest target strategy, and one using fuzzy logic that used additional information available to the crawler to best utilize time and resources [10]. Welling and Edwards (2005), the authors of the paper discovered that:

> *"It was found that a fuzzy logic scheduling system outperformed the baseline system by reducing the amount of time to reacquire all targets."*

Many research and development about the underwater power source are performed. Few things need to be considered such as the power source needs to be small, lightweight, stored in a water resistant vessel, work against low water temperature, vibration, noise and reliability for the maintenance. Since the power source has heaviest weight and big compared to the other components of the vehicle, maneuverability and energy efficiency worsen. Therefore, it is important for the power source fulfil those characteristics [7]. Tadahiro Hyakudome (2011) in his paper had discussed type of power supply to use:

> *"Therefore, it is important that the power source is small and lightweight. Low vibration and low noise environment is important not to interfere acoustic equipments or communication devices. Primary batteries, secondary batteries, internal combustion engines, external combustion engines, radioisotope batteries, small nuclear reactor and fuel cells are considered as an underwater power source."*

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 [7]. The author of the journal, Tadahiro Hyakudome (2011) stated that:

> *"All of underwater vehicles are controlled by electronics. However, the elements of most electronics are not exposed to seawater to short-circuit. In addition, there are the elements of electronics broken by high water pressure. Therefore, solid vessels are necessary to use the electronics in underwater. The pressure vessels are required to be enough strong for water pressure in the working depth, lightweight, not corroded and so on."*

A joint collaborative program involving National Institute of Ocean Technology, (NIOT) India and Institut für Konstruktion (IKS) of University of Siegen, Germany was initiated to develop a deep seabed mining system with a crawler and a flexible riser system. In the first phase it has become essential that the system proved in shallow waters before extending the same concept to deep seas. Hence the flexible riser system was developed and tested in the Indian seas at 410 meter water depths. Four tests have been carried out on this system [11]. They have found out a few methods have can be used for elevation and rising the underwater vehicles such as airlift systems and hydraulic lift system. Unfortunately, both systems have their disadvantages in performing the task. Those researchers from both institutes found that:

> *"In the case of airlift systems, compressed air is injected at intermediate depths and the solids were lifted up as a three phase mixture. Hydraulic lift systems had problems due to wear in the impellers. Maintenance of these systems was also difficult. The performance of the airlift system was much below expected levels. Deployment and retrieval of the heavy pipeline were also very difficult and time consuming. Further, those systems were highly cost intensive."*

Generally, aluminium alloy, Titanium alloy and High Tensile Strength Steel are used as a material of pressure vessel in JAMSTEC. The aluminium alloy is light weight, high strength, reasonable value, but surface treatment is necessary to use it in the sea. The titanium alloy is light weight, high strength, maintenance free, but expensive. The titanium alloy has the following characteristic: the specific gravity is 4.5, high corrosion resistance, low electrical conductivity, low heat conductance, not becomes magnetized, low workability. Particularly, the specific strength of the Ti-6Al-4V alloy is the strongest level. The titanium alloy does not need the surface treatment even if used in the sea. The high tensile strength steel is high strength, moderate value, but heavy weight and surface treatment is necessary to use it in the sea. The specific gravity of the high tensile strength steel is about 7.9. The high tensile strength steel has more than 490Mpa tensile strength [7]. Based on design of RGIII, tests conducted have revealed certain weaknesses in frame designs and motor housing. Thus, it is important to select the best materials in design consideration. Modification and strengthening of the frame was necessary after cracks were discovered in several welds of the motor support. Analysis using ANSYS showed where deformation was great, which known weld failure. Adding ribs to the outer frame support between the main frame of the crawler and the motor housing frame made of 1/4" 6061-T6 aluminium solved this issue. Thus, material selection in design frame is important as other issues [8].

2.3 Usage of Unmanned Underwater Vehicles in Industries

The biggest private users are the Gas and Oil companies that represent 58% of the offshore industry. 83% of its activity are taking place in water depths less than 300m, while the remainder is focused in the deep-water areas. As oil demand is increasing, this ratio will change with exploitation moving into ever-deeper waters (Whitcomb, 2000). Most of the currently used vehicles are Remotely Operated Vehicles (ROVs) designed to perform subsea inspection, construction, and repair operations. An ROV is teleported through an umbilical link, real-time connected to the operator, and has to be able to autonomously reach a desired location, search and lock onto a target on which the operator will perform manipulation: drilling, welding, configuring wellhead valve, plugging cables AUVs are involved in pipe inspection, terrain bathymetry and acoustic sediment analysis for pipeline installation and prospection for new oil and gas fields [9].

While awareness of the usefulness of crawlers may still be needed, subsea technology developments with AUVs are not only widely known in the industry, the vehicles are also being extensively used. That's a situation, according to analysts, that will only continue to grow with oil companies and their suppliers expected to invest a significant amount of dollars in new technologies over the next few years as they look to capitalize on the rich fields that lie beneath the ocean floor in the most cost-effective manner possible [12].

Besides oil and gas industries, ROC also being used in sand mining industry and also in archaeology. Thus this shows that ROC can operate on various types of industry, even though it is not widely used as the submarine type ROV.

Designing an unmanned underwater vehicle (UUV) are not a simple task. The condition of the working environment has influenced the design of the UUV in terms of power supply, design specifications, material selection and even the elevation procedure. It is important to improve many elemental technologies such as a power source and navigation system and so on to achieve this aim. Many technologies have been developed in the remotely operated vehicle to fit the needs of the industry and exploration. All the problems face in developing an underwater vehicle need to understand and studies so that, the design of the vehicle can operate in such underwater conditions.

2.4 Design Comparison

2.4.1 Type of wheels

Current designs mostly using track type of wheels. This is because, it covers a larger surface area than the conventional wheels. Besides that, this type of wheels are more suitable in any surface conditions. On the seabed, there could be muddy, sandy, rocky and unstable surfaces. Thus, with the track wheel, it is more suitable since it provides a huge amount of tractions due to larger surface area covered. Comparing to the ROC that use 4 wheels make it move on the seabed, this design have lack of tractions when it comes to the mussy and slippery surface. As the example shown in Figure 2.1, the RGIII have track wheels made of steels because it operates in underwater sand mining. While the ice Hytec Roving Bat is shown in Figure 2.2 and the Qinetiq EOD Underwater Hull Inspection is shown in Figure 2.3, they use a rubber type or a silicon type since it's their usage as monitoring and cleaning purposes. For the proposed design, the type of wheels will be used is steel chain type wheels.

2.4.2 Actuators

The mechanism to operate the ROC is basically using thrusters and motors or even both. The RGIII used both thrusters and motor to actuate on the seabed. The Eca Hytec in Figure 2.2 uses motor with the support of thrusters from the ROV attached to the it's body. The Qinetiq is shown in Figure 2.3 and the proposed design only used motor to maneuver underwater.

2.4.3 Controller

Type of controller mostly uses the same basis which is using analog and digital controller. This is because some mechanism cannot be control using analog under the water surface to to lack of radio wave transmission. Their cables connected to each design and a communicator with the support vessel.

The operation depth varies among the ROC. The deepest diver among four designs is the RGIII which operates 100 m below sea level while proposed design is operated only 5 m underwater. This is because each ROC have different usage and the design fits to their respective purposes.

2.4.4 Materials Selection

Material selection is one of the most important aspects in designing a ROC. Most ROC developers married different type of materials together so that the ROC become stronger to withstand forces and pressure. Lightweight materials selection is crucial because, as the ROC dive into the deep, the weight they exerted increasing gradually due to pressure, density and atmospheric pressure. The materials must withstand any forces or impact hit to them. The sea is always changing their conditions. The current could drive the ROC to the rock and stumble them upside down.

Figure 2.1: Hybrid Robot Crawler / Flyer RG III

Figure 2.2: Eca Hytec Roving Bat, Hybrid ROV for inspection and cleaning.

Figure 2.3: Qinetiq EOD Underwater Hull Inspection

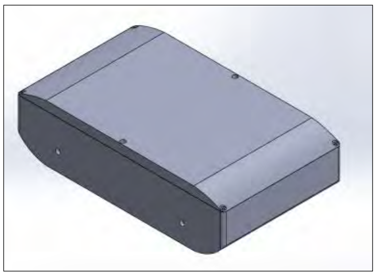


Figure 2.4: Proposed Design

2.5 Summary

In designing a crawler, it is important to consider a certain aspect in order the design to work as expected. One of the important aspect is to know the underwater environment. The current, corrosion and other unexpected situation could happen underwater. The weight of the crawler also plays a role. If the design have air pocket, thus the crawler need more weight or a ballast tank so that it can overcome the buoyant force. Too much weight could limit the ability for the crawler to move and needed powerful motors and high power supply. Besides that material selected in development of the crawler must withstand pressure, force, stress and corrosion. It is important since the crawler will operated in harsh environment. The power supply need to be supplied directly since the battery could not supply enough power for a long time. The crawler itself will be working in a long period of time. Maneuverability of the crawler is influenced by the type of wheel chosen. A chain type wheels cover more surface and tractions to the bed. By manipulating the motors, crawler can crawl in any directions; forward, reverse, left and right. Thus, from the literature review it is concluded that, all factors pointed by researchers help in designing a ROC and also the design comparison among available crawler in the market.

CHAPTER 3

METHODOLOGY

This chapter is about the project planning mechanism, the flow of the project and also propose test or experiments for the design and development of underwater Remotely Operated Crawler. Gathered data is explained in this chapter. Designing an ROC will be done by using a CAD software. Development of the ROC takes about 6 weeks to complete. There are five experiments to conduct in order to measure the ROC performance on land and under water.

3.1 Introduction

Every project must have a draft or plan of execution. Planning is an important as a guidelines in developing a project. From the beginning of the project, every aspects need to be calculated and plan. From the design of the ROC, testing, benchmarking and even calculating the cost for developing the ROC. For the development and modelling of unmanned underwater remotely operated crawler (ROC) for design 2, it all starts with a project plan. Every detail of the project must be pointed out in term of designs, costs, materials selections, components selections and prototype testing and assembly process.

For this project, it is divided into two parts; the final year project 1 and final year project 2. For final year project 1, mostly regarding on achieving the first objective which is to design the remotely operated crawler. The design uses the CAD software (Solidwork) and simulations need to be done for 3 different designs which are Design 1, Design 2 and Design 3. All three designs have a different chassis design while the wheels, movement mechanisms and controller remain the same. Final year project 2 basically on development of the prototype in terms of hardware.

By determining the objectives, research can be done by reviewing journals, conference papers and other research. From the literature review, current problems can be identified and proposed solutions can be made.

From the analysis, then came up the solutions which in terms of conceptual design first then goes into detailed designs. The best designs that fulfil every requirement should be chosen to solve current problems. Each design will be simulated in order to identify design's weakness and strength.

Then, the development of prototype can be done. The prototype must be tested in the lab and even possible field test. Troubleshooting the prototype will help in determining the error or problems and improves the prototype design.

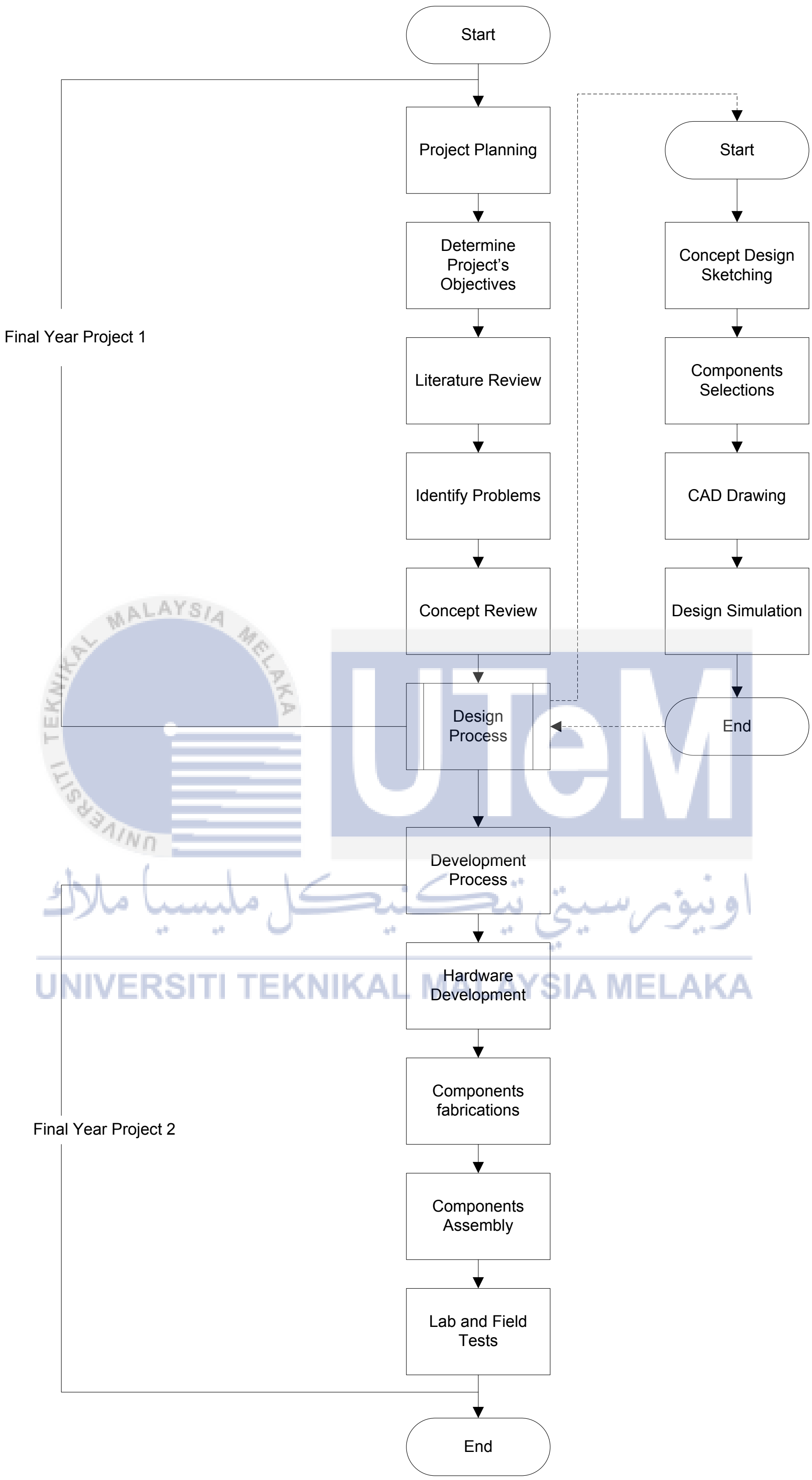


Figure 3.1: Process flowchart.

3.2 Milestone and Project Planning.

Table 3.1: Planning Activities.

No.	Activities	Date
1.	Project studies - Theoretical studies - Hardware design	September – November 2014
2.	Data collections and literature review	September – October 2014
3.	Designing hardware	October – November 2014
4.	Design simulations	October – November 2014
5.	Hardware implementations	November 2013 until January 2014
6.	System implementation	December 2013 until February 2014
7.	Test guidelines	February 2014
8.	Experiments and data collections	February 2014 until March 2014
9.	Hardware analysis	April 2014 until May 2014

3.3 Data Collection

All the information regarding on the constructions of the underwater vehicle need to be searched and review. The constraints, properties and related information about underwater environment have been search through the web, journals, conference papers, books and also obtain from supervisors. All the comparison and review have been written in the literature review section in Chapter 2.

3.4 SolidWork

For designing and conceptual phase, the designs of the Remotely Operated Crawler were sketched and drew in Solidwork software. With this software, it is easy for users to interpret their idea into 3-dimensional drawing with dimension and specifications that stated in the scopes. Later, SolidWork also allow the user to simulate the component designs using the simulation application. The simulation will evaluate the capability of the chassis when forces is applied. From the design, SimulationXpress will convert the solid body to a mesh body drawing and analysed the drawing. Later, forces and pressure is applied to surfaces of the ROC design. Points of the forces and pressure is depend on the condition of the ROC will operated. For example, when ROC is submerged, the pressure exerted from external environment to internal environment. The simulations of the chassis for the ROC is stated in Chapter 4: The Result and Discussion.

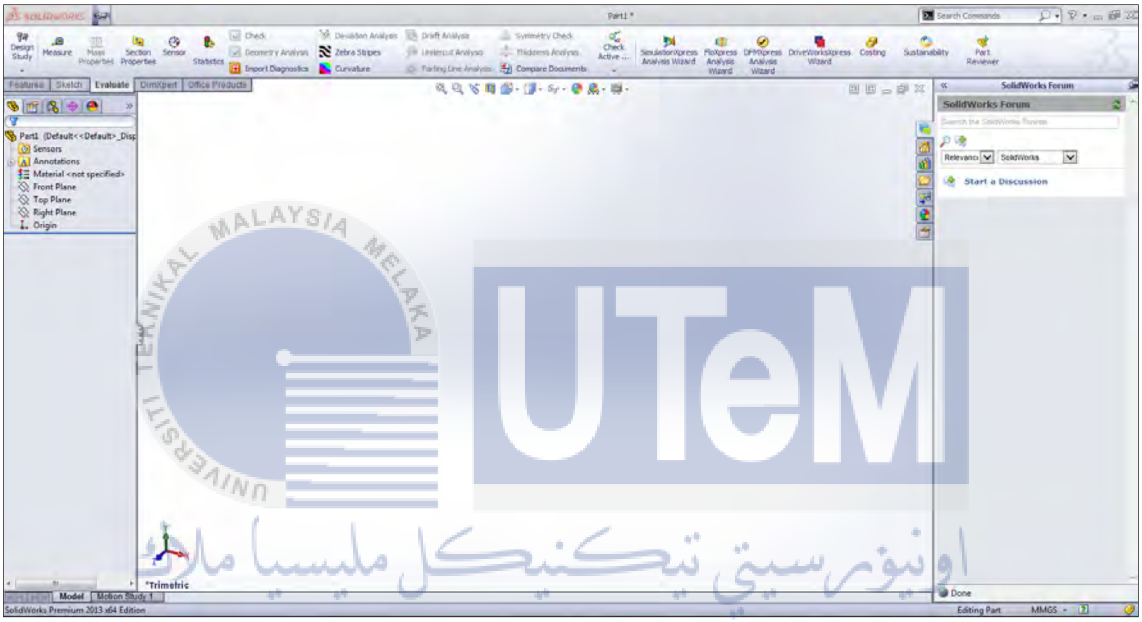


Figure 3.2: The SolidWork Drawing Interface.

3.5 Electronic Construction

In designing a Remotely Operated Controller, there is a need for a controller. For this project, the controller used is a manual type controller which is a PSC28A modulator that connected to the Playstation 2 (PS2) controller. The circuit for this controller is already available at the market. Thus, it is condusively and easy to connect and use for the ROC.

Figure 3.3: A PSC28A controller.

Figure 3.4: Joystick or Controller for Playstation 2.

3.6 Gear Configuration

The configuration for sprocket and chain ratio can be determined from the calculation of gear ratio and configuration. The basic rules and idea for both mechanical power transmitter is the same since both have a number of teeth, diameter and mechanism of their function.

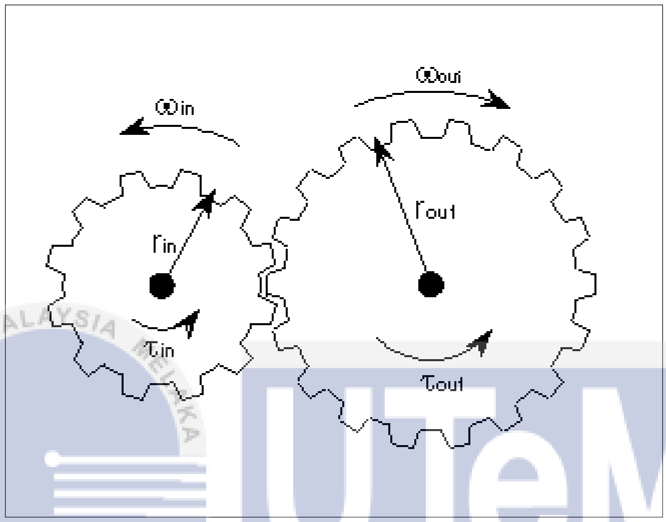


Figure 3.5: Gear Configuration

Terms:

$\boldsymbol{\omega_{in}}$	: Input Angular Velocity	$\boldsymbol{\omega_{out}}$	: Output Angular Velocity
$\boldsymbol{r_{in}}$	: Input Gear Radius	$\boldsymbol{\tau_{out}}$	: Output Torque
$\boldsymbol{\tau_{in}}$	: Input Torque	$\boldsymbol{r_{out}}$	: Output Gear Radius

Gear is one the power transmission element between an energy source and desired output motion besides belt, levers and screw drivers. The power Transmission is always included a Gear Ratio. A Gear Ratio can either increase the output torque or the output speed of a mechanical mechanism. A gear ratio cannot improve both, torque and speed at the same time.

As shown in Figure 3.5, the input gear is rotating counter clockwise with an angular velocity, ω_{in} and the output gear rotating clockwise with an angular velocity, ω_{out}. An input torque, τ_{in}, is applied by the motor onto the input gear, and an opposing output torque, τ_{out}, onto the output gear is applied by the machine. The radius of the gear is taken at the pitch circle of the gear which contact occurs between two gears.

The development and optimizing the gear shape will help to reduce friction loss, reduce noise and even make a smooth power transfer. By including a gear ratio in the design, it will help to increase the output speed or torque of the power transmission.

3.6.1 Gear Ratio calculation

Gear Pair Equation: The relationship between number of teeth and torque.

$$\frac{n_{out}}{n_{in}} = \frac{\tau_{out}}{\tau_{in}} \tag{1}$$

n_{in}	: Number of Input Teeth	τ_{in}	: Input Torque
n_{out}	: Number of Output Teeth	τ_{out}	: Output Torque

Gear Pair Equation: The relationship between radius and torque.

$$\frac{r_{out}}{r_{in}} = \frac{\tau_{out}}{\tau_{in}} \tag{2}$$

n_{in}	: Radius of Input Gear	τ_{in}	: Input Torque
n_{out}	: Number of Output Gear	τ_{out}	: Output Torque

Gear Pair Equation: The relationship between number of teeth and speed.

$$\frac{n_{in}}{n_{out}} = \frac{\omega_{out}}{\omega_{in}} \tag{3}$$

n_{in}	: Number of Input Teeth	τ_{in}	: Input Torque
n_{out}	: Number of Output Teeth	τ_{out}	: Output Torque

Gear Pair Equation: The relationship between radius and speed.

$$\frac{r_{in}}{r_{out}} = \frac{\omega_{out}}{\omega_{in}} \tag{4}$$

n_{in}	: Radius of Input Gear	τ_{in}	: Input Torque
n_{out}	: Number of Output Gear	τ_{out}	: Output Torque

In this project, the crawler needs a high torque power transmission instead of high speed to operate. This is due to the load and the environment that the crawler will operates. Thus, the equation (3) and (4) is neglected for further analysis. Higher torque is needed because the weight of the crawler itself is quite heavy to avoid the crawler floating on the water surface and help it to operate it on the waterbed. Then, the underwater environment has not always had a flat, hard and even seabed. Sometimes, the seabed has a muddy surface, rocky and uneven surface. Thus, it is essential for underwater crawler to gain more power to move on the seabed in any type of surface.

From equation (1)

$$\frac{n_{out}}{n_{in}} = \frac{\tau_{out}}{\tau_{in}}$$

Assume:

Input teeth = 33 Output teeth = 18 Input torque from the motor = 0.9N.m

$$\frac{18}{33} = \frac{\tau_{out}}{0.9}$$

$$\tau_{out} = 0.4909\ N.m$$

Input teeth = 18 Output teeth = 33 Input torque from the motor = 0.9N.m

$$\frac{33}{18} = \frac{\tau_{out}}{0.9}$$

$$\tau_{out} = 1.65\ N.m$$

As a conclusion, when the input gear is smaller than the output gear, the output torque is higher than the input torque. Thus, in designing the power transmission for the underwater crawler, the input gear is having the least number of teeth compare to the output gear to gain higher torque. The design could have 18 teeth for the input gear and 33 teeth for the output gear. The value of input torque depends on the type of motor use later on. The output velocity of the rotation will be lower than the input velocity since the transmission has higher torque.

Figure 3.6: Crawler Gear Ratio Configuration Design.

3.7 Experiment and Project Set Up

Experiment 1: Simulations for the chassis of Remotely Operated Crawler (ROC) Using CAD Software

Objectives:

1. To identify and describe ROC specifications.
2. To analyze each design using simulation software.

Equipment and Apparatus:

1. SolidWork software.
2. Computer.

Procedures:

1. Three different designs of Remotely Operated Crawler (ROC) were drawn using the SolidWork software based on the crawler's design scope.
2. All three designs named as Design 1, Design 2 and Design 3.
3. These three designs have different chassis designs, but have the same type of wheels which is track type wheels, controller, maneuverability mechanism and materials.
4. Strain, stress, displacement and safety analysis tests were conducted using the SolidWork Simulation application.
5. The force and pressure exerted to the chassis were determined and remain the same with all three designs

Experiment 2: Underwater Test (Waterproof Test)

Objectives:

1. To test the crawler in underwater environments.

Equipment and Apparatus:

1. Underwater crawler.
2. Water tank full of water.

Procedures:

1. Assemble all the components of the crawler except the motor.
2. Fill a tank with water.
3. Submerse the crawler into the tank and let it for a few minutes.
4. Unscrew the top chassis after the outer part is wiped dry.
5. See if inside part of the chassis contains water or not.

Experiment 3: Underwater Test (Buoyancy Test)

Objectives:

1. To identify the tendency for the underwater crawler to float.
2. To measure the downward force needed to overcome the buoyant force.

Equipment and Apparatus:

1. Underwater crawler.
2. Iron column.
3. Weight scales.
4. Water tank full of water.

Procedures:

1. Seal the crawler to ensure there is no leakage.
2. Weight the iron column and record the mass of each column.
3. Submerse the crawler into the tank.
4. If the crawler sinks to the bottom of the tank, repeat the test twice.
5. If not, add one iron column one by one and observe the crawler tendency to float and take the mass of the column added.
6. Record the number of columns needed to overcome the buoyant force and take the total mass for the columns used.
7. Tabulate the data obtained.

Experiment 4: Control and Maneuverability Test (On land and Obstacles Test)

Objectives:

1. To observe the movement, time taken for the crawler to crawl in 3m distance on land.
2. To identify the capability of the crawler to climb and crawl on the obstacles.

Equipment and Apparatus:

1. Remotely Operated Crawler.
2. 0.5 cm thick wooden plank.
3. 9.5 cm wooden platform.

Procedure:

1. The crawler is set to crawl the 0.5 cm wooden plank.
2. Time taken for the crawler to climb is taken.
3. Add more wooden plank until it reach maximum height for the crawler to climb.
4. Observe the crawler to climb the obstacles.
5. Add more obstacles and repeat step 1 to 3 for other obstacles.

Experiment 5: Control and Maneuverability Test (Underwater Field Test)

Objectives:

1. To simulate the crawler in the real underwater environment.
2. To evaluate the capability of the crawler to operate underwater.

Equipment and Apparatus:

1. Remotely operated crawler.
2. Brick.
3. Iron column.

Procedure:

1. Inspect the overall parts of the crawler.
2. Connect the crawler with the controller including the power supply and do movements test it on the ground first.
3. Submerse the crawler into the water tank slowly.
4. Take the time taken for the crawler to move for 1m.
5. Test the crawler maneuverability underwater using the controller.
6. Add obstacles such as bricks and iron column for the crawler to climb underwater.
7. Take the time taken for the task.

CHAPTER 4

RESULTS AND DISCUSSION

This chapter shows the results of the research and discussion. The result and discussion of the results are divided by the objectives of the research. The first section about the design of the crawler and its controller. Following section about the data obtain from the field test of the crawler on land and under water.

4.1 Introduction

This chapter discuss on the crawler's design and the simulation test of the chassis. There are three designs of the chassis of the crawler. For each chassis, simulation test is done using SimulationXpress by exerting each of them with force and pressure. With this test, the strength and the weakness point of the chassis can be determined. All crawlers have the same dimensions, gear ratio configuration, type of wheels and type of controller used. Later, field tests will be conducted to the prototype in order to measure the performance in terms of maneuverability, waterproof and its ability to move on any surfaces.

4.2 Design of the Remotely Operated Underwater Crawler

The Crawler

The Remotely Operated Underwater Crawler is an unmanned type vehicle that works underwater seabed. The designs of the crawler are shown in this part. All the designs have the same dimensions, type of wheel used, motor, gears configuration and control.

Table 4.1: The specification of the ROC.

Items	**Dimensions**
Length	**:** 450 mm
Height Of The Chassis	**:** 100 mm
Width	: 297.6 Mm
Height Chassis To The Ground	**:** ± 30mm
Type of Wheels	**:** Track or chain type wheels
Gear Ratio	**:** 1:1 (Use sprocket and chain)
Motor Type	**:** DC Geared Motor
Material	**:** Stainless steel
Weight	: 9.8 kg.

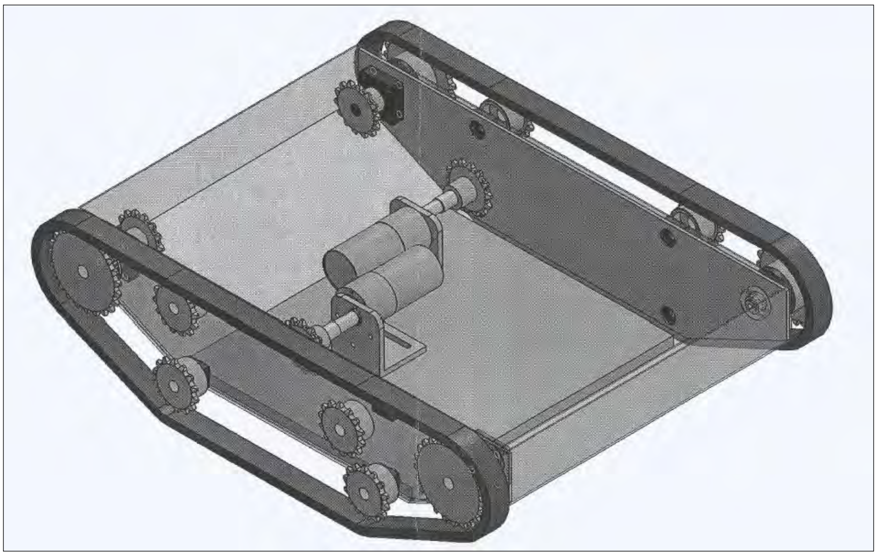


Figure 4.1: Assembly Design of the Crawler.

Figure 4.1 shows the 3D assembly drawing of the crawler. The idea of designing such crawler came out from the mechanism of a tank. With this type of wheels, the crawler can crawl on any surface of the terrain. This will help improving the maneuverability of the crawler. The wheels used sprocket instead of belting and gear. This will reduce the cost in the fabrication process since sprocket is a standard part and available in the market. A little adjustment needed so that the sprocket will fit with the crawler.

(a)

(b)

(c)

Figure 4.2: The prototype of ROC.

Figure 4.3: The prototype of ROC inside view.

The chassis of the ROC is made of stainless steel. The other components of the ROC are made of steel and also aluminum. Figure 4.2 and Figure 4.3 shows the developed ROC. The shaft for motors are made of aluminum and the wheels are steel. In order to avoid corrosion, all parts made of steel will be painted later. Inside each sprocket, waterproof bearings are fixed inside the brackets as shown in Figure 4.4. Brackets will also prevent any water from getting through the chassis.

Figure 4.4: The brackets hold bearings and waterproofing the chassis.

The Control Box

Figure 4.5: The control box.

The control box as shown in Figure 4.5 is actually a box containing all circuits, battery and PS2 controller. The box will protect the circuits and other electronics components from shock and provide an exclusive design. The cables for the crawler can be stored inside this box. Control box is placed on the land while the crawler working underwater. Figure 4.6 is the circuit for the controller.

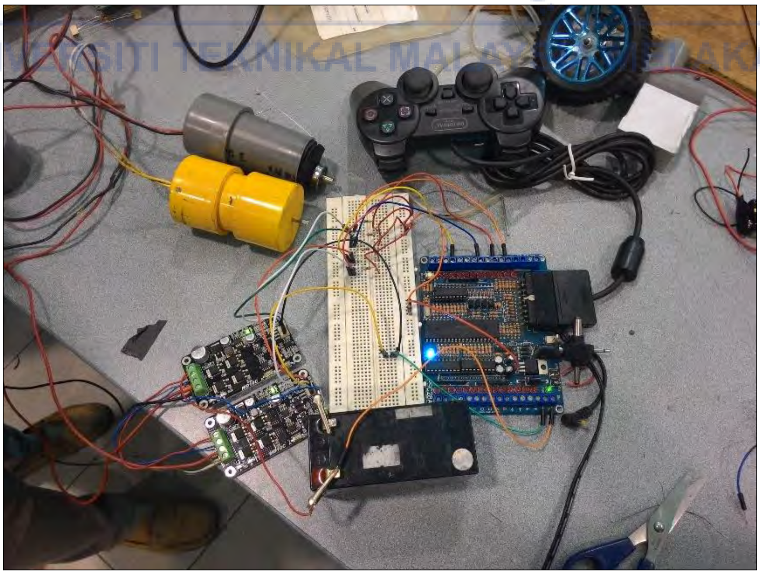


Figure 4.6: The circuit of the controller.

4.3 Chassis Simulation Test

Experiment 1: Design ROC's Chassis Using CAD Software

This test is basically to identify and describe ROC specifications and analyze the design with stress, force and pressure. SimulationXpress is an application to test the design with any value of force, pressure and stress. From all tests available in this application, we can determine the weakest point and shape deformed when force and pressure applied to the chassis. Follows is the result of all the tests obtained from the simulation.

Force	: 10 N
Pressure	: 50000 N/m^2

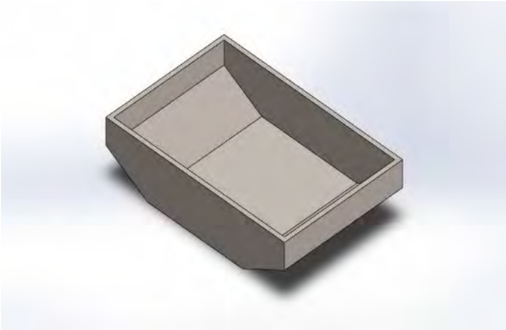
The simulation is done by imitate the pressure and forces exerted to body in 5m depth underwater. The field test is done a pool to observe the performance of the crawler. Stainless steel is chosen to build the chassis because it has enough tensile strength to withstand the pressure and forces. Besides that, stainless steel is cheaper than titanium and other stainless materials. It is also easy to fabricate and being shaped. Thus the selection of stainless steel fulfill the requirement needed in developing the crawler chassis.

Simulation of Chassis

Designer: Solidworks

Study name: SimulationXpress Study

Analysis type: Static



Description

This is a simulation of the ROC chassis when applied pressure of 10k N/m^2 and force of 10 N. The pressure and force are imitate the environment of 5m depth underwater where the crawler is operated and tested.

Table 4.2: Model Information.

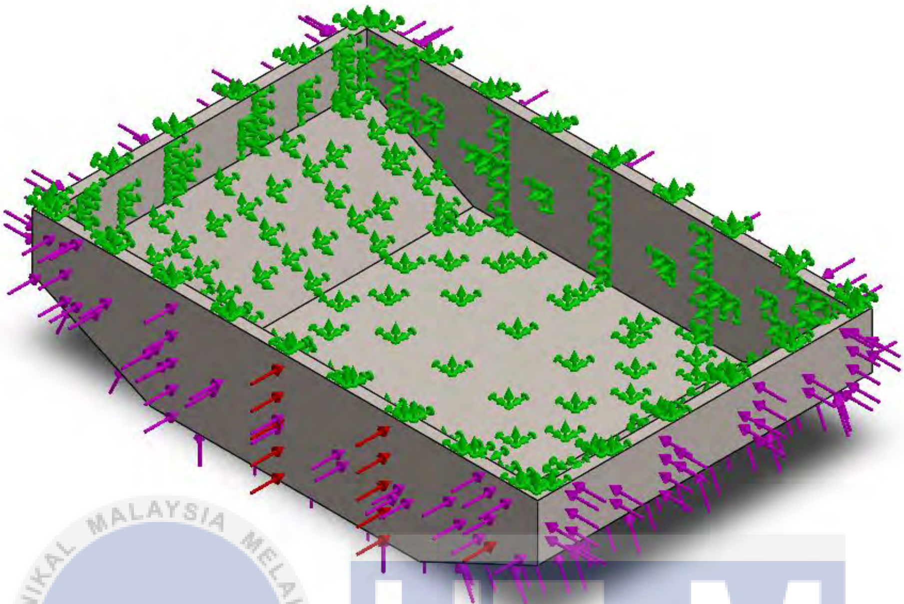
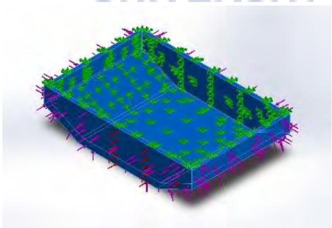
<table>
<tr><td colspan="3">
Model name: Chassis
Current Configuration: Default</td></tr>
<tr><td colspan="3">**Solid Bodies**</td></tr>
<tr><td>**Document Name and Reference**</td><td>**Treated As**</td><td>**Volumetric Properties**</td></tr>
<tr><td>**Boss-Extrude3**
</td><td>**Solid Body**</td><td>**Mass:17.7736 kg**
Volume:0.00227867 m^3
Density:7800 kg/m^3
Weight:174.181 N</td></tr>
</table>

Table 4.2 shows the model information of the chassis design. It is treated as a solid body subject with the approximate mass of 17 kg. In reality the mass of the crawler including all the components is just roughly 9.8 to 10 kg. This is because simulation just take the data set by the software.

Table 4.3: Material Properties.

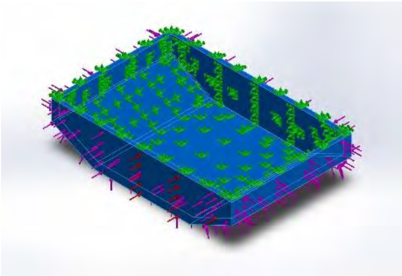
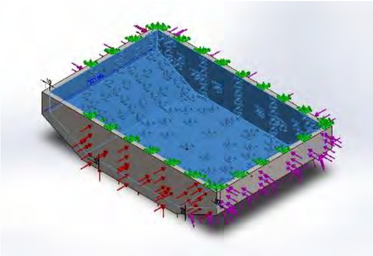
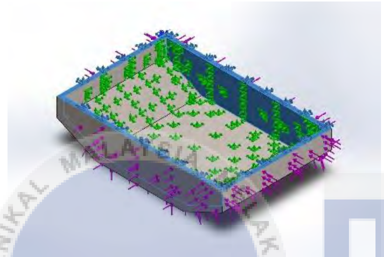
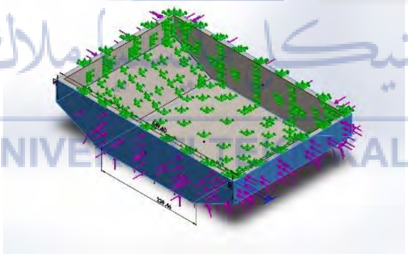
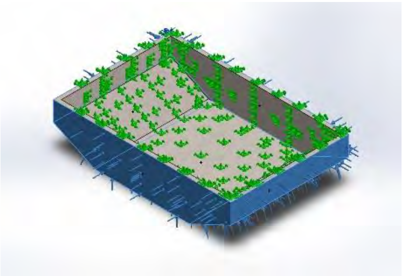
Model Reference	Properties	
	Name:	**Stainless Steel (ferritic)**
	Model type:	**Linear Elastic Isotropic**
	Default failure criterion:	**Max von Mises Stress**
	Yield strength:	**1.72339e+008 N/m^2**
	Tensile strength:	**5.13613e+008 N/m^2**

Table 4.3 is about the material properties of the stainless steel. It is a ferritic in definition:

> *"Ferrite, also known as α-ferrite (α-Fe) or alpha iron, is a materials science term for pure iron, with a body-centered cubic B.C.C crystal structure. It is this crystalline structure which gives steel and cast iron their magnetic properties, and is the classic example of a ferromagnetic material."*

This type of stainless steel have the tensile strength of $5.13613 \times 10^8\ \mathrm{N/m^2}$. The yield strength is about $1.72339 \times 10^8\ \mathrm{N/m^2}$.

Table 4.4: Loads and Fixtures.

Fixture name	Fixture Image	Fixture Details
Fixed-1		Entities: 7 face(s) Type: Fixed Geometry
Fixed-2		Entities: 3 face(s) Type: Fixed Geometry
Load name	**Load Image**	**Load Details**
Pressure-1		Entities: 5 face(s) Type: Normal to selected face Value: 10000 Units: N/m^2
Force-1		Entities: 7 face(s) Type: Apply normal force Value: 10 N

In Table 4.4 explained about the surfaces tested for the stress and pressure test. The minimum faces is 3 and the maximum faces tested are 7. The selection of faces depends on how the crawler will operates and the environment of the surroundings.

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	13.9153 mm
Tolerance	0.695767 mm
Mesh Quality	High

Table 4.5 and Table 4.6 respectively shows the mesh analysis of the design. It creates wired or mesh analysis throughout the design's surfaces. The blue arrow indicates the pressure exerted to body from outside environment and the green arrow indicates the forces to withstand the pressure.

Table 4.6: Mesh Information – Details.

Total Nodes	14963
Total Elements	7326
Maximum Aspect Ratio	4.3515
% of elements with Aspect Ratio < 3	99.8
% of elements with Aspect Ratio > 10	0
% of distorted elements(Jacobian)	0
Time to complete mesh(hh;mm;ss):	00:00:04

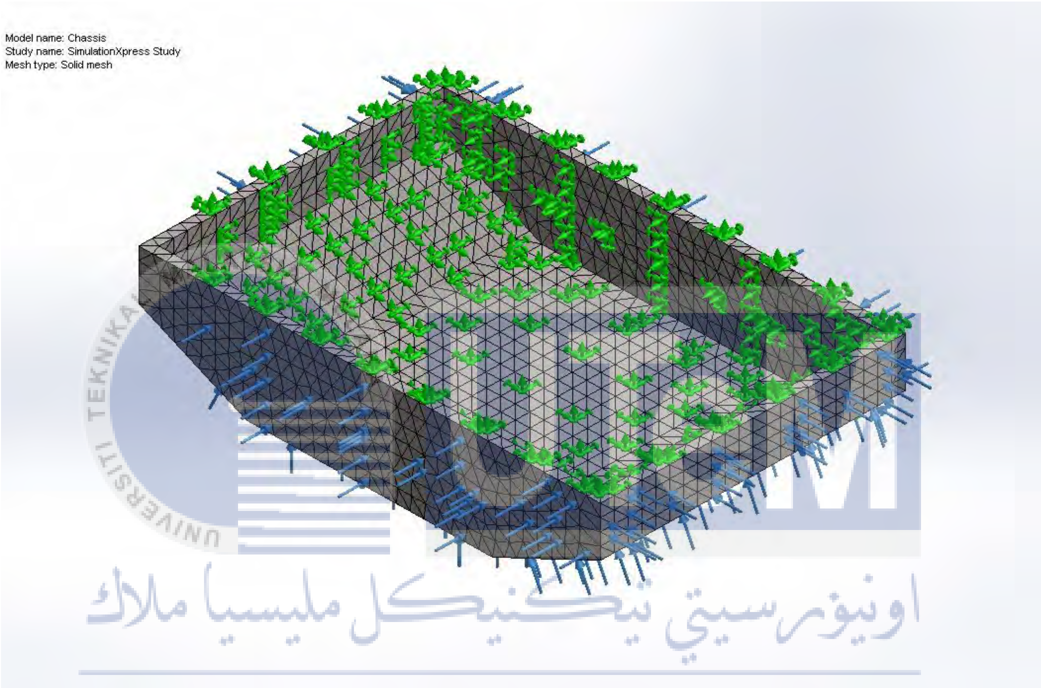
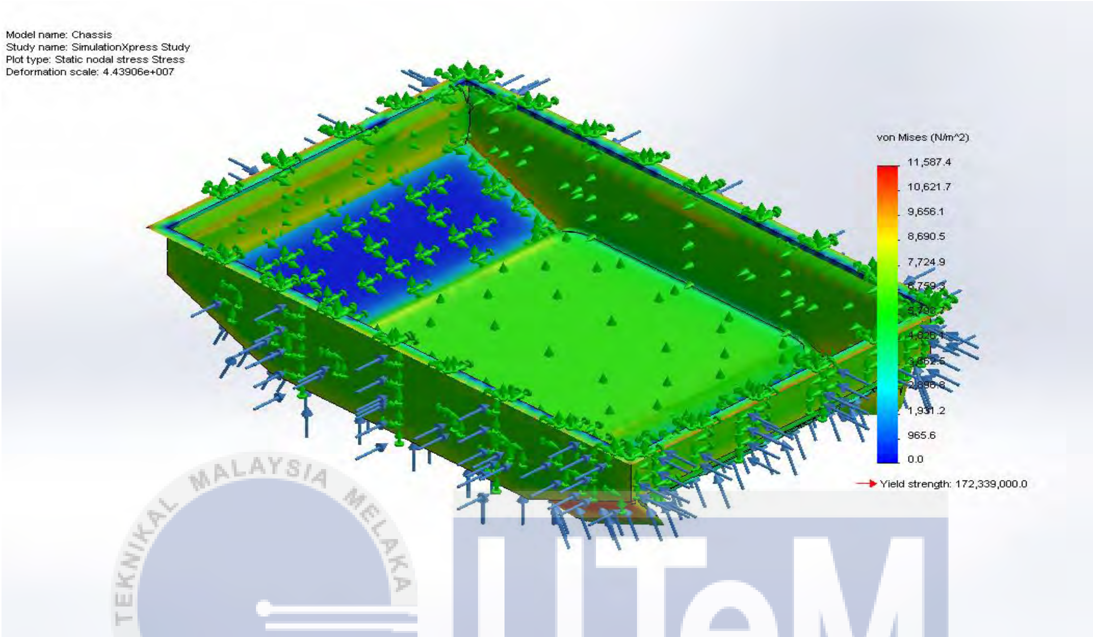


Table 4.7: Stress Results.

Name	Type	Min	Max
Stress	VON: von Mises Stress	0.000116464 N/m^2 Node: 14362	11587.4 N/m^2 Node: 207



Chassis-SimulationXpress Study-Stress-Stress

Table 4.7 is a graphic image of the result when forces is applied to the chassis. It calculate the weakest and strongest point of the chassis. The strongest part is indicates as a blue area and the weakest point is in red. As a conclusion, the stainless steel chassis can withstand the pressure and forces applied to it without any complication of deformation.

Table 4.8: Displacement Results.

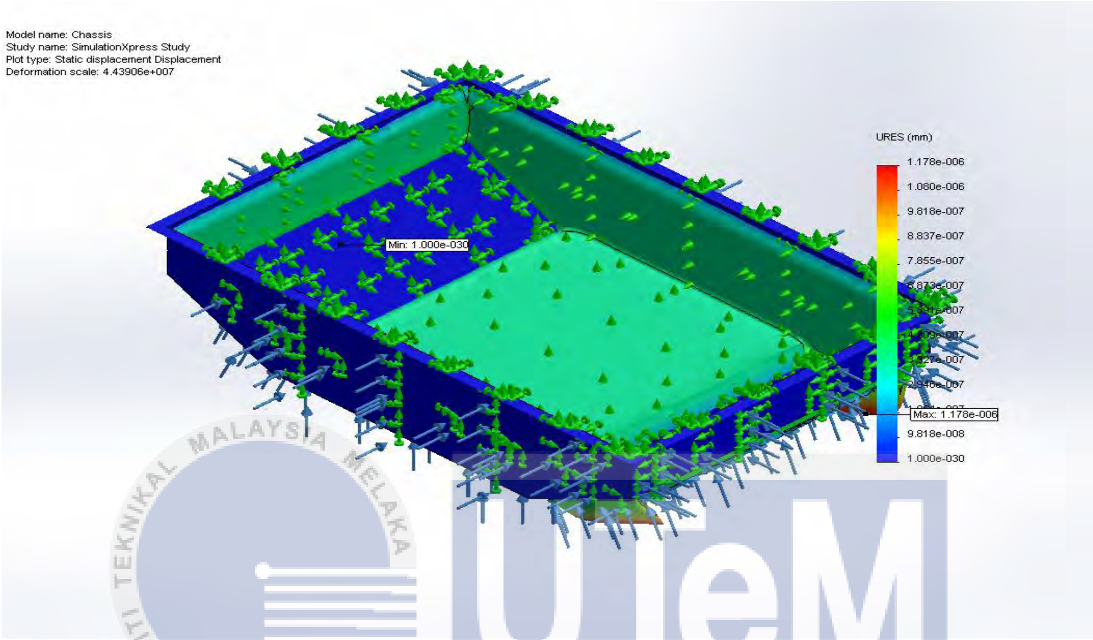
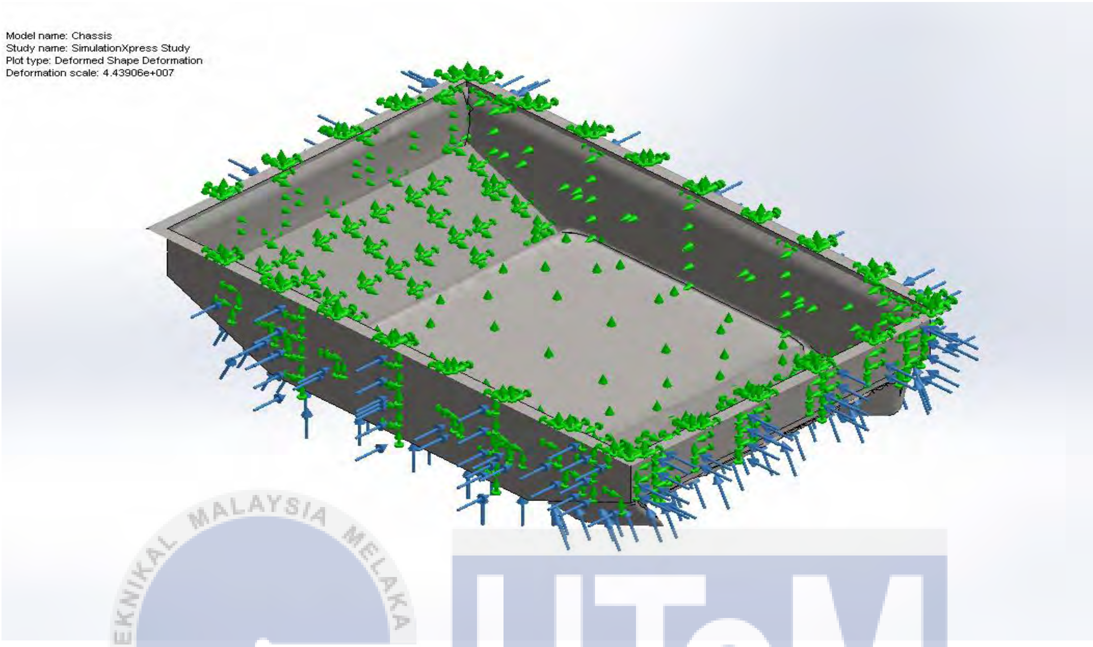
Name	Type	Min	Max
Displacement	URES: Resultant Displacement	0 mm Node: 1	1.17821e-006 mm Node: 905
 **Chassis-SimulationXpress Study-Displacement-Displacement**			

Table 4.8 and Table 4.9 is about displacement test of the rigid body. This test will show the deformation of the structure. In this case, the deformation is quite minimum since the most of the faces can withstand the test. A few faces deformed due to weak structural integrity. The prototype have a few adjustment to overcome this problem. The wall of the body is double platted and provide weight to the crawler.

Table 4.9: Deformation Results.

<table>
<tr><th>Name</th><th>Type</th></tr>
<tr><td>Deformation</td><td>Deformed Shape</td></tr>
<tr><td colspan="2">

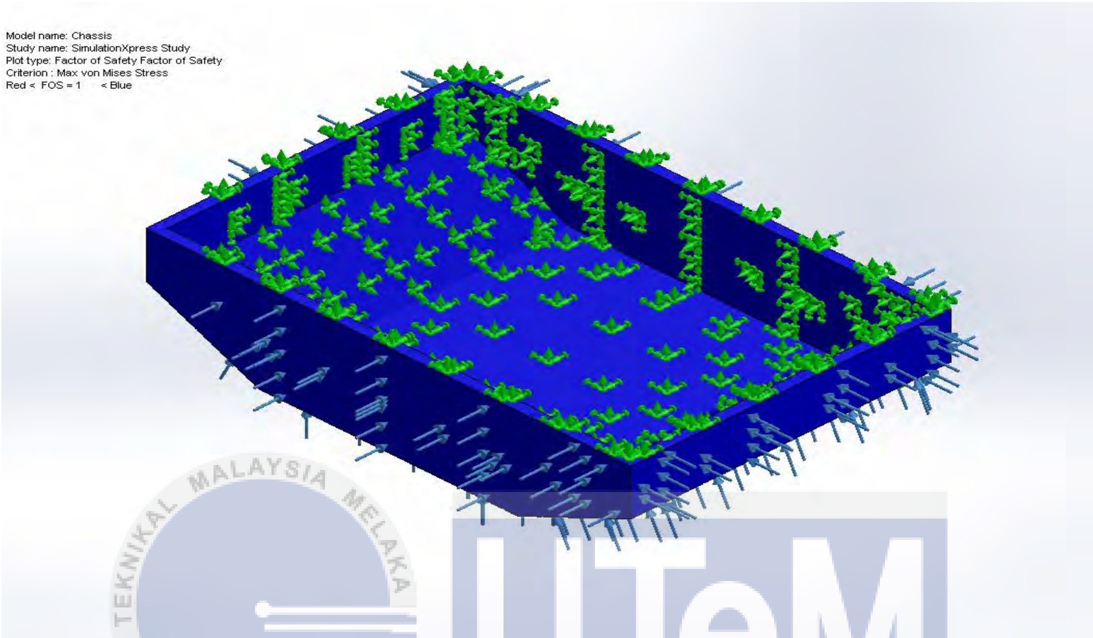


Chassis-SimulationXpress Study-Displacement-Deformation

</td></tr>
</table>

Table 4.10: Factor of Safety Results.

Name	Type	Min	Max
Factor of Safety	Max von Mises Stress	14873 Node: 207	1.47976e+012 Node: 14362



Chassis-SimulationXpress Study-Factor of Safety-Factor of Safety

Factor of safety is shown in Table 4.9. This simulation shows the integrity of the body when forces applied to it. Factor of safety explain the structural capacity of a system beyond the expected loads or the actual loads.

4.4 Field Test

Experiment 2: Waterproof test

In this test, the crawler is sealed and all the connections are completely attached. . Before any further steps continue, motors are removed and the inside part of the chassis is clean and dry as shown in Figure 4.7 and submerged to test any leakage from the chassis. This procedure will help to verify there is no leakage from the chassis. Later, the crawler was dipped into a water tank as in Figure 4.8 After a few minutes dipped, the crawler is retrieved back and the chassis is opened. If there is no water or contamination inside the crawler, thus, it is concluded that the crawler is waterproof. The result obtained is, the crawler is waterproof and good to go for underwater operations.

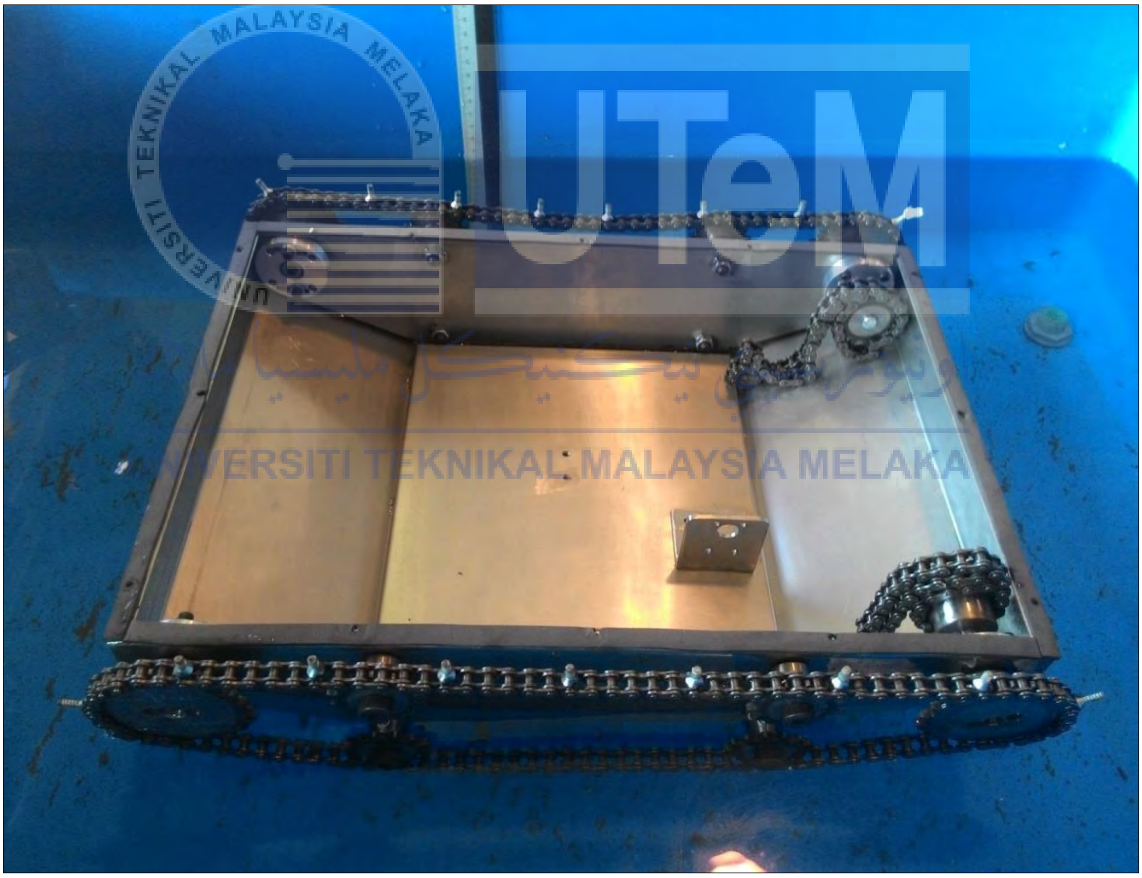


Figure 4.7: Chassis is submersed to identify any leaking.

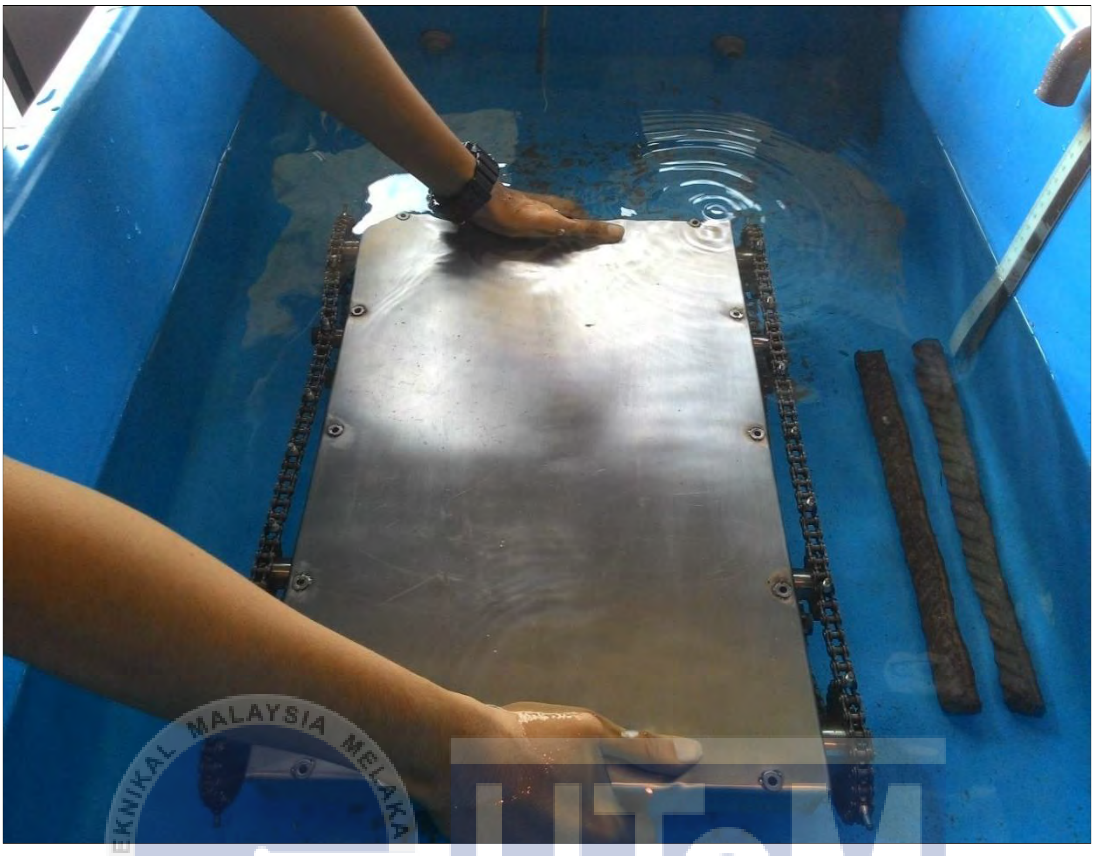


Figure 4.8: The crawler is sealed and tested for leakage.

The waterproof test is done twice in order to confirm there is no leakage. Since the first test is failed, a second test is done. The first test shows a leakage to the body due to improper sealed. The results are shown in Table 4.10. The water still can get through the body via the joint of the cover to the chassis. In the second test shown in Table 4.11 indicates there is no leakage since more proper sealant is applied.

Table 4.11: Waterproof Test (Test 1).

Test	Time (mins)	Condition	Remarks
1	10	No leakage	Ok
2	20	Slightly leakage	Small amount of water found in the body
3	30	Slightly leakage	The amount of water increases
4	40	Slightly leakage	The amount of water increases with moderate amount
5	50	Slightly leakage	The test is stopped due to leakage and avoid the body full of water.

Table 4.12: Waterproof Test (Test 2).

Test	Time (mins)	Condition	Remarks
1	10	No leakage	Ok
2	20	No leakage	Ok
3	30	No leakage	Ok
4	40	No leakage	Ok
5	50	No leakage	Ok

Experiment 3: Underwater Test (Buoyancy Test).

Buoyancy test is done in order to identify the ability of the crawler to float. The crawler supposed not to float since it will operate in the underwater bed. Since the crawler design has a confine space, eventually, it will float due to air is trapped inside the body. Thus, it will float like a boat. The crawler pass the water surfaces with full of its body sink underwater. In order to overcome this problem, weight is added to the crawler. The crawler still can move even though the weight is added because it weight is supported by buoyant force. Table 4.12 shows the results obtained. Each iron column has a mass of 1.1 kg to 1.3kg.

Figure 4.9: Iron column is added to overcome the buoyant force.

Table 4.13: Results of the Buoyant Test.

No of Iron Column	Mass (kg)	Condition
1	1.1	Positive Buoyancy
2	1.1	Positive Buoyancy
3	1.3	Positive Buoyancy
4	1.2	Positive Buoyancy
5	1.2	Positive Buoyancy
6	1.1	Negative Buoyancy
Total Mass	7.0	

The total mass of the crawler is 16.8 kg. Since the crawler operates under water, the mass reduces since there is still a buoyant force applied to it.

Experiment 4: Control and Maneuverability Test (Field Test)

Experiment 3 is about testing the ability of the crawler to operate in any terrain. First, the crawler is tested on the land. There are three surfaces that been chosen for the crawler to operate which is on hard surface (cement), dirt and on the grass. Time taken for the crawler to complete 3 m distance is recorded as follows:

Table 4.14: The time taken for the crawler to crawl in a distance of 3 m.

Surfaces	Time Taken (s)					Mean time taken (s)
	Test 1	Test 2	Test 3	Test 4	Test 5	
Cement	56.23	56.35	56.18	56.44	56.87	56.41
Dirt	57.67	57.73	57.46	57.80	58.45	57.82
Grass	59.34	59.56	59.89	60.45	60.13	59.87

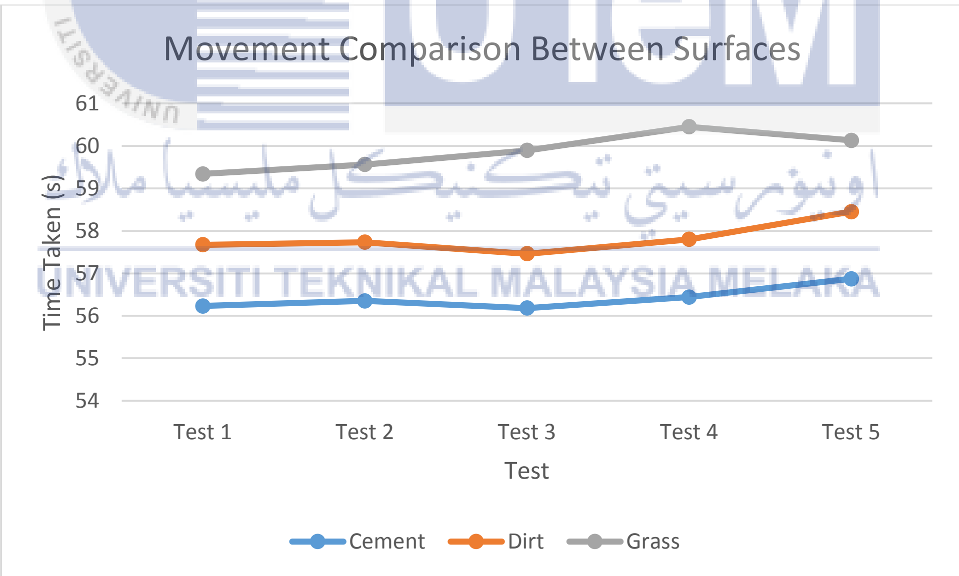


Figure 4.10: Comparison chart between surfaces against the time taken.

The chart indicates that, the crawler moves slower on the grassy terrain compare to other conditions which is dirt and cemented surfaces. This is because, the crawler exerted more friction on the base of the crawler with the grass. Besides that, grassy surface provides more uneven surface. It is a bumpy ride as we can describe. The cemented surface gives no friction to the base of the crawler. The only frictions come from the wheels spike to the surface. There is a difference in time taken for each test even though tested at the same terrain. This is because other external factor such as, power supplied by the battery is decreasing, surface interventions and the way the crawler has been controlled. Thus, if this test is done underwater, the time taken will be much higher due to water resistance and the surfaces of the terrain.

Obstacles test is done to measure how height and identify the limit of the crawler. The first two tests are carried out on the land and the last test is in the tank fill with water. The time taken for the crawler to climb the obstacles of each height is recorded. Wooden planks are used for this test. Each plank is 0.5 cm thick. The maximum height to crawler can climb is 9.5 cm. The results as follows:

Table 4.15: Table for the crawler to climb the wooden plank.

Test	Height (cm)	Time Taken (s)	Descriptions
1	**0.5**	1.35	-
2	**1.0**	2.80	-
3	**1.5**	4.20	-
4	**2.0**	5.43	-
5	**2.5**	6.23	-
6	**3.0**	7.12	-
7	**3.5**	8.34	-
8	**4.0**	9.51	-
9	**4.5**	10.43	-
10	**5.0**	11.35	-
11	**5.5**	13.54	-
12	**6.0**	15.76	-
13	**6.5**	16.48	-
14	**7.0**	18.02	Slightly stuck
15	**7.5**	19.79	Slightly stuck
16	**8.0**	21.78	Slightly stuck
17	**8.5**	23.89	Slightly stuck

18	**9.0**	25.87	Slightly stuck
19	**9.5**	27.78	Stuck but can climb
20	**10.0**	-	The base stuck to the obstacles
21	**10.5**		The base stuck to the obstacles

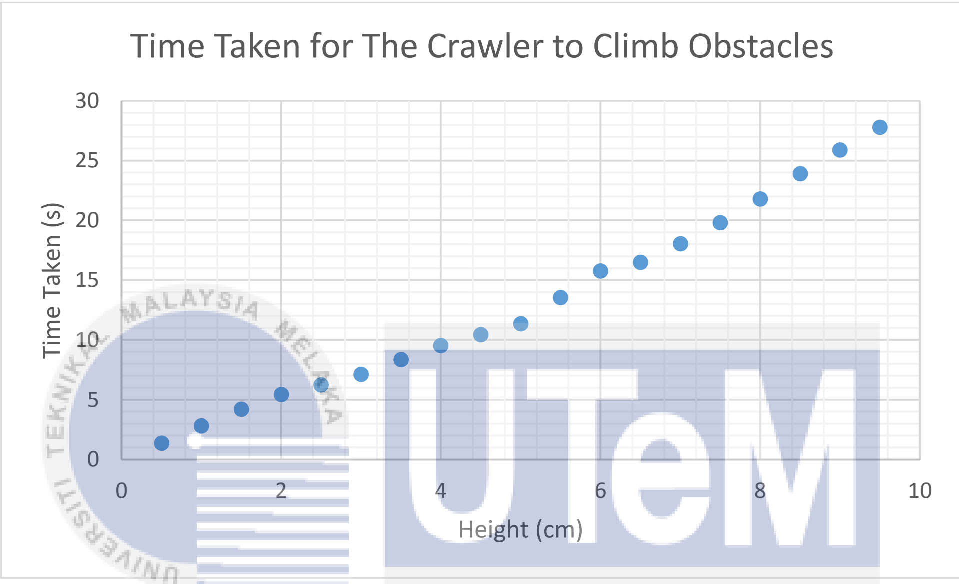


Figure 4.11: The ability of the crawler to climb chart.

The time taken for the crawler to climb the obstacles of the height of 9.5 is recorded. Wooden platform is used for this test. The results as follows:

Table 4.16: Table for the crawler to crawl over wooden platform.

Test	Height (cm)	Time Taken (s)	Descriptions
1	**9.5**	25.28	Able to climb
2	**9.5**	24.79	Able to climb
3	**9.5**	25.44	Able to climb
4	**9.5**	25.56	Able to climb

Figure 4.12: The crawler climbed the 9.5 cm obstacles.

The crawler can climb up to 9.5 cm obstacles and it is the maximum height it can climb. This is because the bottom base of the crawler stuck to the edge of the obstacles. Spikes on chain help the crawler to have greater tractions and pull the crawler up. This condition can be overcome by having larger sprocket that tied to the chain or weld longer spike to the chain.

Experiment 5: Control and Maneuverability Test (Underwater Field Test)

The first objective is to determine the time taken for the crawler to crawl underwater with the distance covered for 1m. This test is done in water tank with the depth of 0.9m. The following table is the result of the test. As we can evaluate, the time taken is high for the crawler to crawl and slow. This is because of the design of the wheels which the chain type wheels, weight of the crawler and also resistance.

Table 4.17: 1m underwater test.

Test	Time Taken (s)
1	16.23
2	16.31
3	16.28
4	16.34
Average	16.29

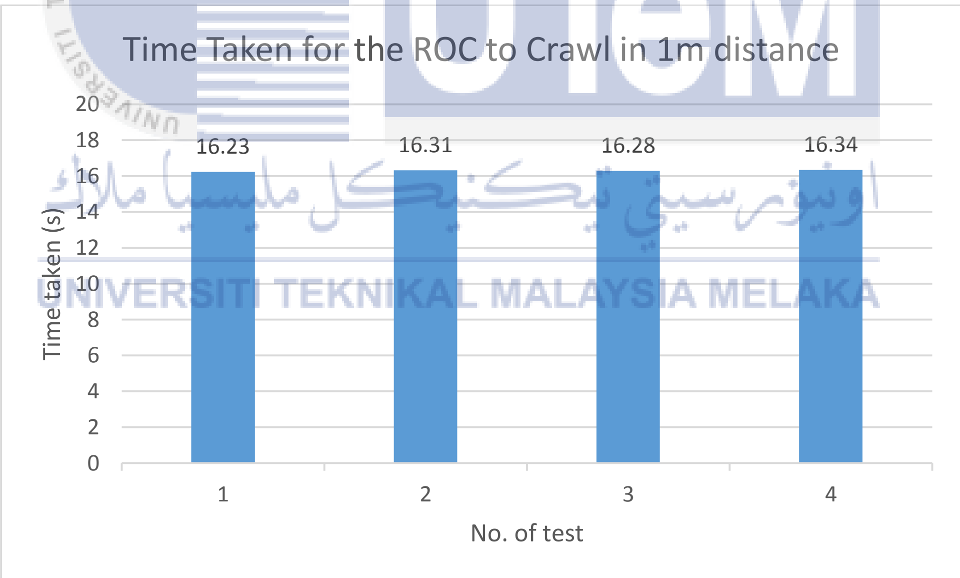


Figure 4.13: Underwater time result.

The last obstacles test is carried out underwater. Iron column and brick are used for this test. The crawler is submerged and controlled to climb obstacles in the tank which places in a line with the distance of 1m. Time taken for the crawler to climb the obstacles is recorded. All the obstacles can be climbed by the crawler. The hardest obstacles for the crawler to climb is the brick. The results as follows:

Table 4.18: Table for the crawler to crawl over underwater obstacles.

Test	Time Taken (s)	Descriptions
1	34.67	Able to climb
2	42.34	Able to climb
3	45.44	Able to climb
4	44.65	Able to climb

Figure 4.14: Underwater Obstacles Test.

CHAPTER 5

CONCLUSIONS

5.1 Conclusions

Designing an Unmanned Underwater Vehicle (UUV) gives a lot challenge. The first objective of this project is; to design an unmanned underwater Remotely Operated Crawler (ROC) using CAD. SolidWork is used as the software and platform in designing the crawler. Several simulation test is done using the application available in the software which is the SimuationXpress. Based on the application, the chassis design of the crawler is tested with force of 10N and a pressure of 50000 N/m^2 To imitate the condition of the 5m underwater environment and above. The test included the stress, displacement, deformation and factor of safety test. The data generated by the SimulationXpress are mentioned in Chapter 4. All simulations show that the design of the chassis plays an important role for the crawler to withstand the underwater environment. As a conclusion, the simulation test helps in the decision making process. It provides details about the material used, sustainability and simulation when the design is tested in real situations.

Second phase of this project is developing the ROC. Since the fabrication process is challenging, few steps need to be done. First, calculate the budget of the project. The price of raw material and of the components is changing each day. Material such as stainless steel could have a price of RM 400 per half of the plate. Managing a budget is the most important to avoid overspending. The price of electronic components gets higher after Goods and Service Tax (GST) is implemented by 1st April 2015. Cost for fabrication process may vary depends on the workshop. The quality of the craftsmanship also different from one another.

It is better to do a survey before decided on fabricated the prototype at any workshop. The cost for the prototype of the ROC is around RM 3500 including the price of materials, mechanical components, electronic components and fabrication process.

Every detail must be precise since the ROC will operate underwater. From the design process of fabrication, the ROC is inspected and developed properly. The fabrication process that has done to develop the ROC are bending, welding and modify the available components to suit the application of the crawler. Sprocket for example, is available in the market. But for it can be used in the ROC, some adjustment have been done to them so that it can fit to the shaft that linked with motors. Motors selection also important. The weight of the crawler is determined and suitable motor is chosen. The torque of the motor is 1960 mNm which can carry the weight of the crawler.

Waterproofing the crawler also gave a challenge. The body of the crawler is sealed with sealant, chassis are welded perfectly, and components are designed to fit the chassis so that the body of the ROC is waterproof. This is important to protect motors inside it. The total weight of the crawler once it's completed is 9.8 kg.

After the completion of the ROC, the last objective is; to analyze the maneuverability of the ROC underwater and on land. Tests are set up to identify the limits and capable of the crawler to operate. One of the tests is obstacles test. In this test, obstacles set up for the ROC to climb. This test is carried out on land and also underwater. The ROC is capable of climbing an obstacle of the maximum height of 9.5 cm. This is because of the design of the chassis and wheels.

Another test is carried out is buoyancy test. This test is crucial for crawler needs to sink since it will operate on the seabed not floating. From the test, weight of 7kg need to be added to the crawler. Less than 7kg will cause the crawler to have a positive buoyancy.

In this project, all objectives that have been stated are achieved. The ROC operates as expected by theory even though there is unexpected problems emerged. One of the problems is the body of the ROC is hollow. Hence, there is an air pocket inside it. In theory, 10 kg is quite heavy and the crawler will sink but it won’t. Weight need to be added so that the ROC will sink to the bottom. The design of the ROC is based on tank and have a slot modular design. More components can be added and the design can be improvised for future work.

5.2 Recommendations

As students, we need to have a schedule and benchmark of our target in a project. Most students tend to do their project in last minute. Hence, some will drop off the subject. It is such a waste of time if they need to extend their studies for another one semester. In order to avoid this, students and supervisor need to work together. Lectures will help in advising about the project while student need to alert their timeline and follow instructions given by the supervisors.

Recommendation for the project are, additional components can be added to the ROC such as camera, ballast tank, floating devices and sensors can be added to it. The design never be completed and more improvement can be made. The ballast tank will help the ROC to sink and floating by injecting and releasing water into it. Upon completion, the ROC can be commercialized for industries such as oil and gas, shipping and others. The completed ROC can be developed to become autonomous and operates from its own.

More research needs to be done so that ROC will play an important role in underwater exploration. Research on machine vision can be done by adding camera besides giving a live feed to the operator. Deeper underwater exploration of marine biology research is not impossible since the ROC will be able to go deeper to the seabed. Underwater constructions is then will have a steady and stable working base because compare to unmanned submarine, crawler works direct contact to the seabed.

Hence, this project has a future for improvements. By adding more features, the value of the ROC will increase.

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APPENDICES